A Living Map for a Changing Landscape – fine-scale vegetation mapping in Sonoma County

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AGENDA

1. Sonoma Veg Map program overview
2. Veg Map methods
3. Accuracy assessment
4. Veg Map uses and updates

1. PROGRAM OVERVIEW

- **Countywide LiDAR and LiDAR Derivatives**
- **Countywide fine-scale vegetation map**
  - ¼ acre to 1 acre MMU (map class dependent)
  - NVCS classification ~ 85 map classes, generally at alliance level, few at group
- **Croplands map, impervious surfaces map, and carbon/biomass map**

PROJECT PARTNERS

AG + OPEN SPACE SONOMA COUNTY

- Sonoma County Agricultural Preservation and Open Space District
- Sonoma County Water Agency
- County of Sonoma Information Services Department
- County of Sonoma Transportation and Public Works Department
- City of Petaluma
- California Department of Fish and Wildlife
- California Native Plant Society
- The Nature Conservancy
- Save the Redwoods League
- US Geologic Survey
- NASA / University of Maryland

COUNTY FUNDING PERSPECTIVE

- **Sonoma County Ag + Open Space District and Water Agency needed ortho-imagery, lidar derived products and detailed land use and land cover maps to efficiently and effectively fulfill their missions. The two agencies:**
  - Led the effort and collaborated with NASA and USGS for federal funding and support.
  - Developed a consortium of academic, state, county, local, and NGO partners to fund data acquisition and creation of value-added datasets.
- **Besides supporting public agency decision-making, this public investment also provides significant benefits to NGO and private sector users.**

PROJECT TEAM

- Tukman Geospatial
- Kass Green and Associates: Kass Green and Gene Forsburg
- Prunuske Chatham, Inc.
- Dr. Kyle Christie, Wendy McBride
- Dr. Matt Clark, Sonoma State University
- Department of Fish and Wildlife
- California Native Plant Society
- San Francisco Estuary Institute
- Local Ecology and Botany Group
- Vegetation Mapping and Remote Sensing Advisory Committee

SONOMA VEG MAP DATA PRODUCTS

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- **34 products created to date**
- **Countywide ortho-imagery, lidar and lidar derivatives (16)**
  - Point cloud, DEMs, canopy height, canopy density
  - Hydroenforced dems, stream thalwags, watersheds
- **Land use land cover maps (14)**
  - Countywide fine-scale vegetation map and derivatives:
    - Lifeform map
    - Croplands map
    - Water and wetland vegetation
  - Impervious surfaces map
  - Carbon/biomass map
- **Applications (4)**
  - Viewers and tools to download and visualize data

TESTIMONIALS

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- *"I cannot speak highly enough about the quality and usefulness of this data. The LiDAR data products have improved cartography quality, and enabled more advanced and accurate data analysis. These products are an amazing resource for Sonoma County GIS professionals."*

- Andrew Bartshire, Russian River Salmon and Steelhead Monitoring Program

- *These tools help us to be more precise in our regulatory efforts, and provide innumerable other benefits to the citizens of Sonoma County. We are only beginning to fully understand how critical this data set is to improving our programs! Thank you!"*

- Cree Morgan, Sonoma County Department of Agriculture

TESTIMONIALS

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- *“Its amazing – like stumbling into King Tut’s tomb. The data is unifying. It gets everybody on the same page and helps us to prioritize. It reveals hidden treasures such as historic walls and roads, and facilitates exceptional cartography.”*

  - Joe Kinyon, Sonoma Land Trust

- *“We use the data all the time, everyday. It is part of every map. We always look at it before we even think of going into the field.”*

  - Alex Young, Sonoma Ecology Center

TESTIMONIALS

- *"The Sonoma County Veg Map Project is by far one of the best uses of public money I have seen in a long time. It benefits Public Agencies and Private Landowners (directly or through their consultants). Land planning and the growing requirements for onsite information make these data a great bridge to address concerns more accurately with less out of pocket field costs to land owners."*

  - Walter Moody, Ray Carlson and Associates

- *"The products are saving us months on design" … "they help to build trust with clients up front"*

  - Jason Hocheder, Always Engineering

PROJECT TIMELINE

August, 2012	The Program Begins
December, 2013	LiDAR Data Products Released
June, 2014	VegCAMP/CNPS Plot Data Collection Complete
October, 2015	Mapping Classification and Decision Rules Complete
January, 2016	Draft Lifeform and Croplands Map Released
February, 2016	Impervious Surfaces Map Released
March, 2016	Hydrologic Data Deliverables (centerlines, HE DEM, etc.) Released
May, 2017	Fine Scale Vegetation and Habitat Map Released
October, 2018	Accuracy Assessment and Final Report

2. VEG MAPPING METHODS - Overview

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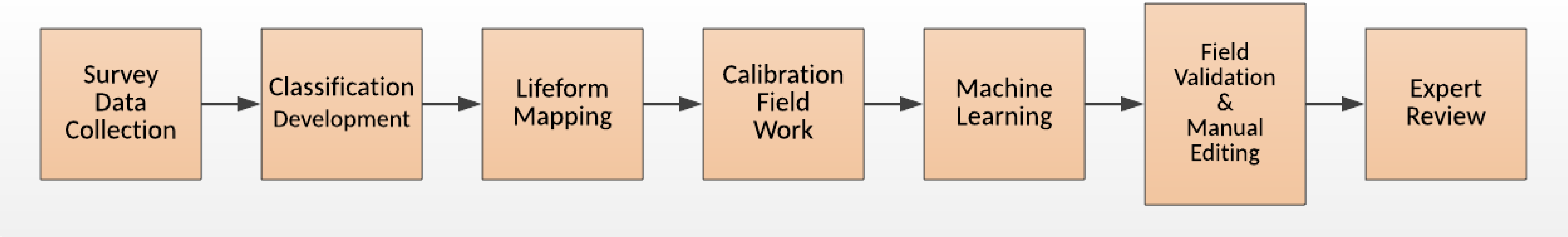
Employed state of the art mapping techniques to combine field data collection with semi-automated mapping processes

1. Create lifeform map in Ecognition that serves as a foundation for the fine scale vegetation map
2. Use machine learning models trained on field collected data to predict vegetation occurrence
3. Manually edit the model predictions using photo-interpretation and field validation
4. Assess Accuracy

METHODS - Overview



Sonoma County Vegetation Mapping Process

METHODS - Survey Data

- Summer 2013 through Spring 2014
- Approx. 800 rapid assessment and relevé surveys; additional recon surveys
- California Department of Fish and Wildlife (VegCAMP), CNPS, Prunuske Chatham

METHODS - Survey Data

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- Classification development
- Used to "train" machine learning classifiers
- Used as field validation to guide photo interpreters
- Some surveys reserved for map accuracy assessment

METHODS - Classification Development

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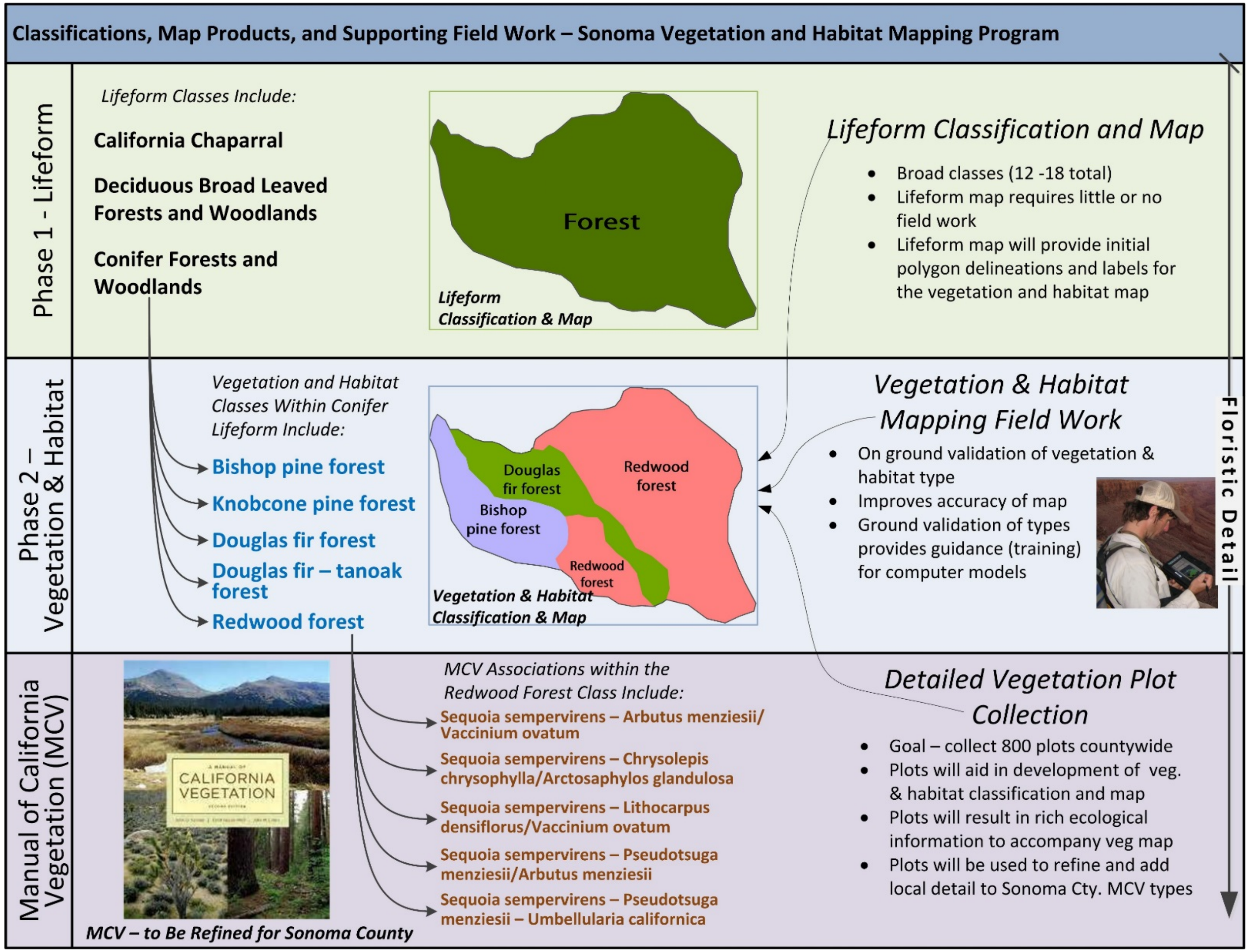
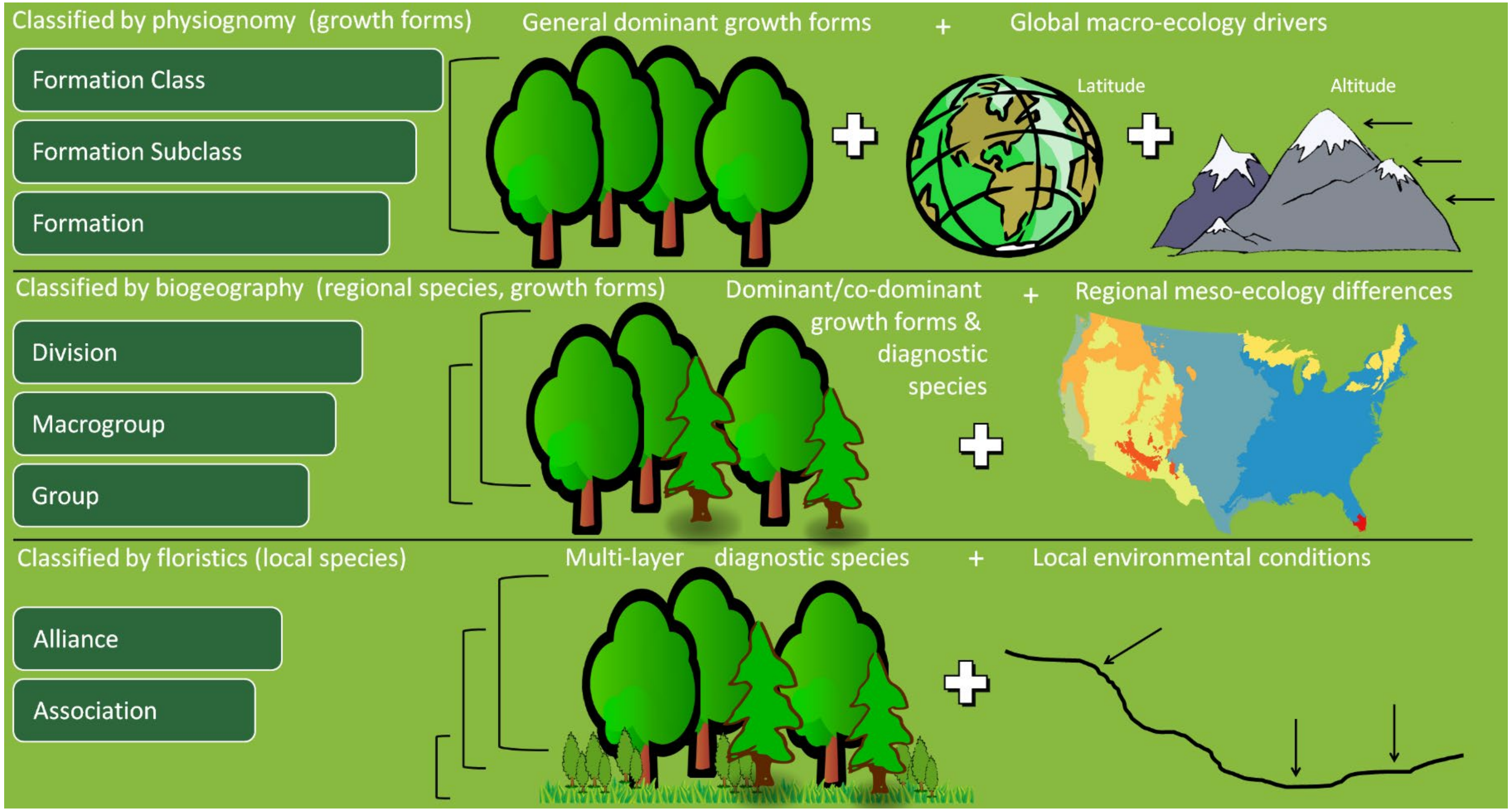
- **Classification Development**
  - Based on analysis and ordination of survey data
  - VegCAMP, CNPS, Prunuske Chatham
  - Work resulted in the following key deliverables:
    - **Detailed classification** of Sonoma County Alliances (with descriptions and stand tables!)
    - **Fine Scale Mapping Key**!

METHODS - Classification Development



METHODS - Classification Development



From: http://usnvc.org/data-standard/natural-vegetation-classification/

METHODS - Classification Development

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Sonoma Veg Map - Minimum Mapping Units for Vegetation Map Products

Map Class	MMU	MMU for Contrasting Lifeforms
Agricultural Classes	1/4 Acre	--
Woody Upland Classes	1 Acre	1/2 Acre
Woody Riparian Classes	1 Acre	1/4 Acre
Upland Herbaceous Classes	1 Acre	1/2 Acre
Wetland Herbaceous Classes	1 Acre	1/4 Acre
Bare Land	1/2 Acre	--
Impervious Features - Pervious/Impervious Map	1000 square feet**	--
Impervious Features - Lifeform Map	2/10 Acre	--
Water	400 square feet	--

**200 square feet for buildings

METHODS - Classification Development – Keys

Class A. Tree-Overstory (Woodland / Forest) Vegetation

Section I: Woodlands and forests dominated or characterized by needle or scale-leaved conifer trees. Includes *Abies*, *Hesperocyparis*, *Pinus*, *Pseudotsuga*, and *Sequoia*.

1. Temperate rainforest dominated or co-dominated by *Sequoia sempervirens* or *Abies grandis*. Found in maritime climates with summertime fog.

Vancouverian Rainforest Macrogroup

Vancouverian Hypermaritime Lowland Rainforest Group

1a. *Sequoia sempervirens* dominates, co-dominates, or characterizes (rarely with as little as 5% cover) stands near streams, along all slopes and aspects, or on ridges. Associated trees include *Acer macrophyllum*, *Notholithocarpus densiflorus*, *Pseudotsuga menziesii*, *Torreya californica*, and *Umbellularia californica*, which are typically sub- to co-dominant but may occasionally exceed *Sequoia* in cover. *Vaccinium ovatum*, *Oxalis oregana*, and *Woodwardia fimbriata* may intermix in the understory.

***Sequoia sempervirens* Alliance**
Sequoia sempervirens – Acer macrophyllum – Umbellularia californica Association
Sequoia sempervirens – Notholithocarpus densiflorus / Vaccinium ovatum Association
Sequoia sempervirens – Pseudotsuga menziesii – Notholithocarpus densiflorus Provisional Association
Sequoia sempervirens –– Pseudotsuga menziesii – Umbellularia californica Association
Sequoia sempervirens –– Umbellularia californica Association
Sequoia sempervirens / Oxalis oregana Association
Sequoia sempervirens / Woodwardia fimbriata Riparian Provisional Association

1b. *Abies grandis* has strong dominance in the tree overstory, with *Pinus muricata* and *Sequoia sempervirens* intermixing locally as sub-dominants. Stands are rare in the county. One stand, found on a convexity running along a middle slope up to the ridgetop, was sampled for this project

***Abies grandis* Alliance**

2. Cool-temperate coniferous forests and woodlands influenced by warm, relatively dry summers and cool rainy winters. Stands are dominated or co-dominated by *Pinus ponderosa*, *Pseudotsuga menziesii*, or *P. menziesii* in combination with *Notholithocarpus densiflorus* in the tree overstory.

Californian–Vancouverian Montane and Foothill Forest Macrogroup

2a. Vegetation characterized by a mixture of *Pseudotsuga menziesii* and *Notholithocarpus densiflorus* in the canopy. *Pseudotsuga* is typically dominant to co-dominant with *Notholithocarpus*, but may occasionally be slightly sub-dominant.

Vancouverian Evergreen Broadleaf and Mixed Forest Group

***Pseudotsuga menziesii – Notholithocarpus densiflorus* Alliance**
Pseudotsuga menziesii – Notholithocarpus densiflorus Association

Section II. Forests and Woodlands with tree canopy dominated or co-dominated by needle or scale-leaved conifer trees (relative tree cover >30% conifer). Includes *Sequoia*, *Pinus ponderosa, and Pseudotsuga*.

10. *Sequoia sempervirens* and/or *Pseudotsuga menziesii* dominant or co-dominant with hardwoods or Pinus ponderosa in the tree canopy. Conifers comprise > 30% relative cover in the canopy.

10a. *Sequoia sempervirens* has >20% relative conifer cover. Associated trees often include *Acer macrophyllum, Notholithocarpus densiflorus, Pseudotsuga menziesii, Torreya californica, and Umbellularia californica*, which are typically sub to co-dominant but may occasionally exceed *Sequoia* in cover.

***Sequoia sempervirens* Alliance**

11. *Pinus ponderosa* and/or *Pseudotsuga menziesii* dominant or co-dominant with *Notholithocarpus densiflorus* in the tree canopy. Conifers comprise > 30% relative cover in the canopy.

Californian–Vancouverian Montane and Foothill Forest Macrogroup

11a. *Pseudotsuga menziesii* is dominant or co-dominant in the conifer canopy; *Notholithocarpus densiflorus* has greater than 10% relative tree cover.

Vancouverian Evergreen Broadleaf and Mixed Forest Group
***Pseudotsuga menziesii - Notholithocarpus densiflorus* Alliance**

11b. *Pinus ponderosa* and/or *Pseudotsuga menziesii* is dominant or co-dominant in the conifer canopy; relative tree cover of *Notholithocarpus densiflorus* is less than 10%.

Upland Vancouverian Mixed Woodland and Forest Group

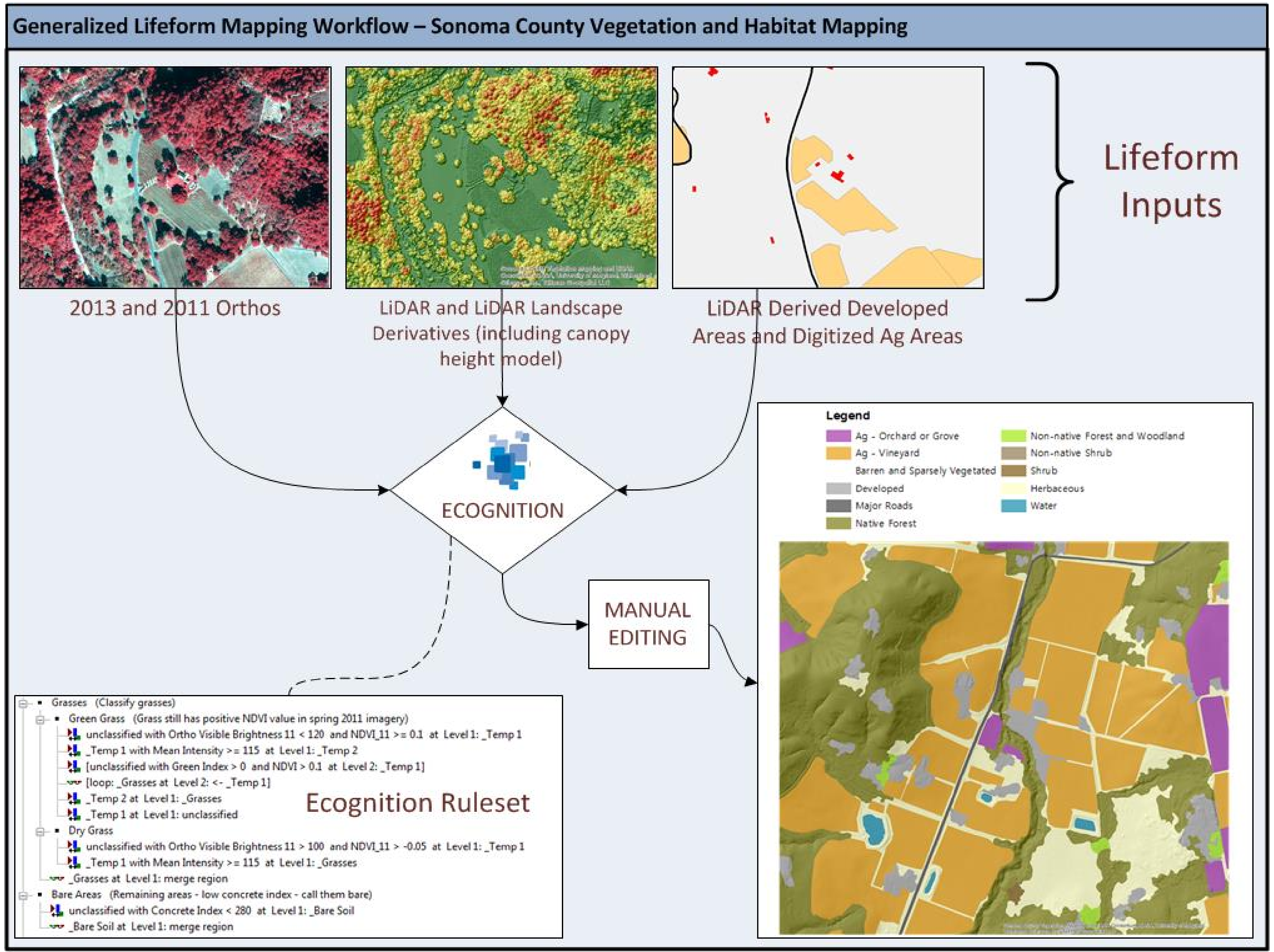
11b1. *Pinus ponderosa* is dominant or co-dominant with *Pseudotsuga menziesii* in the conifer canopy. Stands with significant *Pinus ponderosa* were only encountered twice for this project – in the higher elevation, eastern portion of the county. In both instances, *Arbutus menziesii, Arctostaphylos manzanita* and *Quercus chrysolepis* were present. This type will be mapped where seen in the field only and will not be included in accuracy assessment or machine learning.

Mapping Key and Full Floristic Key Available at – sonomavegmap.org/data-downloads

METHODS - Lifeform Mapping

- **Phase 1 → Lifeform Mapping**
  - Initial, generalized map of the landscape
  - First step for subsequent more detailed mapping
  - Ecognition segmentation/classification followed by manual editing
- **Phase 2 → Fine Scale Mapping (~Alliance Level)**
  - Use mapping key created from survey data to define classes
  - Use calibration field data as training
  - Machine learning (Random Forests and SVM) followed by manual editing

METHODS - Lifeform Mapping



METHODS - Fine Scale Segments

2013 Imagery

Lifeform Map (green is forest)

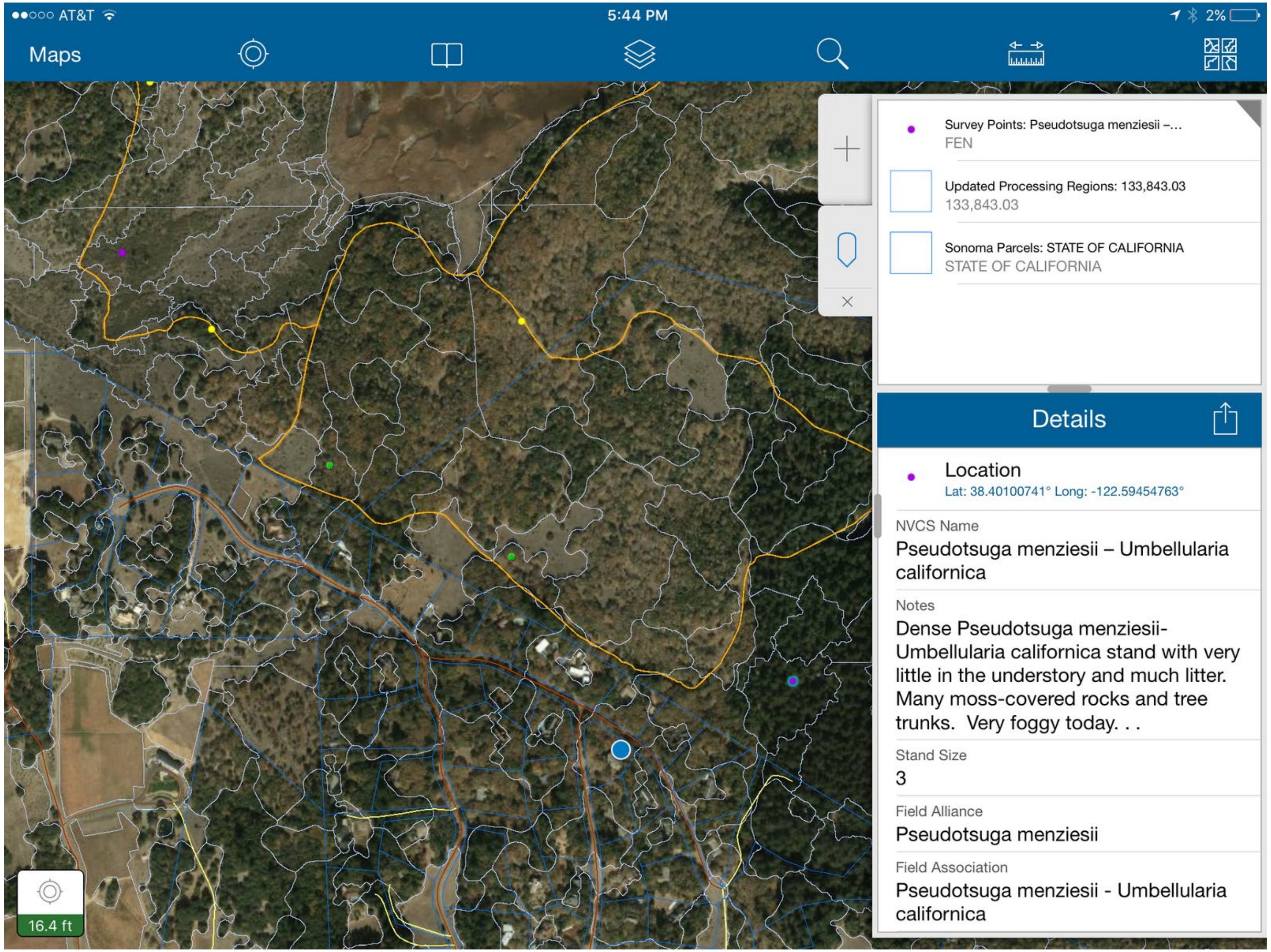
Fine scale segments (yellow outlines)

METHODS - Calibration Field Work

- Label segments with field verified fine scale map class – data used as training for machine learning
- Critical for ‘calibrating’ vegetation mapper’s eyes
- Collect fine-scale map class, relative cover and additional notes

METHODS - Calibration Field Work

- ESRI's Collector App useful for navigation and reference
- Also used collector for field photos



METHODS - Machine Learning

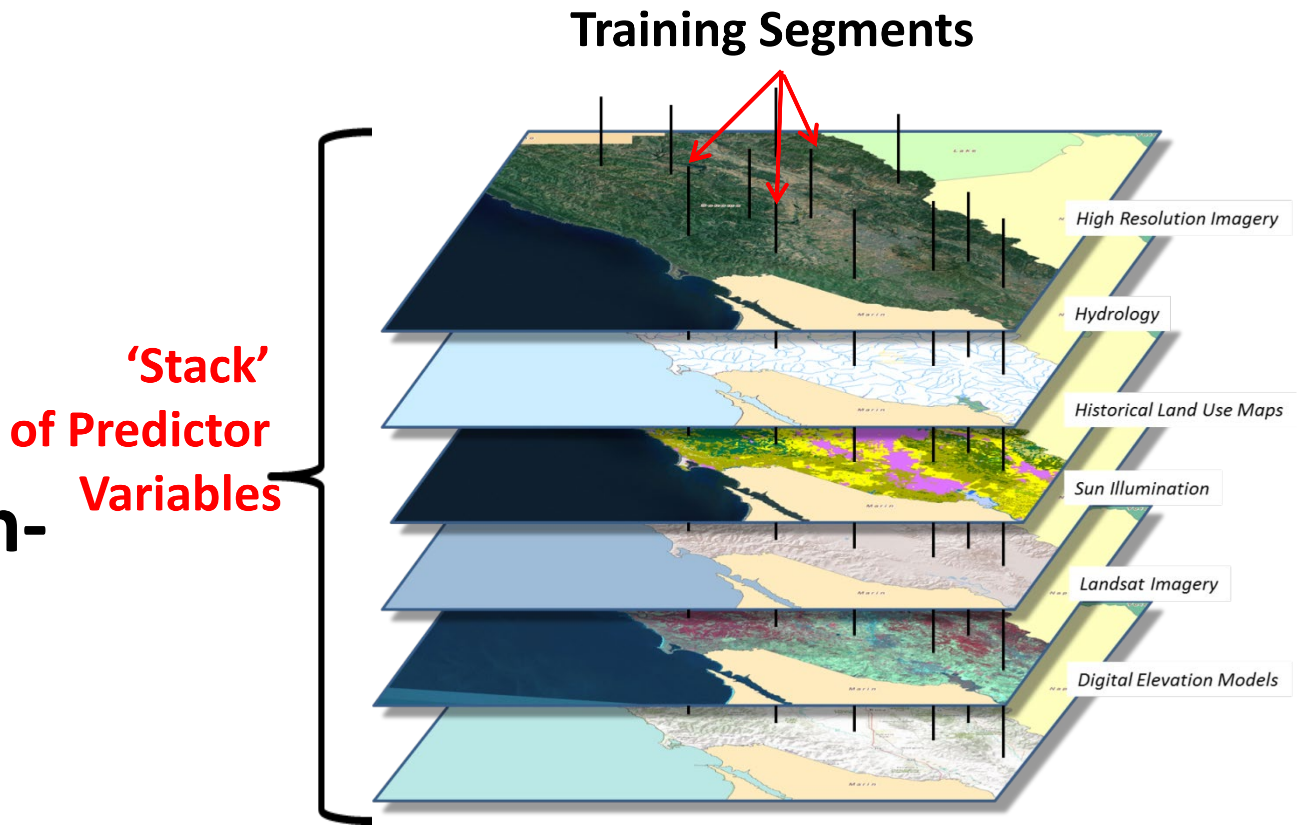
- **Combined two algorithms in 'ensemble' approach**
  - Random Forests
  - Support Vector Machines
  - Both algorithms applied in R scripts
  - Growing literature that these are two of the most effective machine learning approaches for vegetation mapping
  - Dr. Matt Clark (SSU) advised and developed custom R code for our approach

METHODS - Machine Learning

- **Random forests and SVMs are powerful data mining tools for vegetation mapping because:**
  - They accept continuous and categorical data inputs
  - No assumptions are required concerning distributions of independent variables
  - They identify simple and complex relationships between variables that other techniques might not uncover
  - They force consistency and analytical rigor into segment labeling process
  - They are cost efficient

METHODS - Machine Learning

- Training segments are intersected with predictor variables
- Machine learning predicts veg classes based on training
- Model is then applied across un-sampled areas
- Segment labels are then edited



Machine Learning

Machine Learning Predictor Variables

- **LiDAR derivatives**: Canopy Slope, Proximity to Stream Centerlines, Aspect, Elevation, Stand Complexity, Flow Accumulation…
- **Hyperspectral**: AVIRIS Indices
- **Spectral**: Multidate Landsat imagery & indexes, Landsat NIR difference images, 2009/2012 NAIP imagery & indexes, Spring 2011 6-inch imagery & indexes, Fall 2013 6-inch imagery & indexes
- **Other**: geology, fire history, fog occurrence, distance from coast and precipitation
- **Total of 314 Predictor Variables**

METHODS - Machine Learning

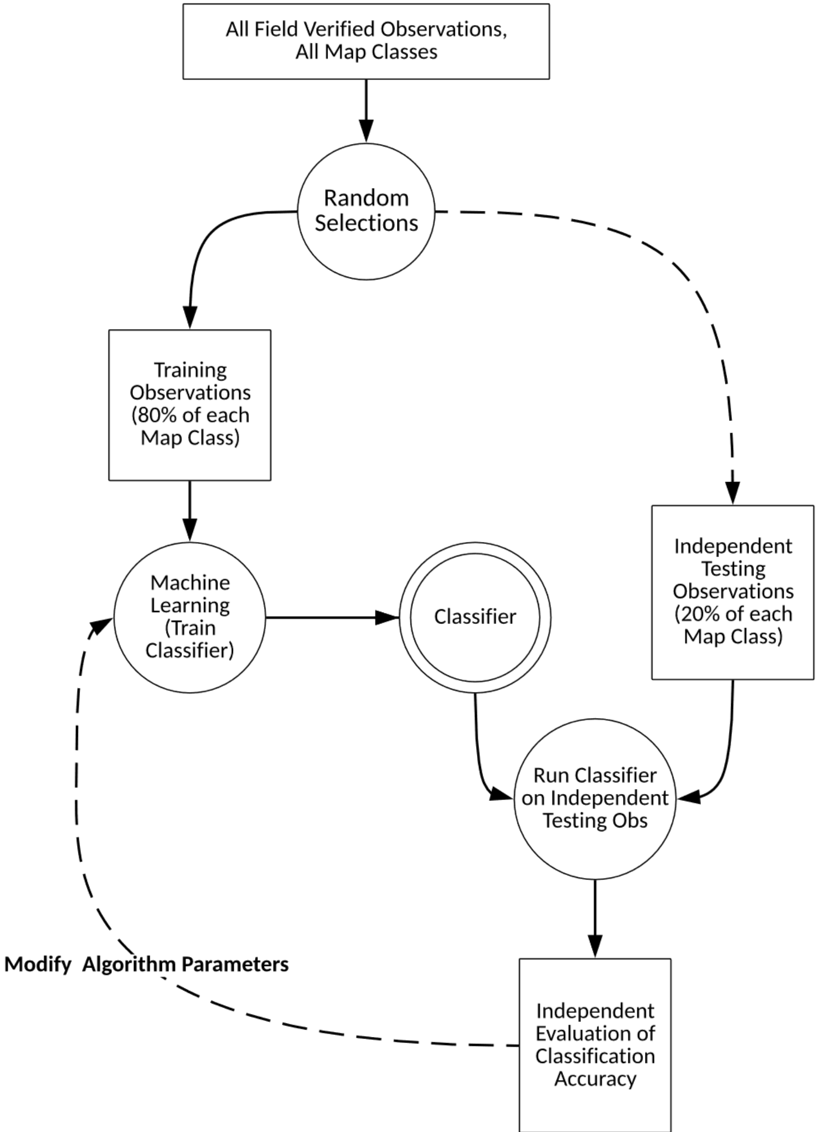
- **Ensemble approach**
  - Both algorithms produced a first and second vote and confidences (or probabilities of correctness) votes
  - If algorithms agreed, label stand with agreed upon prediction
  - If they disagreed, label stand with prediction from algorithm with higher confidences
  - If each had low confidence in prediction, manually edit

METHODS - Machine Learning

- **Machine learning workflow**
  - Create predictor variable statistics for all segments
  - Randomly segregate training samples into training and testing pools by fine scale map class
  - Run Random Forest and Support Vector Machines using R
  - Logical post-processing of model results in python

METHODS - Machine Learning

- Machine learning algorithms require optimization
- Key is to set aside observations for testing algorithm accuracy with varied parameters
- We use approximately 20% of calibration sites for testing



METHODS – Machine Learning

- **Predictor variable importance matrix for *Quercus garryana* alliance**
- **NDVI important**
- **Landsat difference images important (band 5 difference, spring minus winter)**

Predictor Variable Abbreviation	**Predictor Variable Description**	***Quercus garryana* Alliance**
MN_HINDVI	% of canopy w/ high NDVI in '13 orthos (not including non-veg areas)	0.080
MN_GREENDX	Green index (Green-Red)/(Green + Red), 2013 orthos	0.075
MN_B5DF_32	Mean Landsat 8 band 5 difference, March minus Feb	0.060
MN_B5DF_42	Mean Landsat 8 band 5 difference, April minus Feb	0.057
MN_LONDVI	% of canopy w/ low NDVI in '13 orthos (not including non-veg areas)	0.055
MN_NDVI	Mean NDVI, 2013 orthos	0.048
MN_NDVI_RA	Ratio of NDVIs between 2011 and 2013 orthos	0.036
MN_B5DF_52	Mean Landsat 8 band 5 difference, May minus Feb	0.033
MN_SOLARRA	Mean solar radiation	0.030
MN_SLOPE	Mean slope from lidar-derived bare-earth DEM	0.028
MN_BRIGHT	Mean 2013 ortho brightness index (from Ecognition)	0.027
MN_TM_NDVI	Mean Landsat 8 NDVI from 5/25/13	0.024
MN_BARE	Mean ground elevations from lidar-derived bare-earth DEM	0.023
MN_TM_GN	Mean Landsat 8 tasseled cap greeness from 5/25/13	0.022
MN_Wtr1AbAr_AV	Mean AVIRIS leaf water absorption index	0.022
MN_P90_30F	Mean lidar 90th percentile height from lascanopy	0.020
SD_P10_30F	Standard deviation lidar 10th percentile height from lascanopy	0.018
MN_STD_30F	Standard deviation lidar height from lascanopy (all returns)	0.018
MN_PRECIP	Mean average annual precipitation	0.017

Machine Learning

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Overall Predictor Variable Importance (South Sonoma County)*

Importance	Predictor	Description
1	MN_COAST	Distance from Coast
2	MN_SLOPEHH**	Canopy Slope
3	MN_GREENDX	Ecognition green index
4	MN_EWT_AV	AVIRIS Index
5	MN_Wtr1AbAr_AV	AVIRIS Index
6	MN_NDVI	Mean NDVI, 2013 Orthoimagery
7	MN_FOG	Mean summer fog - June to August
8	MN_P90_30F**	Mean LiDAR 90th percentile height from LasCanopy
9	MN_100_150**	% of LiDAR returns between 100 to 150 feet above ground
10	MN_STD_30F**	SD LiDAR height from LasCanopy

*These are for overall model importance for Random Forests only; predictor variable importance for individual vegetation classes varies

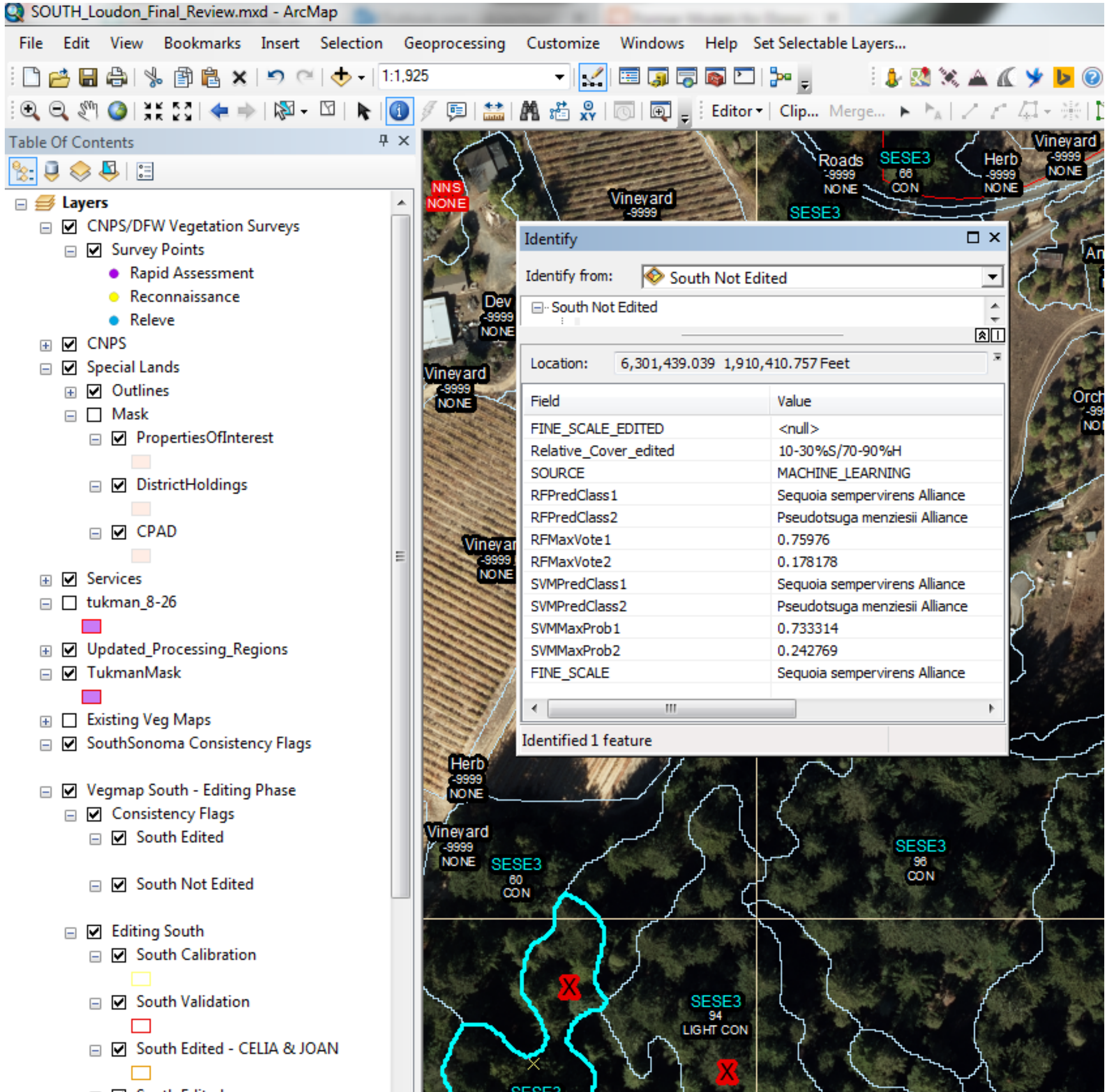
**LiDAR derived variable

METHODS - Validation Field Work

- **Manual editing protocols**
  - Edits at a 1,800 scale, in 100 acre editing tiles
  - Editors use the same editing template with same symbology, reference layers, and labeling
  - Editing standards and best practices documented and shared with team
  - Weekly editor meetings to calibrate and discuss difficult to PI areas

METHODS - Manual Editing

- **Manual editing map document**
  - Predictions/confidences from machine learning provided for every polygon
  - Symbology set up for imagery
  - Advanced labeling rules pre-configured
  - Dynamic error flags to notify editors of inconsistencies – built in QA/QC



METHODS - Manual Editing

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Manual Editing – Supporting Datasets

Raster Datasets	Vector Datasets
2008 Pictometry (mostly leaf-off)	100-acre tiles (editing units) for tracking editing progress
2009 NAIP (1-meter, 4-band), displayed as an RGV and CIR composite	Roads and trails
2011 Sonoma County imagery (6-inch, 4-band), displayed as an RGV and CIR composite	Reconnaissance photos
2012 NAIP (1-meter, 4-band), displayed as an RGV and CIR composite	CNPS survey points
2013 Sonoma County imagery (6-inch, 4-band), displayed as an RGV and CIR composite	Field calibration segments
2013 LiDAR derived bare earth DEM	Geology (USGS)
2013 LiDAR derived bare earth hillshade	Soils (NRCS)
Vertical height above river (derived from 2013 LIDAR)	Ultramafic layer (CNPS)
2013 LiDAR derived canopy height	Serpentine mask
USGS 7.5-minute topography	Existing vegetation maps
Historic 'soil-veg' maps	Fire history

METHODS – Fine Scale Mapping

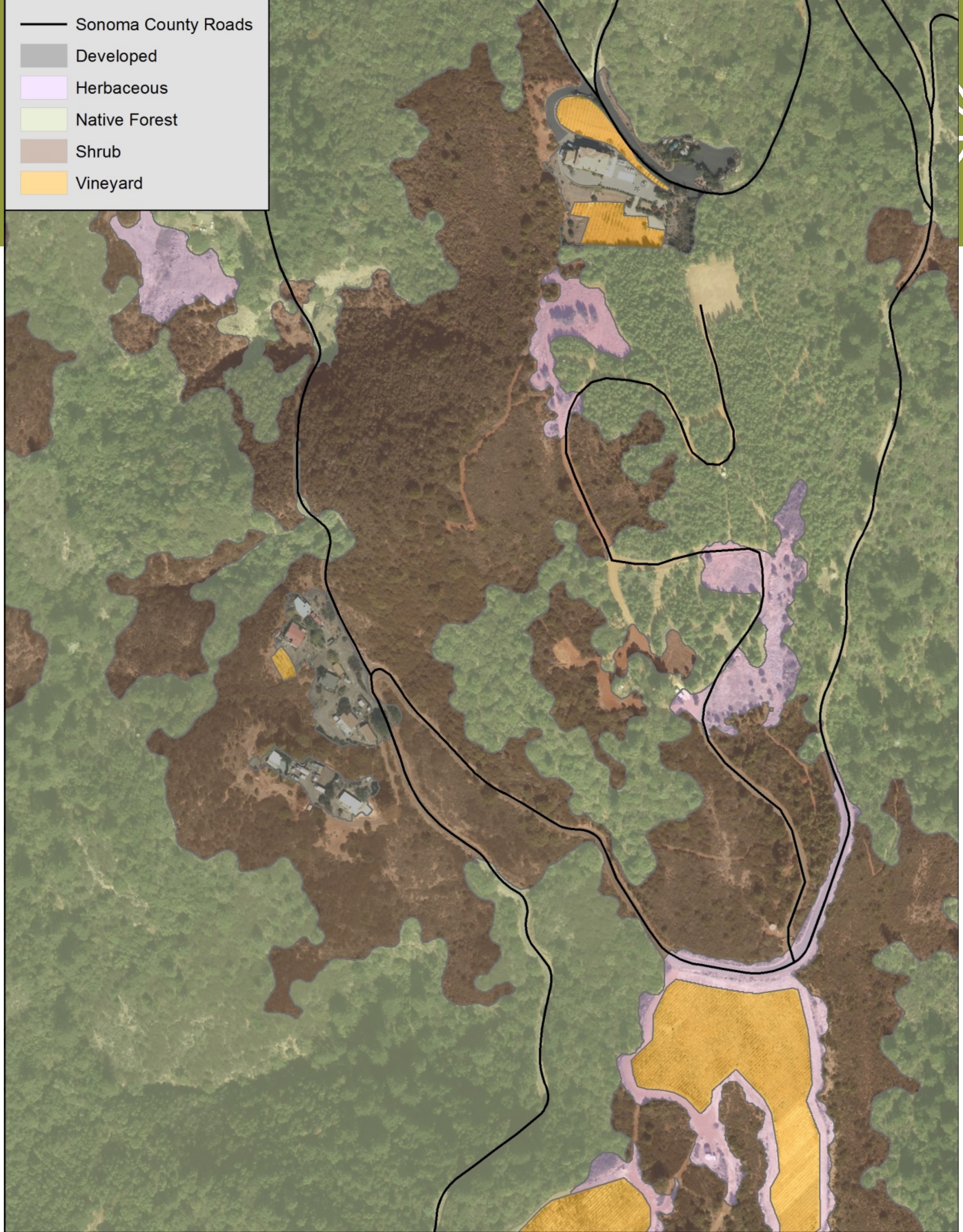
Lifeform

Lifeform with Finescale Segments

Field Data

Machine Learned Fine Scale Map

Edited Fine Scale Map



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METHODS – Sensitive Habitats

- **More detailed mapping for sensitive habitats of special interest – wetlands, riparian and serpentine**
- **Crucial ecosystem services**
  - flood protection
  - water supply and quality protection
  - climate resilience
  - wildlife and fisheries resources…
- **Diminished extent, importance to District for protection**

METHODS – Senstive Habitats (Herbaceous Wetlands)

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- Integrate BAARI and NCAARI data products into Sonoma County Vegetation and Habitat Map
- Use the 2013 LiDAR and other high resolution imagery to help refine BAARI and NCAARI
- Use the 2013 LiDAR and high resolution imagery to map herbaceous wetlands outside of the BAARI/NCAARI areas

METHODS – Sensitive Habitats(Herbaceous Wetlands)

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Integration of San Francisco Estuary Institute (SFEI) Wetlands Data with Manual Delineations

3. ACCURACY ASSESSMENT

1. Sample Design
2. Analysis
3. Discussion

ACCURACY ASSESSMENT – Sample Design

- Two maps assessed – lifeform and fine scale vegetation
- Sample units - segments
- Two types of samples
  - Manually Interpreted – easy to photointerpret lifeform classes like vineyard, orchard, barren, developed, water…
  - Field Verified – shrub, wetland and native forest fine scale vegetation types

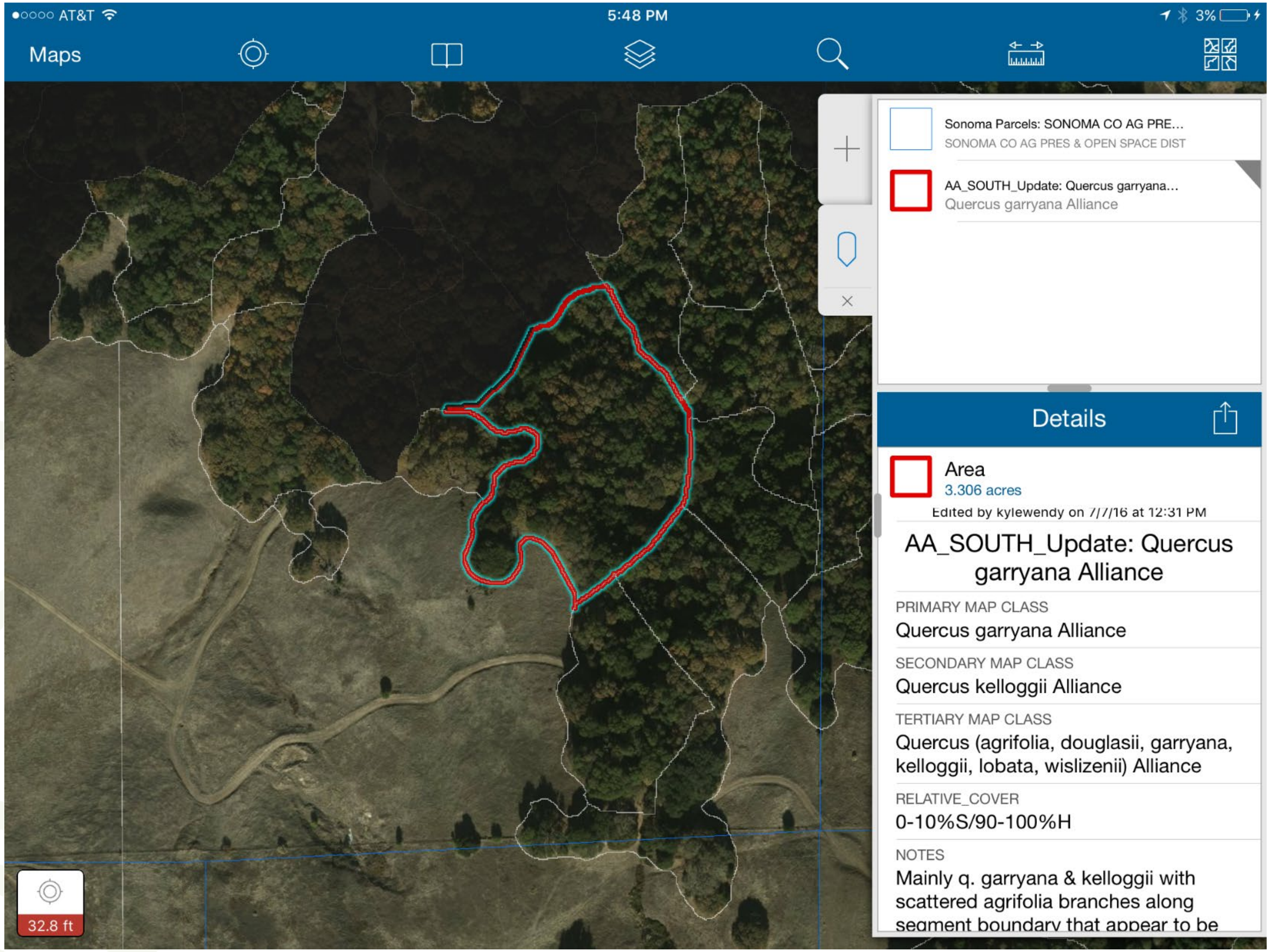
ACCURACY ASSESSMENT – Sample Design

- Manually interpreted samples
  - A random number generator was used to select 30 samples per lifeform class
  - Reference labels were developed using manual interpretation
  - A total of 378 manually interpreted samples were collected

ACCURACY ASSESSMENT – Sample Design

- Field verified sites
  - Combined stratified random /cluster sampling
  - Created an access/no access layer
  - Samples were selected within the accessible portions of the county using a stratified random sample
  - At each sample, field personnel estimated % cover by species and fine scale map class
  - Field personnel were encouraged to collect 2-3 additional samples (in adjacent segments) with fine scale map classes different from the allocated segment

ACCURACY ASSESSMENT – Sample Design



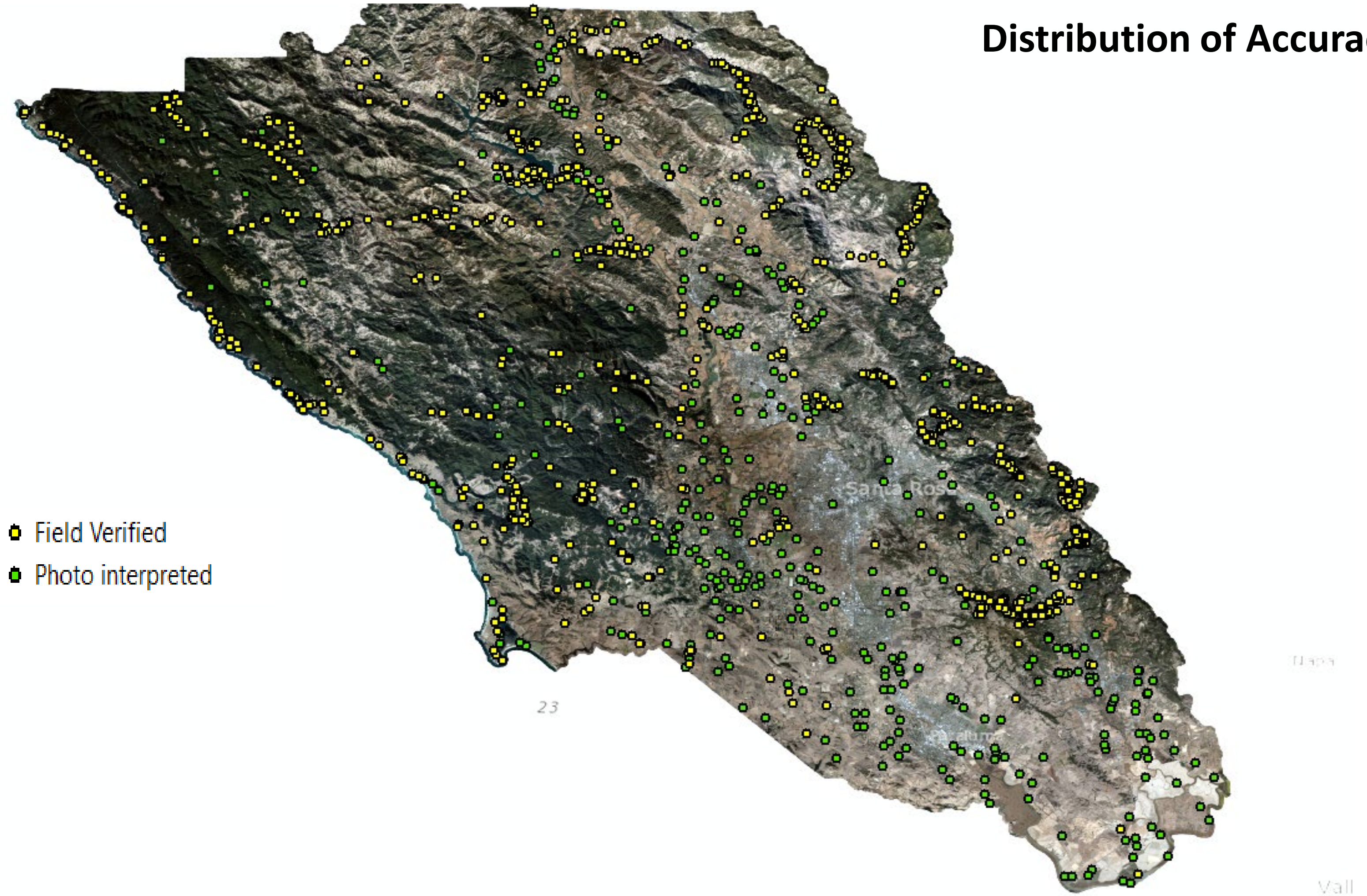
iPad Field Form

ACCURACY ASSESSMENT – Sample Design

- **Field verified sites**
  - **Allowed for more than one acceptable reference label because**
    - **Humans are incapable of precisely estimating percent cover, resulting in an average variance in cover estimates of +/- 10%**
    - **Classification schemes often impose boundaries between types which actually transition on a continuum**
  - **961 field verified sites collected to assess 48 fine scale map classes**
  - **Quality control resulted in 75 sample segments being removed from the data set**

ACCURACY ASSESSMENT – Sample Design

Distribution of Accuracy Assessment Samples



ACCURACY ASSESSMENT – Analysis

- **Overall Accuracies**
  - **94% Lifeform Map**
  - **78% Fine Scale Map**

ACCURACY ASSESSMENT – Analysis
Lifeform Map

Map Labels	Annual Cropland	Barren & Sparsely Vegetated	California Annual and Perennial Grassland Macrogroup	Developed	Eucalyptus (globulus, camaldulensis) Semi-natural Alliance	Intensively Managed Hayfield	Irrigated Pasture	Native Forest	Non-native Forest & Woodland	Non-native Shrub	North American Pacific Coastal Salt Marsh Macrogroup	Orchard or Grove	Shrub	Vineyard	Water	Total	User's Accuracy
	Reference Labels																
Annual Cropland	28	1	1									1				31	90%
Barren & Sparsely Vegetated		28	1			1										30	93%
California Annual and Perennial Grassland Macrogroup		3	27	1												31	87%
Developed		3		33					1							37	89%
Eucalyptus (globulus, camaldulensis) Semi-natural Alliance					26			1	3							30	87%
Intensively Managed Hayfield	1	2				27										30	90%
Irrigated Pasture			1			4	25									30	83%
Native Forest		2						620					11			631	98%
Non-native Forest & Woodland		1			2			2	30							35	86%
Non-native Shrub										9						9	100%
North American Pacific Coastal Salt Marsh Macrogroup		1	1					1			26		1			30	87%
Orchard or Grove	1		1						1			30				33	91%
Shrub								13		1			223			237	94%
Vineyard		1				1						1		30		33	91%
Water								1							30	31	97%
Total	30	42	32	34	28	33	25	638	35	10	26	32	238	30	30	1267	
Producer's Accuracy	93%	67%	84%	97%	93%	82%	100%	97%	86%	90%	100%	94%	94%	100%	100%	94%	

ACCURACY ASSESSMENT – Analysis
Lifeform Map

Map Class	Number of Map Samples	User's Accuracy	Number of Reference Samples	Producer's Accuracy
Annual Cropland	31	90%	30	93%
Barren & Sparsely Vegetated	30	93%	42	67%
California Annual and Perennial Grassland Macrogroup	31	87%	32	84%
Developed	37	89%	34	97%
Eucalyptus (globulus, camaldulensis) Semi-natural Alliance	30	87%	28	93%
Intensively Managed Hayfield	30	90%	33	82%
Irrigated Pasture	30	83%	25	100%
Native Forest	631	98%	638	97%
Non-native Forest & Woodland	35	86%	35	86%
Non-native Shrub	9	100%	10	90%
North American Pacific Coastal Salt Marsh Macrogroup	30	87%	26	100%
Orchard or Grove	33	91%	32	94%
Shrub	237	94%	238	94%
Vineyard	33	91%	30	100%
Water	31	97%	30	100%

ACCURACY ASSESSMENT – Analysis Fine Scale Map

Map Label	Acer macrophyllum Alliance	Adenostoma fasciculatum Alliance	Aesculus californica Alliance	Arbutus menziesii Alliance	Arctostaphylos (bakeri, montana) Alliance	Arctostaphylos (canascens, manzanita, stanfordi	Arctostaphylos viscida Alliance	Baccharis pilularis Alliance	California Annual and Perennial Grassland Macr	California Coastal Evergreen Bluff and Dune Sc	Californian Mesic Chaparral Group	Ceanothus cuneatus Alliance	Ceanothus oliganthus Alliance	Hesperocyparis macrocarpa Semi-Natural Allia	Hesperocyparis sargentii Alliance	Notholithocarpus densiflorus Alliance	Pinus attenuata Alliance	Pinus muricata Alliance	Pinus ponderosa - Pseudotsuga menziesii Allian	Pinus sabiniana / Quercus durata Provisional All	Populus fremontii Alliance	Pseudotsuga menziesii - Notholithocarpus densi	Pseudotsuga menziesii Alliance	Quercus (agrifolia, douglasii, garryana, kelloggii,	Quercus agrifolia Alliance	Quercus chrysolepis Alliance	Quercus douglasii Alliance	Quercus durata Alliance	Quercus garryana Alliance	Quercus kelloggii Alliance	Quercus lobata Alliance	Quercus wislizeni (shrub) Alliance	Quercus wislizeni (tree) Alliance	Rubus armeniacus Alliance	Sequoia sempervirens Alliance	Southwestern North American Riparian Evergreen	Southwestern North American Riparian/Wash S	Umbellularia californica Alliance	Vancouverian Coastal Riparian Scrub Group	Vancouverian Riparian Deciduous Forest Group	Western North America Vernal Pool Macrogroup	Grand Total	User's Accuracy	Fuzzy User's Accuracy
Acer macrophyllum Alliance	6																																									6	100%	100%
																																										0		
Adenostoma fasciculatum Alliance		30				2		1				5																1				2	1									46	65%	74%
												4																														4		
Aesculus californica Alliance			1																								1															2	50%	50%
																																										0		
Arbutus menziesii Alliance				18																				1						1		2						2				27	67%	78%
																1									2																	3		
Arctostaphylos (bakeri, montana) Alliance					5	1																																				6	83%	83%
																																										0		
Arctostaphylos (canascens, manzanita, stanfordiana) A. glandulosa Mapping		2			1	15	4	1									1																									26	58%	65%
		1					1																																			2		
Baccharis pilularis Alliance								25		2																								1					1			29	86%	86%
																																										0		
California Annual and Perennial Grassland Macrogroup									1																									1								3	33%	67%
																																		1								1		
California Coastal Evergreen Bluff and Dune Scrub Group										11																																11	100%	100%
																																										0		
Californian Mesic Chaparral Group		4									4																															9	44%	56%
												1																														1		
Ceanothus cuneatus Alliance												7	2																			1										13	54%	77%
						1											1															1										3		
Ceanothus oliganthus Alliance		1										1	2																													4	50%	75%
																	1																									1		
Hesperocyparis macrocarpa Semi-Natural Alliance														2																												2	100%	100%
																																										0		
Hesperocyparis sargentii Alliance															9	1	1																									11	82%	82%
																																										0		
Native and Non-native Perennial Coastal Grassland Mapping Unit								2																																		2	0%	0%
																																										0		
Non-native Shrub								1																																		1	0%	0%
																																										0		
Notholithocarpus densiflorus Alliance																23						2				1																28	82%	89%
																						1				1																2		
Pinus attenuata Alliance																	12															1			1							14	86%	86%
																																										0		
Pinus lambertiana Alliance																			2																							2	0%	0%
																																										0		
Pinus muricata Alliance																		24																								24	100%	100%
																																										0		
Pinus ponderosa - Pseudotsuga menziesii Alliance																			2																							2	100%	100%
																																										0		
Pinus radiata Alliance																		1					1																			2	0%	0%
																																										0		
Pinus sabiniana / Quercus durata Provisional Alliance																	1			25					1																	28	89%	93%
																									1																	1		
Populus fremontii Alliance																					13																			1		15	87%	93%
																																				1						1		
Pseudotsuga menziesii - Notholithocarpus densiflorus Alliance																2						9	3												1							17	53%	65%
																1							1																			2		
Pseudotsuga menziesii Alliance				1												1						3	31		1	1																46	67%	85%
				1												1						3													2					1		8		
Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizenii) Alliance				1																				12	1		3		4	2	1		2					1				39	31%	62%
																										1	5		2	2	2											12		
Quercus agrifolia Alliance				1																			2	1	21	1							2		1							33	64%	76%
				1																									1	1								1				4		
Quercus chrysolepis Alliance				1																		1	1			11							2									17	65%	71%
																																	1									1		
Quercus douglasii Alliance																								1			23		1		1											26	88%	88%
																																										0		
Quercus durata Alliance		4				1									1													25														36	69%	83%
		2			1		1					1																														5		
Quercus garryana Alliance	1																							2		1			30	4	1							1				45	67%	78%
																								3						2												5		
Quercus kelloggii Alliance																								2						16					1							20	80%	85%
				1																																						1		
Quercus lobata Alliance																								6			2		1		25		1					1				36	69%	69%
																																										0		
Quercus wislizeni (shrub) Alliance		1									1	1																				3										7	43%	57%
													1																													1		
Quercus wislizeni (tree) Alliance				2		1																	1		1	2					1	1	12					1				23	52%	57%
																										1																1		
Rubus armeniacus Alliance																																		9								9	100%	100%
																																										0		
Sequoia sempervirens Alliance																1						6	4												30					1		46	65%	74%
																2						1				1																4		
Southwestern North American Riparian Evergreen and Deciduous Woodland Group																					3															11	5					23	48%	70%
																					2																2			1		5		
Southwestern North American Riparian/Wash Scrub Group								1													2																22			1		30	73%	87%
																																				2				2		4		
Umbellularia californica Alliance																										3									1			20				32	63%	88%
	1																						2	1		3			1													8		
Vancouverian Coastal Riparian Scrub Group																																					1		13	2		17	76%	82%
																		1																								1		

ACCURAC
Scale Ma

Map Label	Number of Map Samples	User's Accruacy	Number of Reference Samples	Producer's Accuracy
Hesperocyparis macrocarpa Semi-Natural Alliance	2	100%	2	100%
Western North America Vernal Pool Macrogroup	1	100%	1	100%
Pinus muricata Alliance	24	100%	26	96%
Pinus sabiniana / Quercus durata Provisional Alliance	28	93%	25	100%
Acer macrophyllum Alliance	6	100%	9	89%
California Coastal Evergreen Bluff and Dune Scrub Group	11	100%	13	85%
Rubus armeniacus Alliance	9	100%	13	77%
Quercus durata Alliance	36	83%	27	93%
Vancouverian Coastal Riparian Scrub Group	17	82%	14	93%
Notholithocarpus densiflorus Alliance	28	89%	33	85%
Hesperocyparis sargentii Alliance	11	82%	10	90%
Quercus douglasii Alliance	26	88%	34	82%
Arctostaphylos (bakeri, montana) Alliance	6	83%	7	86%
Pinus attenuata Alliance	14	86%	17	82%
Southwestern North American Riparian/Wash Scrub Group	30	87%	31	81%
Baccharis pilularis Alliance	29	86%	31	81%
California Annual and Perennial Grassland Macrogroup	3	67%	1	100%
Vancouverian Riparian Deciduous Forest Group	68	75%	49	90%
Umbellularia californica Alliance	32	88%	29	76%
Quercus garryana Alliance	45	78%	40	85%
Populus fremontii Alliance	15	93%	31	68%
Quercus kelloggii Alliance	20	85%	28	75%
Pseudotsuga menziesii Alliance	46	85%	46	74%
Quercus agrifolia Alliance	33	76%	29	83%
Sequoia sempervirens Alliance	46	74%	38	84%
Quercus lobata Alliance	36	69%	31	87%
Arbutus menziesii Alliance	27	78%	27	78%
Aesculus californica Alliance	2	50%	1	100%
Pinus ponderosa - Pseudotsuga menziesii Alliance	2	100%	4	50%
Adenostoma fasciculatum Alliance	46	74%	45	73%
Ceanothus cuneatus Alliance	13	77%	20	70%
Arctostaphylos (canascens, manzanita, stanfordiana) A. glandulosa Mapping Unit	26	65%	21	76%
Quercus chrysolepis Alliance	17	71%	27	67%
Californian Mesic Chaparral Group	9	56%	5	80%
Southwestern North American Riparian Evergreen and Deciduous Woodland Group	23	70%	25	64%
Pseudotsuga menziesii - Notholithocarpus densiflorus Alliance	17	65%	26	54%
Quercus wislizeni (tree) Alliance	23	57%	21	62%
Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizenii) Alliance	39	62%	29	55%
Ceanothus oliganthus Alliance	4	75%	5	40%
Quercus wislizeni (shrub) Alliance	7	57%	11	36%
Arctostaphylos viscida Alliance	0	0%	6	33%
Pinus lambertiana Alliance	2	0%	0	0%
Pinus radiata Alliance	2	0%	0	0%

ACCURACY ASSESSMENT – Discussion

- **Lifeform Map**
  - **Very little confusion**
- **Fine Scale Map**
  - **Most of the confusion is spurious and consists of 1 or 2 sites in various cells across the matrix.**

ACCURACY ASSESSMENT – Discussion

- Sources of confusion in the fine scale map
  - 25 samples confused between *Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizenii)* Alliance and the alliances of the species which comprise it.
  - 15 samples confused between the riparian classes of Southwestern North American Riparian Evergreen and Deciduous Woodland Group, Vancouverian Riparian Deciduous Forest Group, and Southwestern North American Riparian/Wash Scrub Group.

ACCURACY ASSESSMENT – Discussion

- Other sources of confusion
  - 10 samples representing errors of omission of *Populus fremontii* Alliance mapped as either Southwestern North American Riparian Evergreen and Deciduous Woodland Group, Southwestern North American Riparian/Wash Scrub Group, or Vancouverian Riparian Deciduous Forest Group.
  - 10 samples representing errors of commission of either *Pseudotsuga menziesii - Notholithocarpus densiflorus* Alliance or *Pseudotsuga menziesii* Alliance to *Sequoia sempervirens* Alliance.

ACCURACY ASSESSMENT – Discussion

- **Other sources of confusion**
  - **6 samples of confusion between *Pseudotsuga menziesii - Notholithocarpus densiflorus* Alliance and the *Pseudotsuga menziesii* Alliance, with errors of commission and omission equal to one another.**
  - **6 errors of commission of either *Adenostoma fasciculatum* Alliance (4), *Arctostaphylos (canascens, manzanita, stanfordiana) A. glandulosa* Mapping Unit (1), or *Hesperocyparis sargentii* Alliance (1) to *Quercus durata* Alliance.**

ACCURACY ASSESSMENT – Discussion

- **Other sources of confusion**
  - **5 samples with errors of commission from *Ceanothus cuneatus* Alliance to *Adenostoma fasciculatum* Alliance.**

4. VEG MAP USES AND UPDATES

VEG MAP PRODUCTS

- **Veg map designed for use at many floristic and spatial scales**
  - At its highest floristic resolution, the map depicts the landscape at NVC alliance level, which characterizes vegetation patches by their dominant plant species
  - This detailed product is useful to managers interested in very specific information about vegetation composition but may be too much information for those interested in more general land use and land cover
  - To make the information contained in the map accessible to the most users, the vegetation and habitat map is published as a suite of deliverables, each with different end users

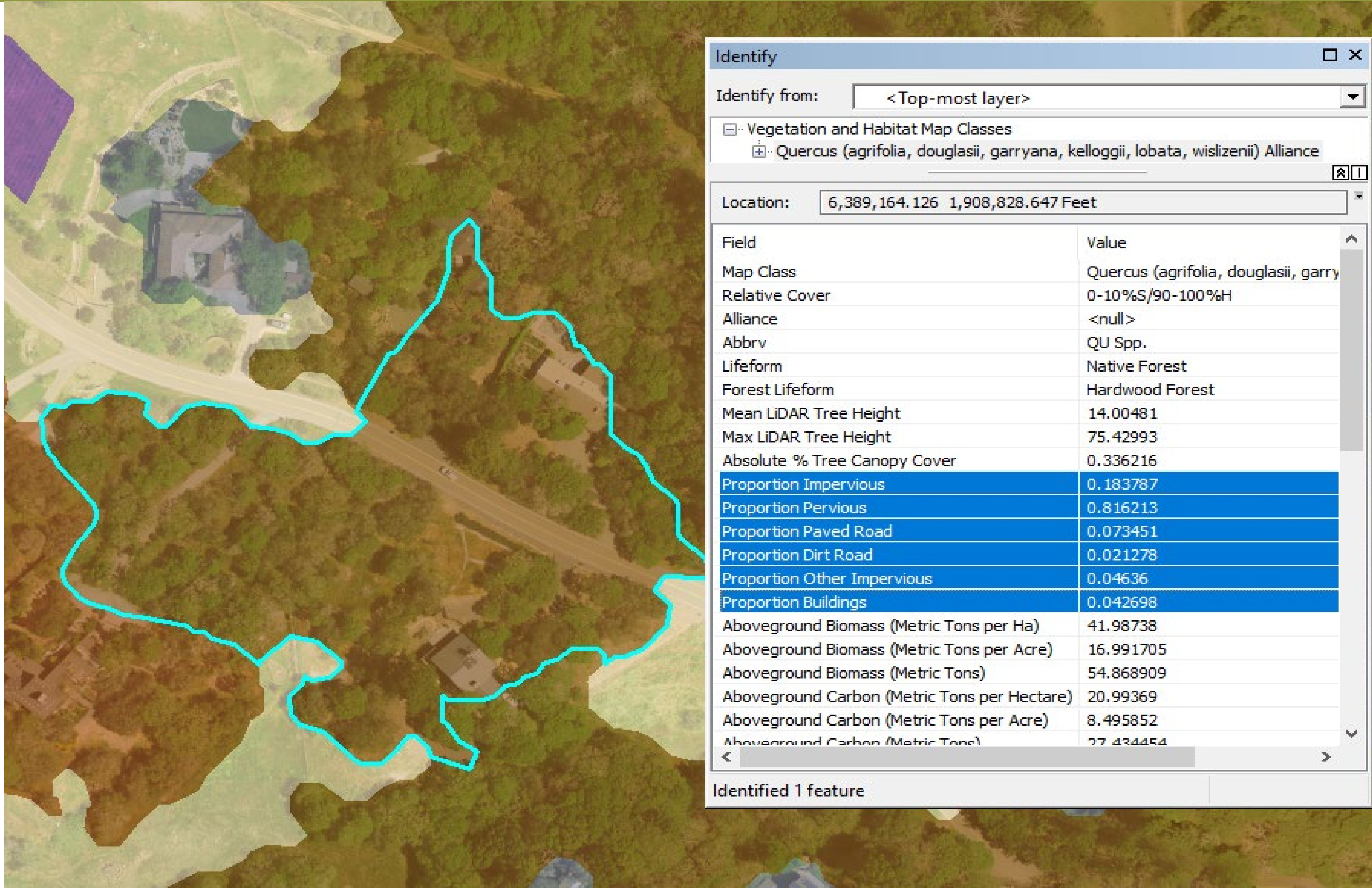
VEG MAP PRODUCTS

- **Fine Scale Vegetation Map (83 classes)**
- **Derivatives**
  - Croplands (8 classes)
  - Lifeform (19 classes, including all 8 ag classes)
  - ‘Forest’ Lifeform (17 classes)
  - Water and Wetland Vegetation (8 classes)
- **Veg map and derivatives publicly available as services and GIS layers**

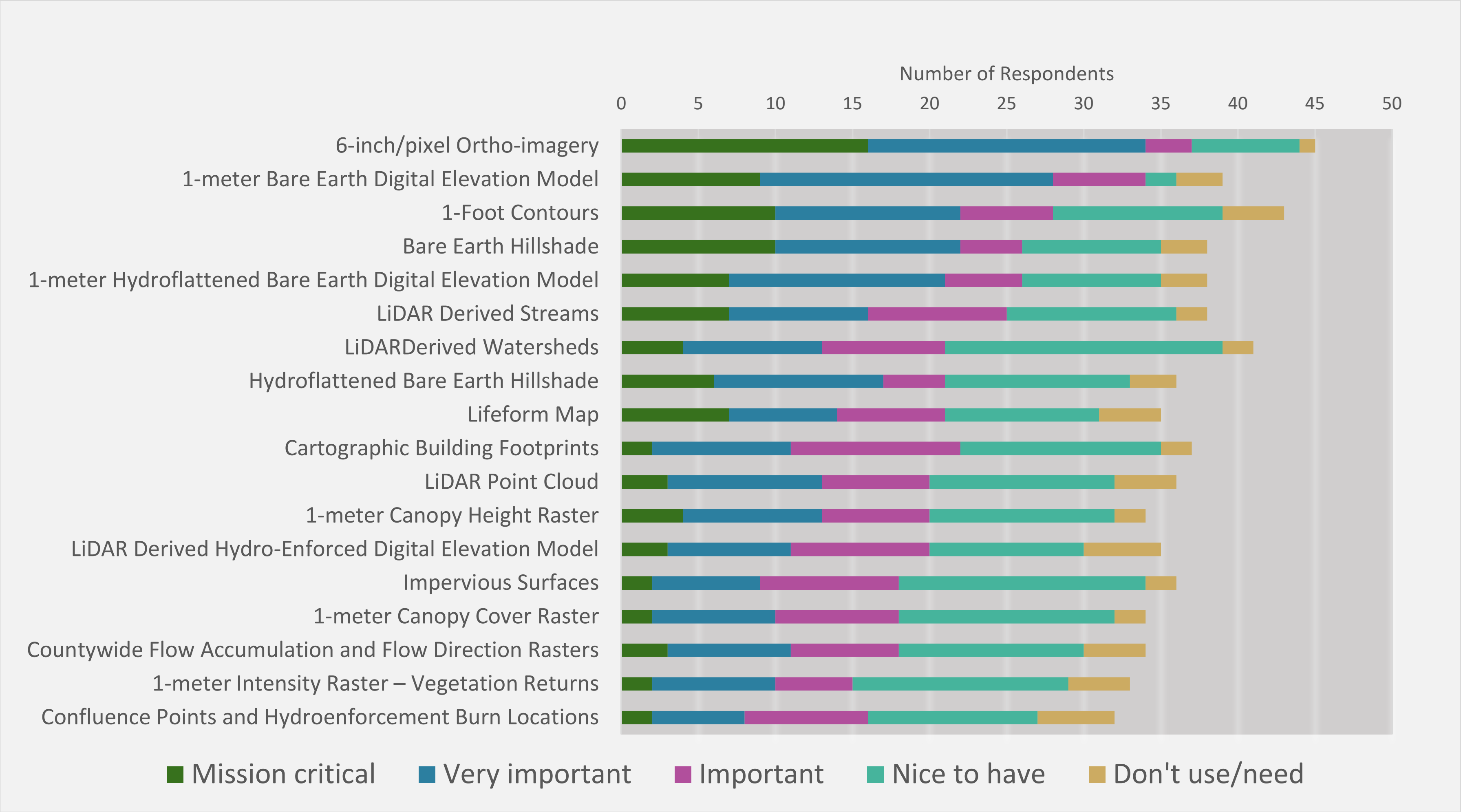
VEG MAP PRODUCTS – Stand Attributes

- **Fine scale map polygons contain the following attributes:**
  - Proportion imperviousness of each polygon
  - Mean & max stand height (forest stands)
  - Absolute canopy density
  - Relative cover --> hardwood v. conifer (forest stands)
  - Total aboveground carbon & biomass (forest stands)

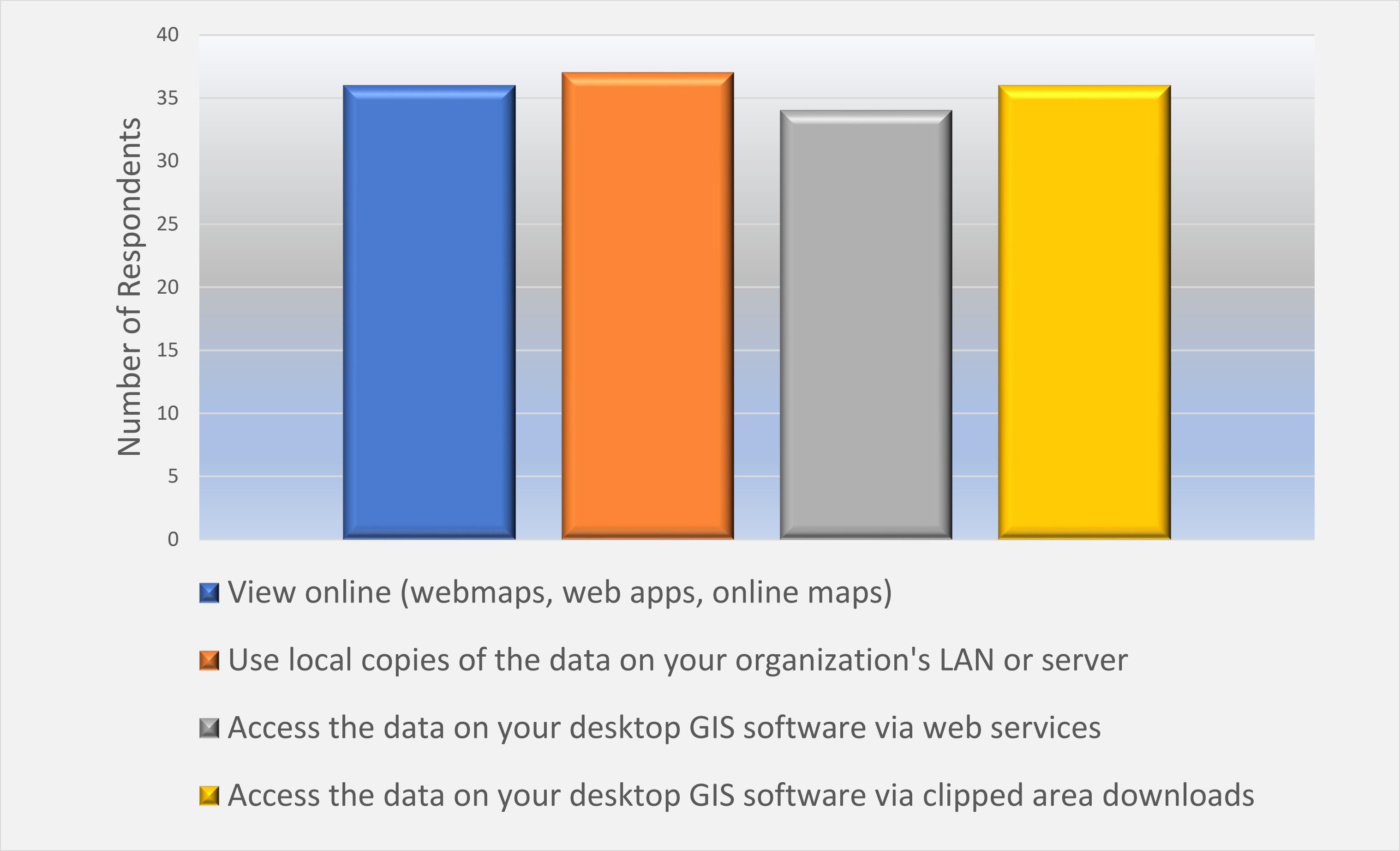
VEG MAP PRODUCTS – Stand Attributes



VEG MAP PRODUCTS – Use of Products



Users Access the Products Using Every Method Made Available by the County



"As Francis Bacon famously said, 'Knowledge is power' and in that spirit we feel powerful with access to this data. Thank you."

- William Hart, Gold Ridge Resource Conservation District

VEG MAP PRODUCTS – Uses

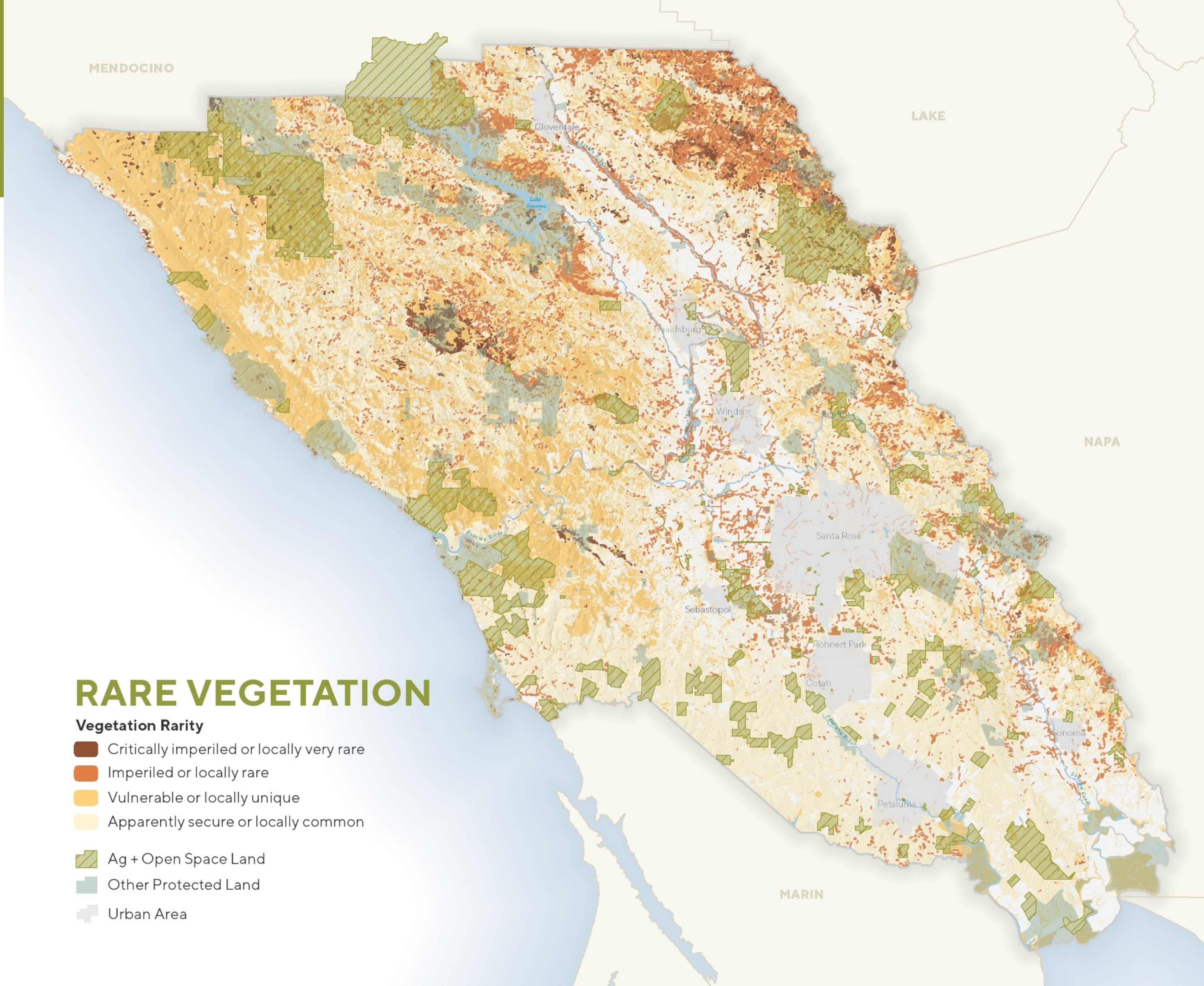
- **Allison Schichtel, Sonoma Ag + Open Space**

We are using data from the Sonoma Veg Map program to answer questions like, "What are the highest priority places to protect because they support rare vegetation communities? Where are floodplains in Sonoma County, and how can we work with our local agency and non-profit partners to restore and protect these places?"

The LiDAR data, derivative products, and veg map data are foundational to our work. From how we develop our conservation priorities, to informing how we draft our easements, to supporting long-term monitoring of our easements and management of our fee properties. These data are integrated into every single one of our processes…

VEG MAP USES – Rare Vegetation

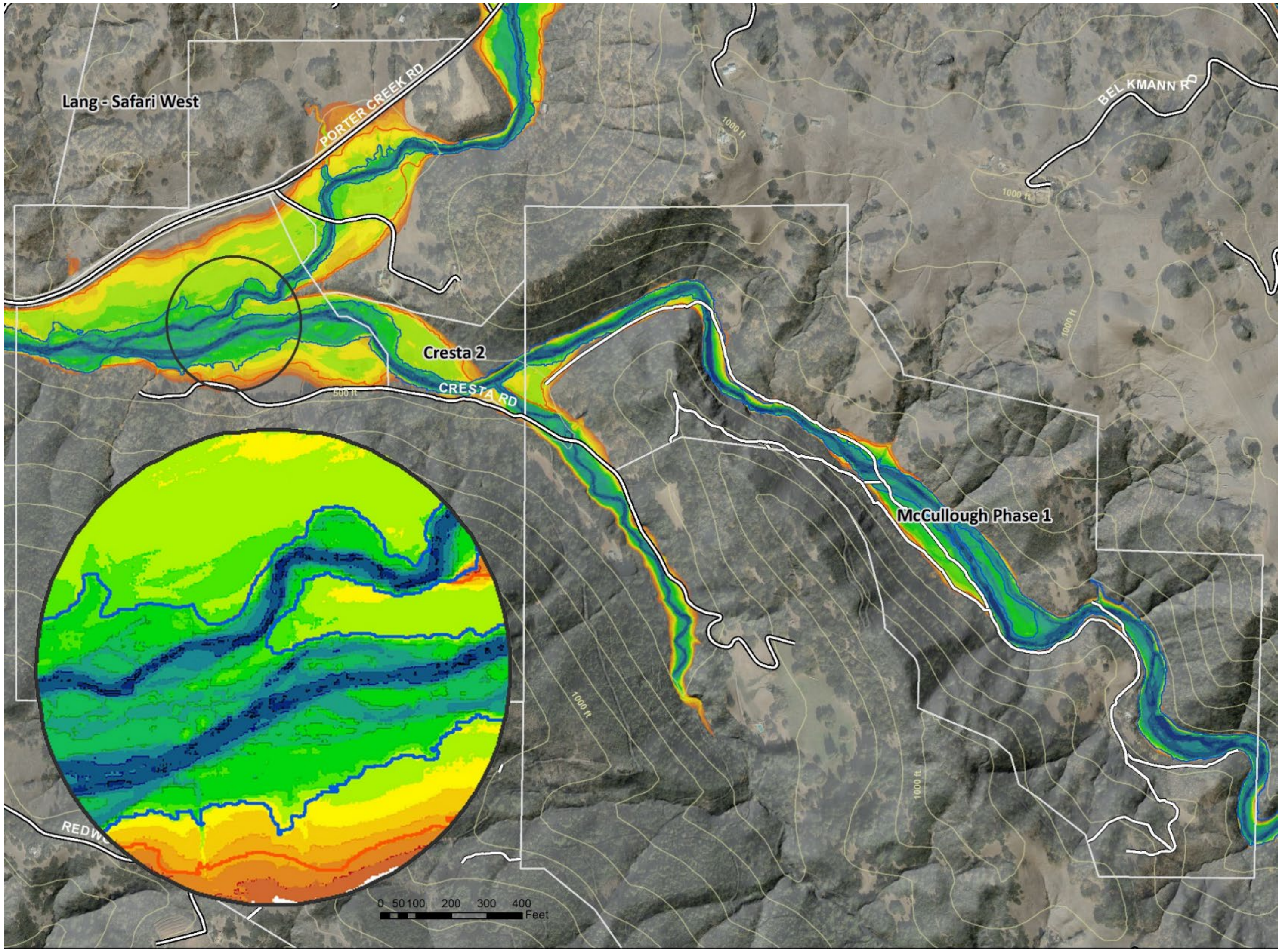
- State rarity rank per Survey of CA Vegetation
- Percent area in Sonoma County (i.e. local rarity)

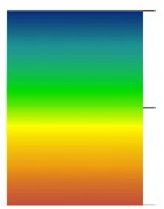


Wetlands + Streams

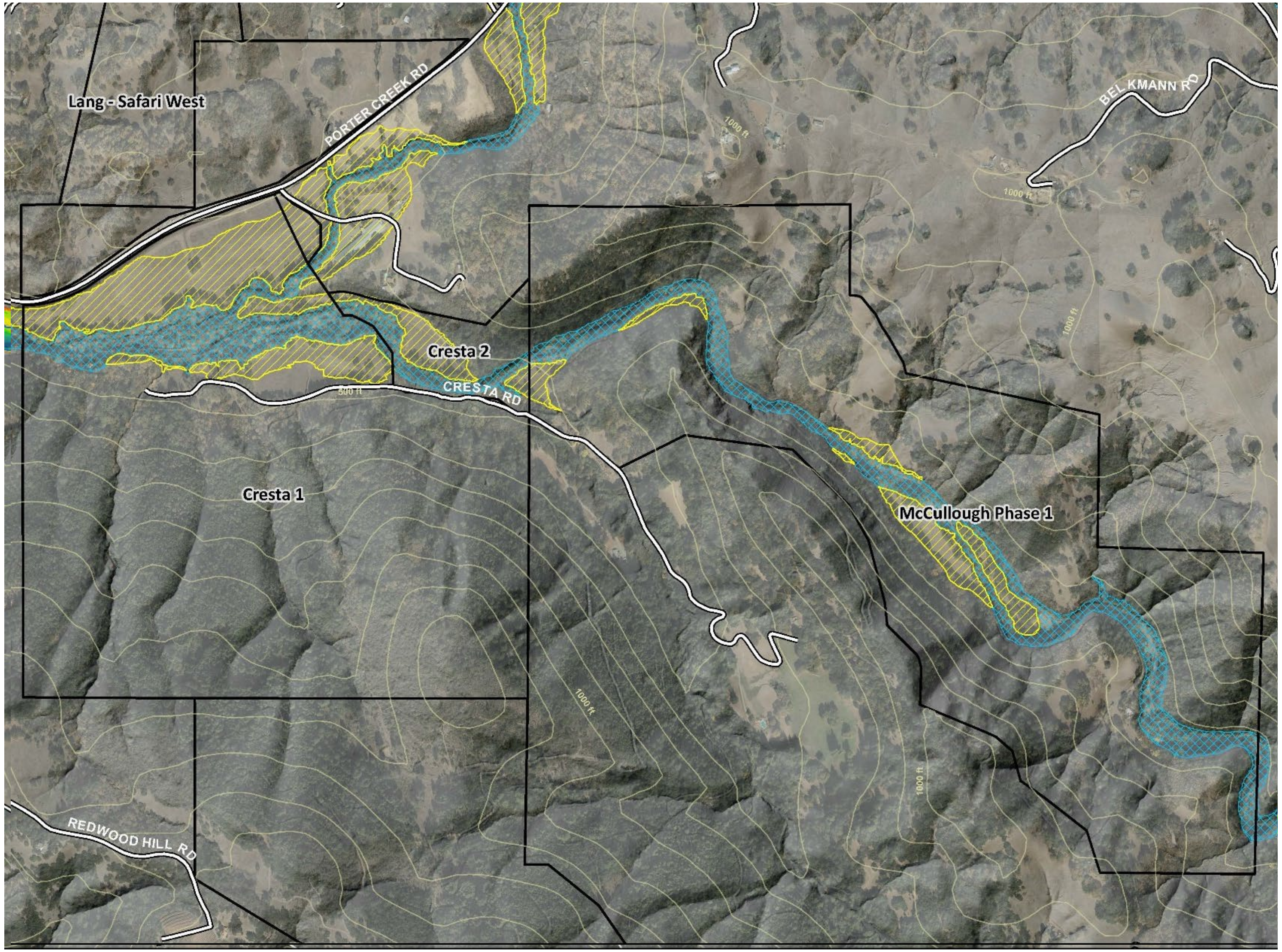
- Wetland features
  - Vernal Pool
  - Estuary
  - Tidal Salt Marsh
  - Freshwater Herbaceous
  - Lake/Reservoir
- Streams that support salmonid populations
  - Coho salmon
  - Chinook salmon
  - Steelhead trout

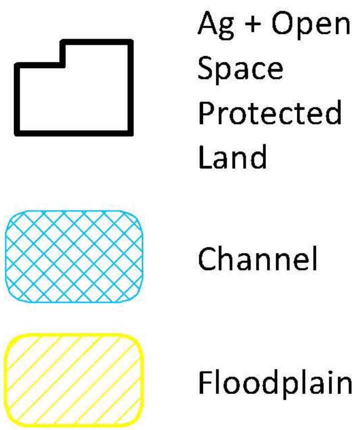
VEG MAP USES - Riparian Corridors





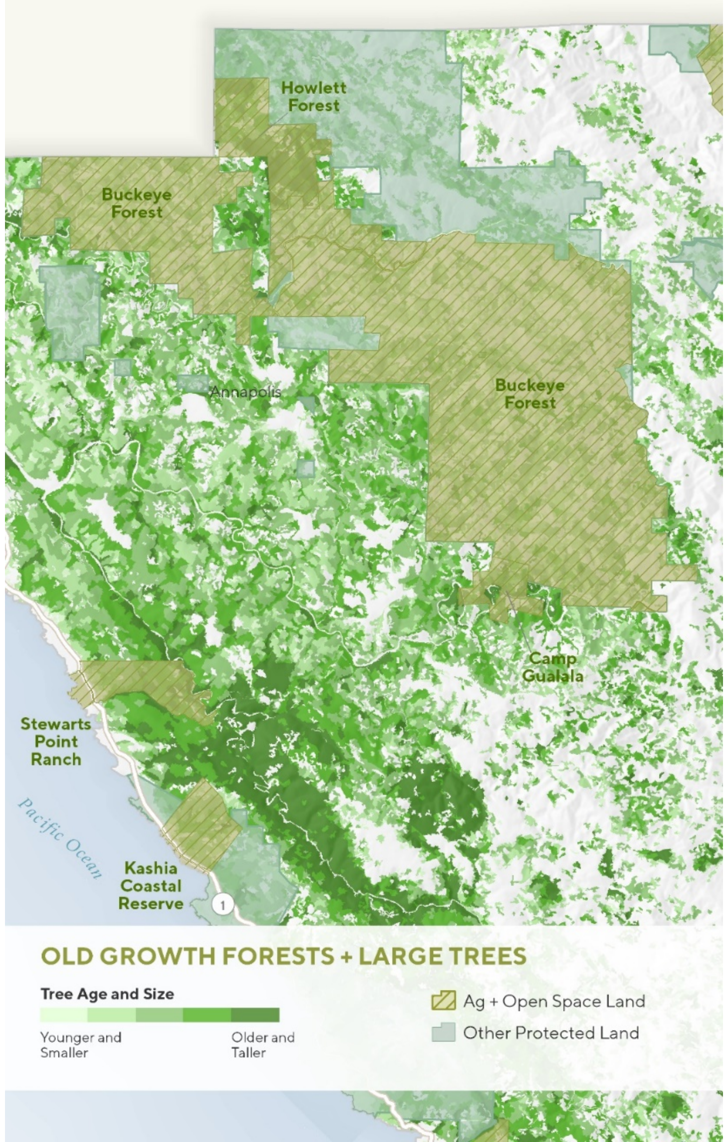
VEG MAP USES - Riparian Corridors

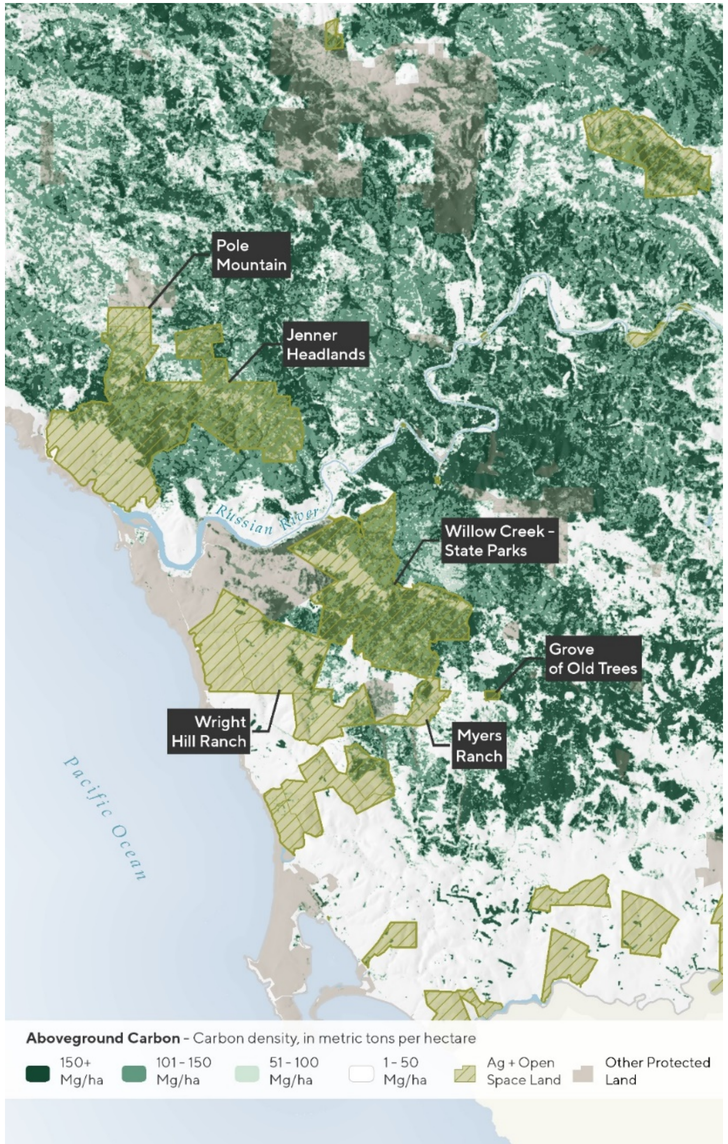




VEG MAP USES - Old Growth Forests + Aboveground Carbon

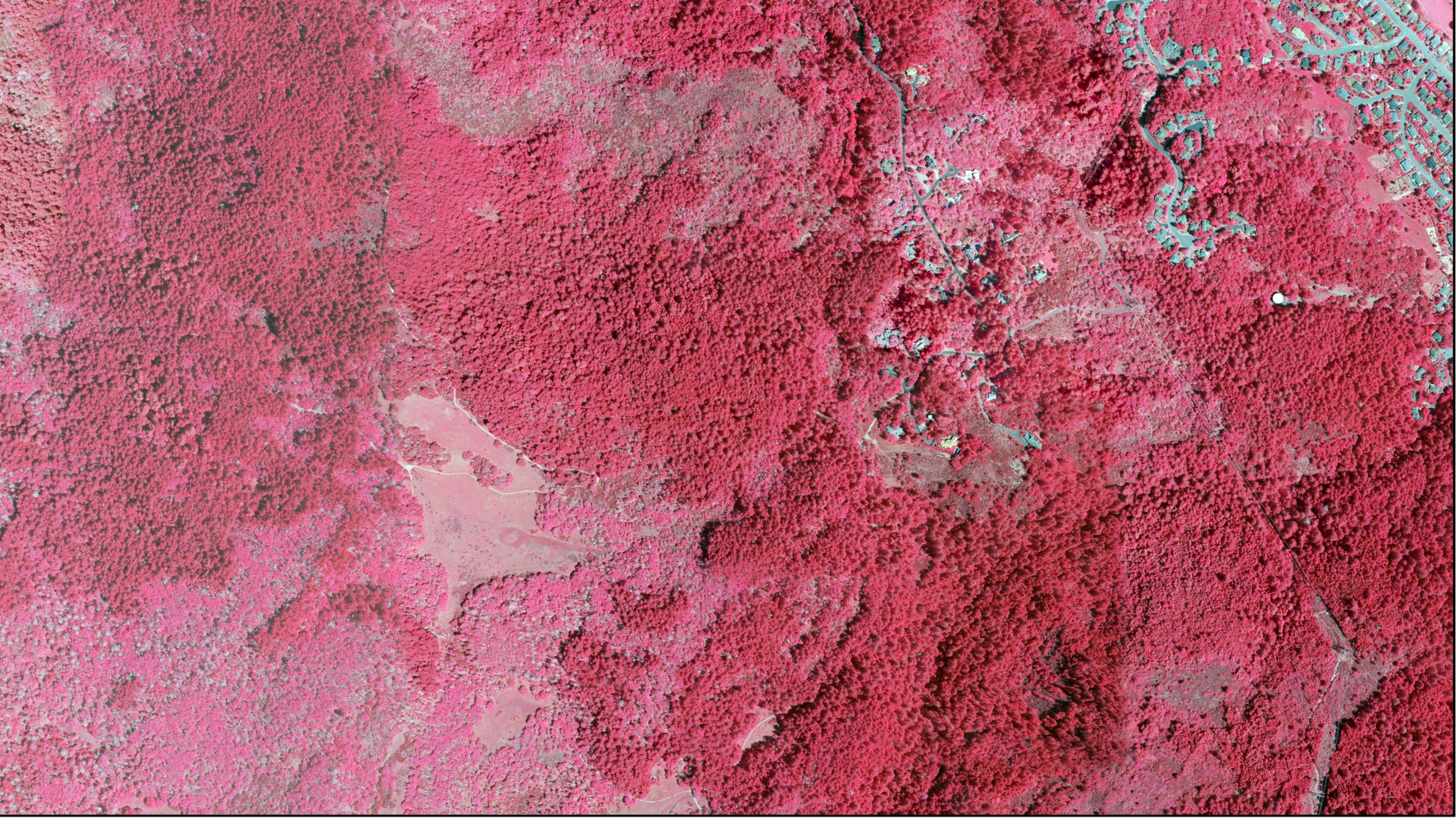
AG + OPEN SPACE SONOMA COUNTY

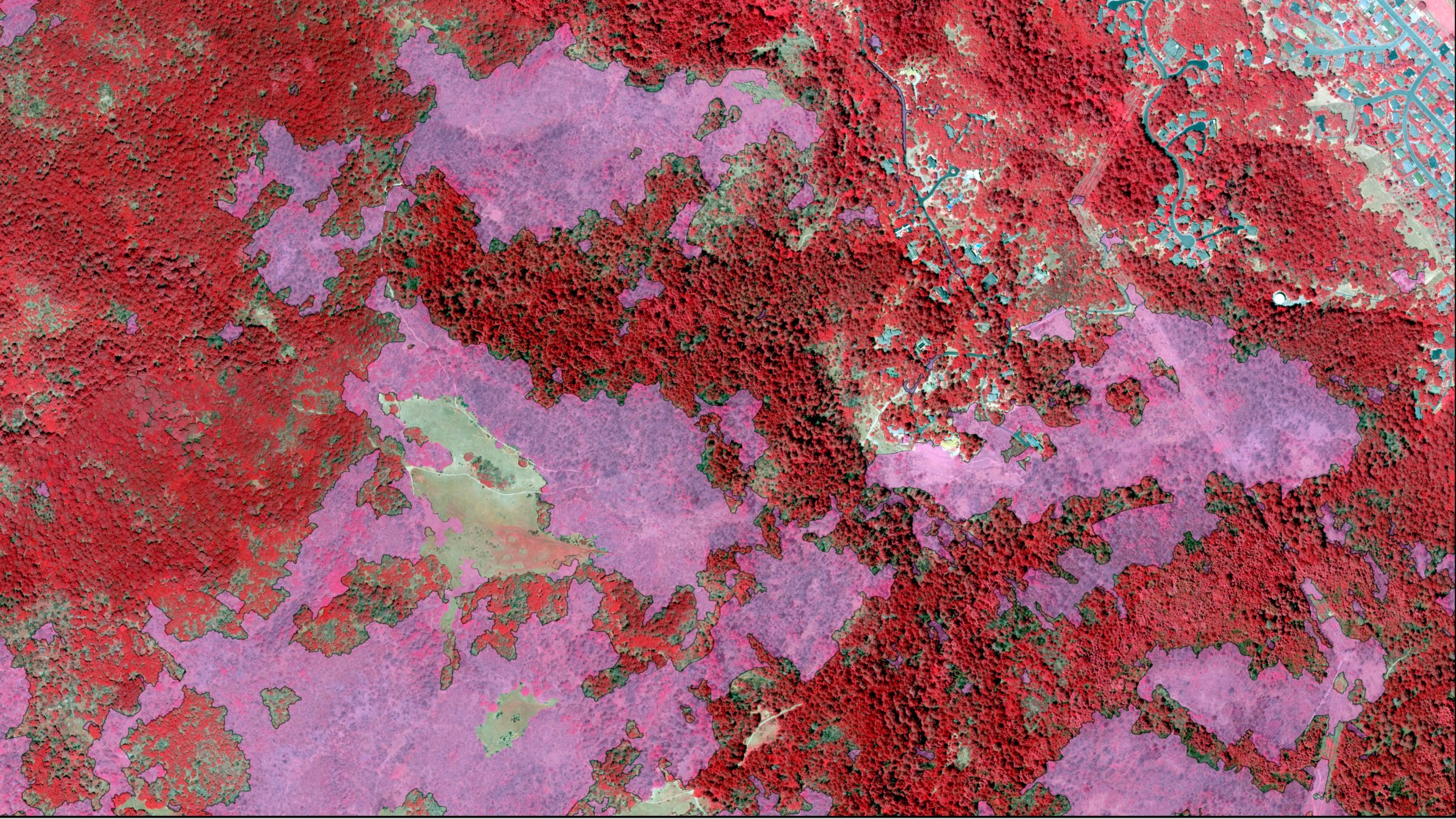




VEG MAP AS A 'LIVING MAP'

- **County's intent is for the vegetation and habitat map to be updated at a regular interval**
- **Protocol for periodic updates under development now**
  - Update to address areas of non-catastrophic change (e.g., land use conversion, small fires, etc.)
  - NASA grant to remap 2017 fire areas in progress (one time update)
- **Refinements/corrections can be catalogued continuously and added to map at time of each update**





VEG MAP UPDATE – 2017 FIRES

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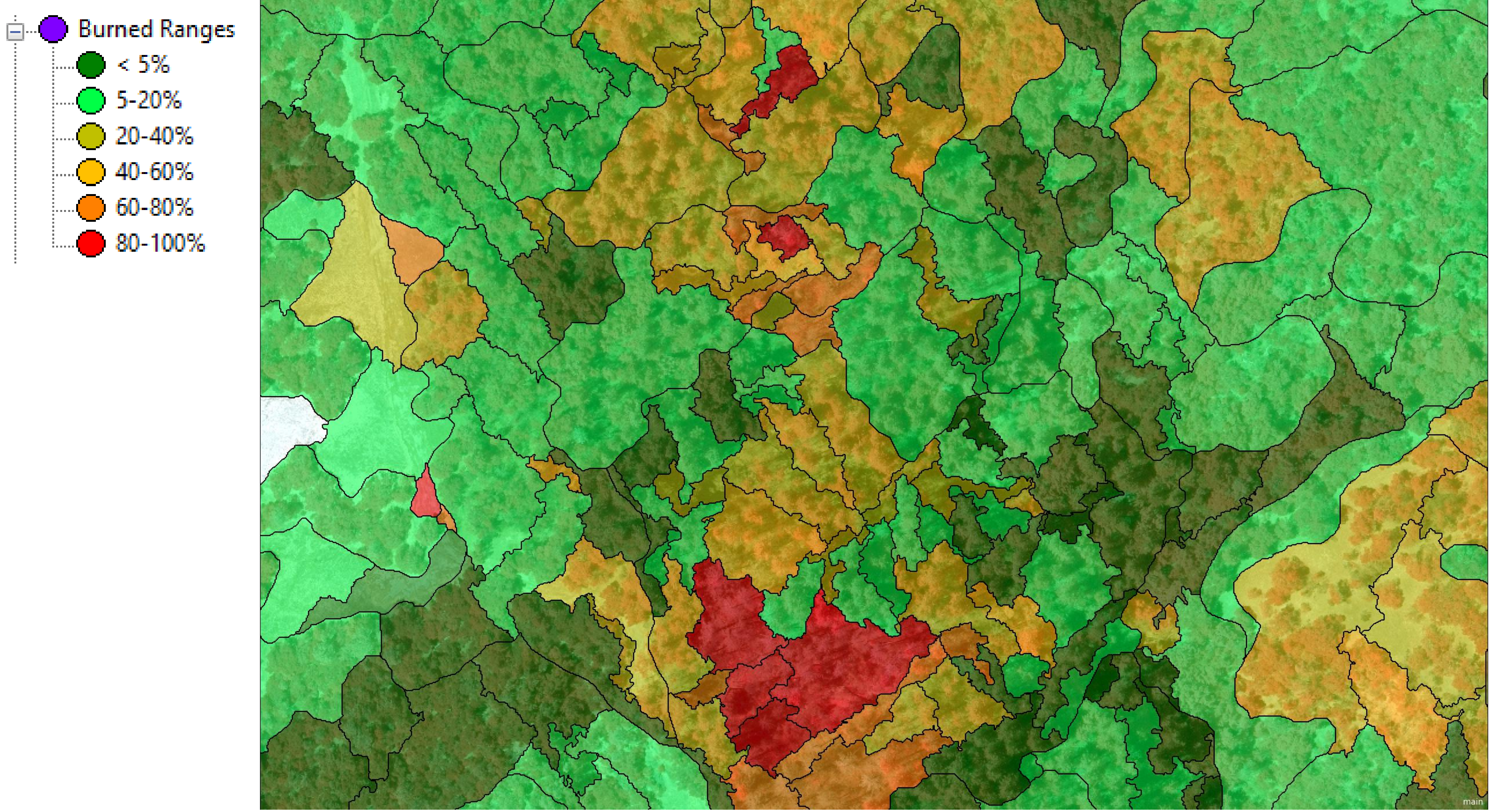
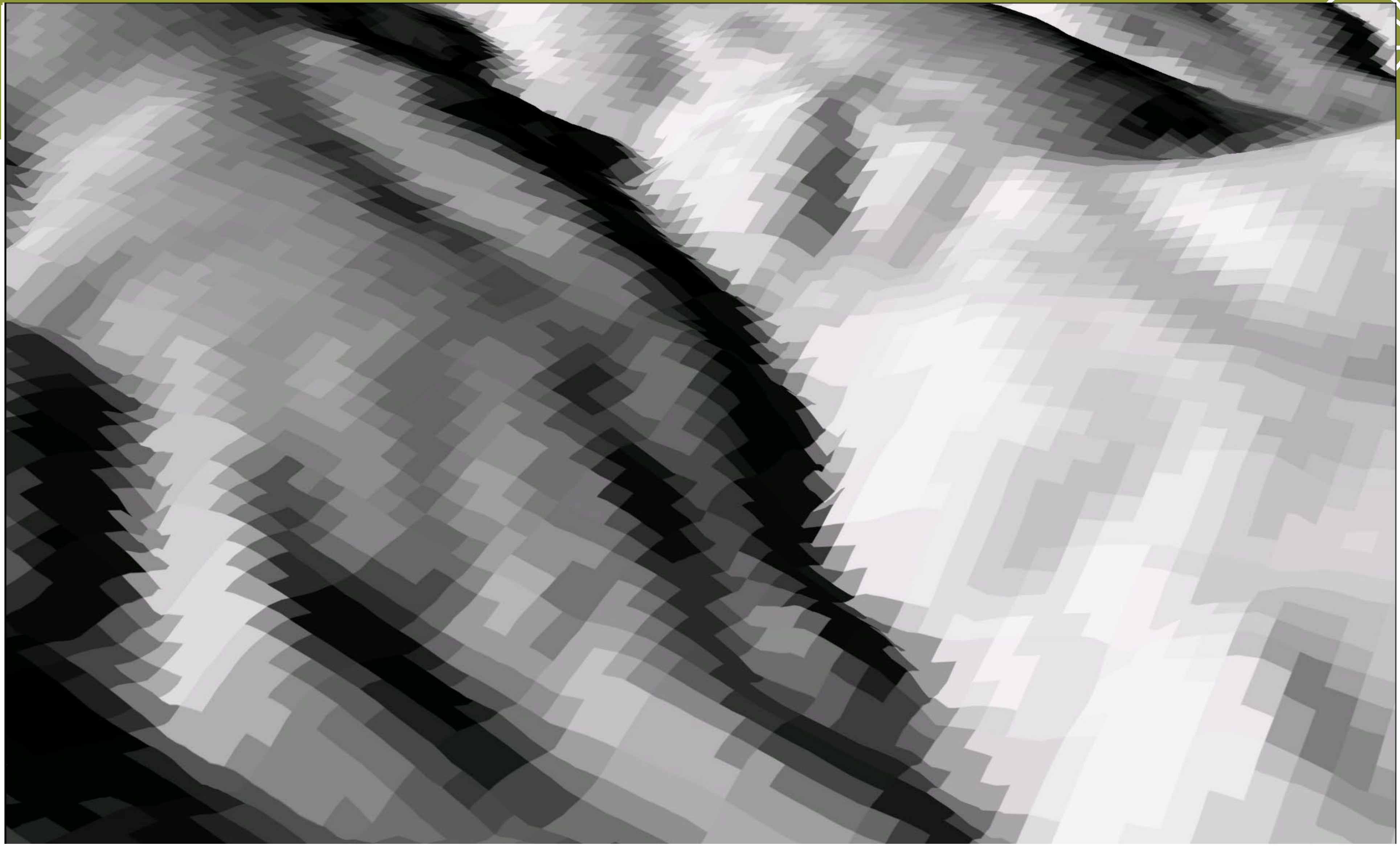
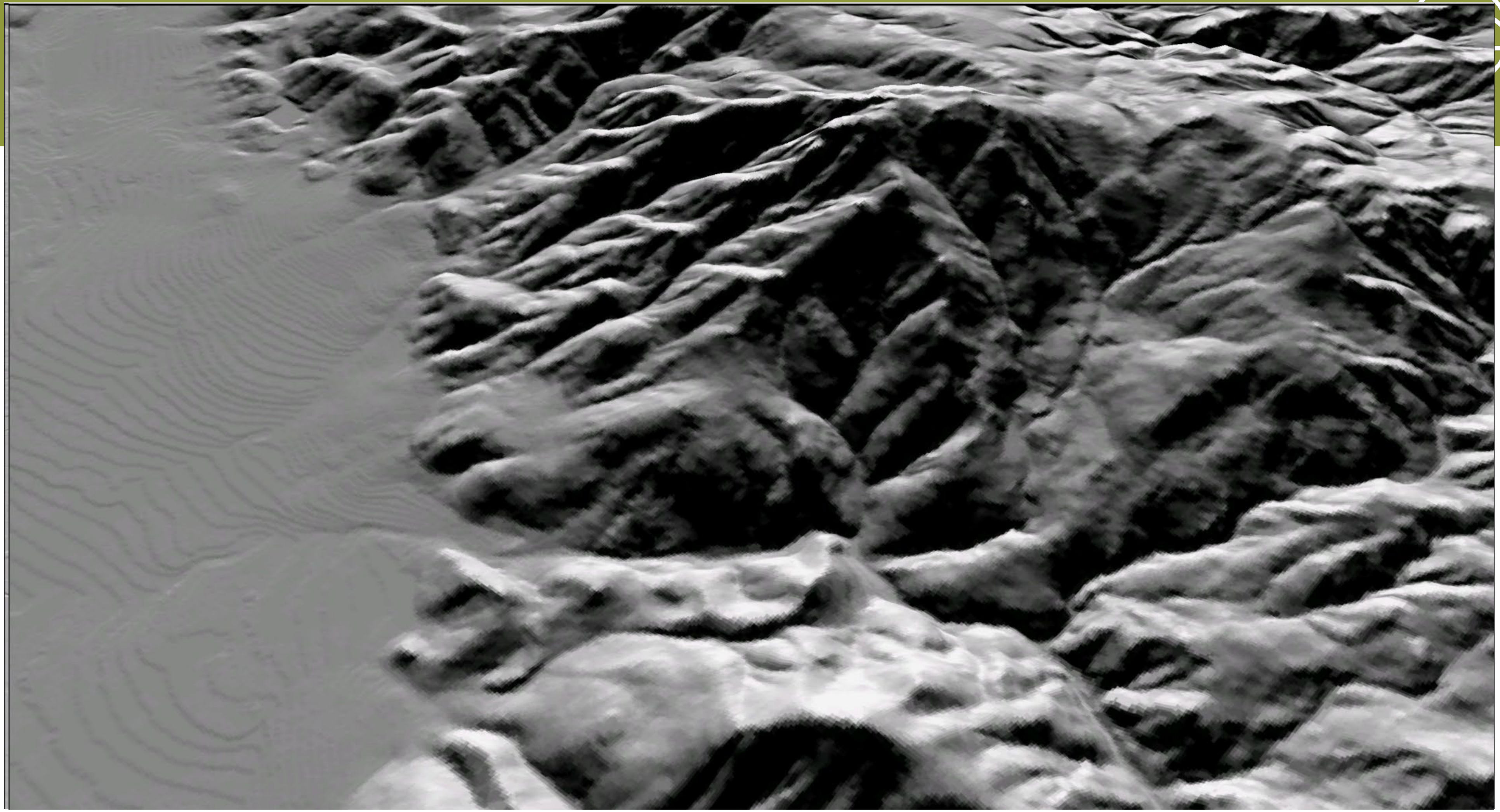


Updated vegetation polygons with sub-polygons indicating percent of shrub and forest canopy damaged by fire. This percent damage information will be embedded in the vegetation map.



Old Topography (10-meter hillshade)

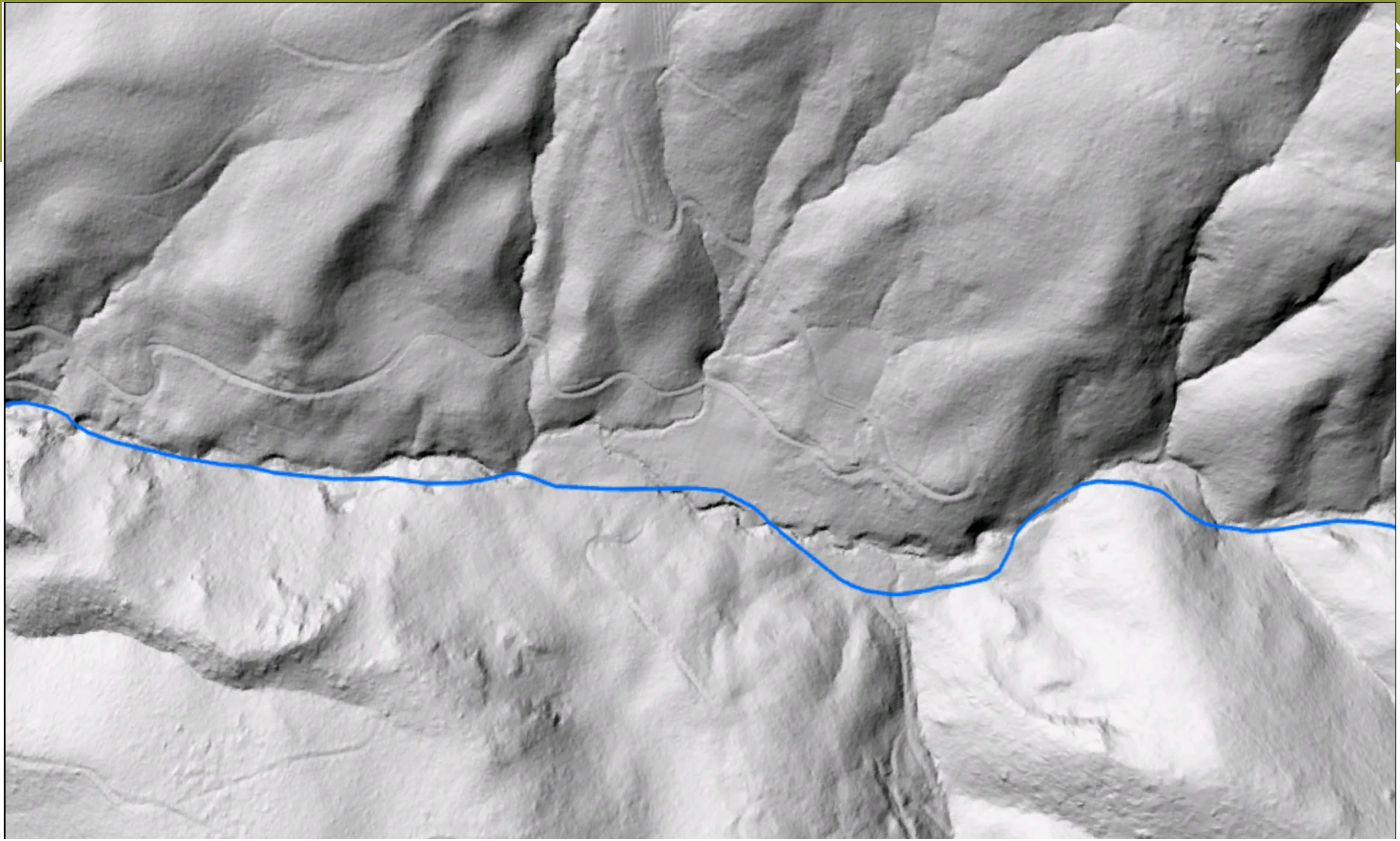
New Topography (1-meter hillshade)



Old Topography (10-Meter Hillshade)

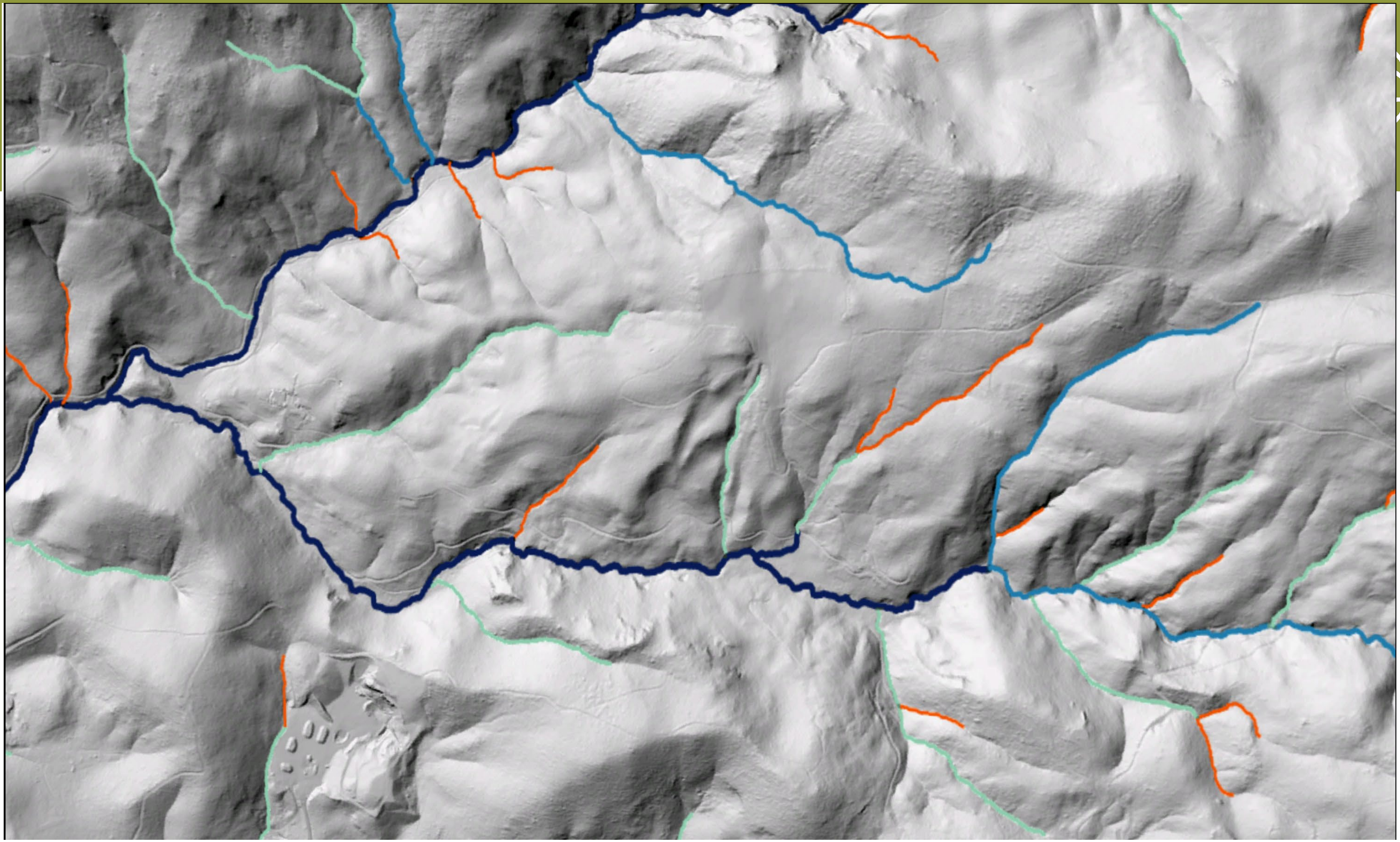
New Topography (1-Meter Hillshade)

AG + OPEN SPACE SONOMA COUNTY



Old National Hydrography Dataset

New Lidar-derived Stream Centerlines



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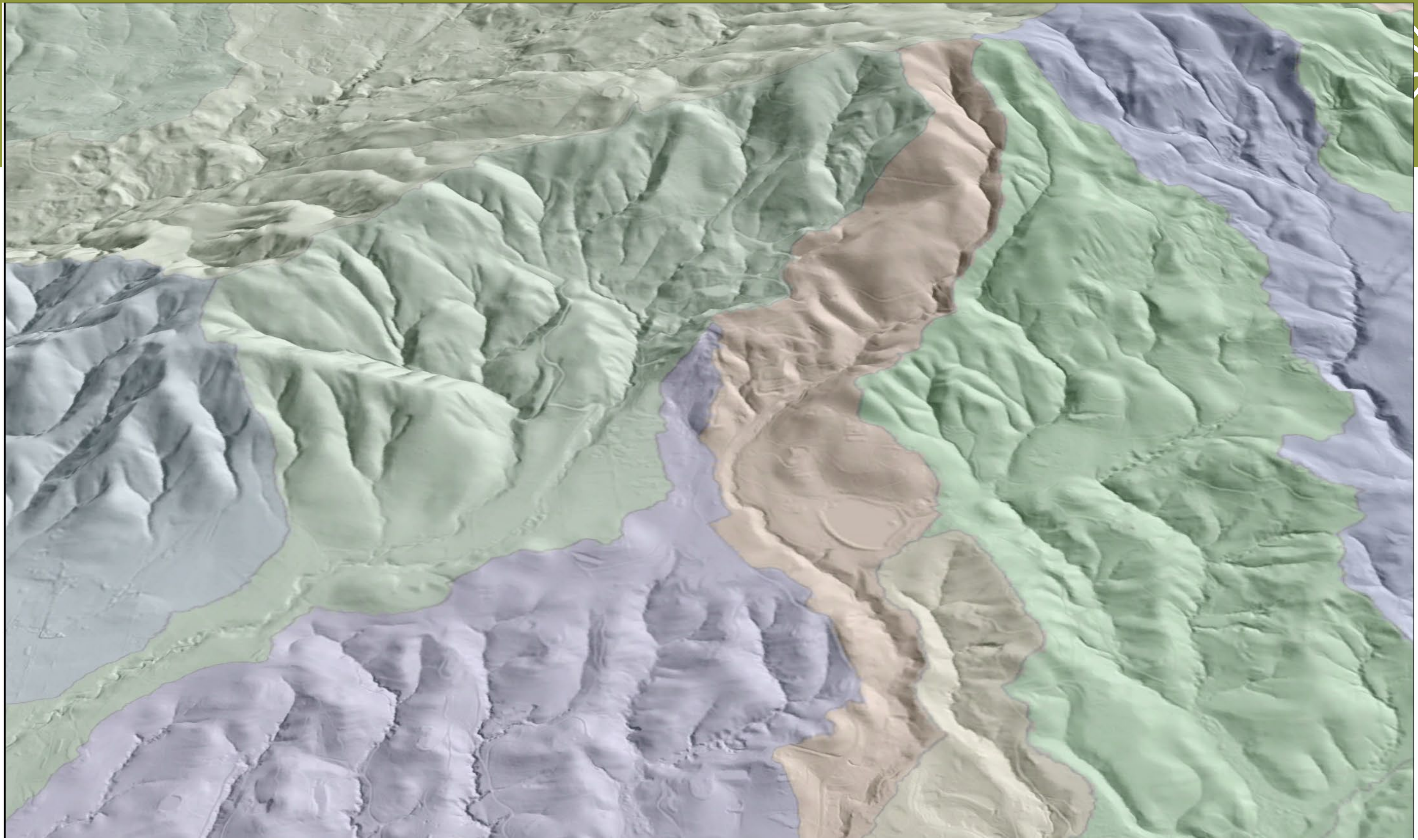
Stream Centerlines With Flow Accumulation

- Catchment Size < 15 Acres
- 15 Acres < Catchment Size < 40 Acres
- 40 Acres < Catchment Size < 240 Acres
- Catchment Size > 240 Acres



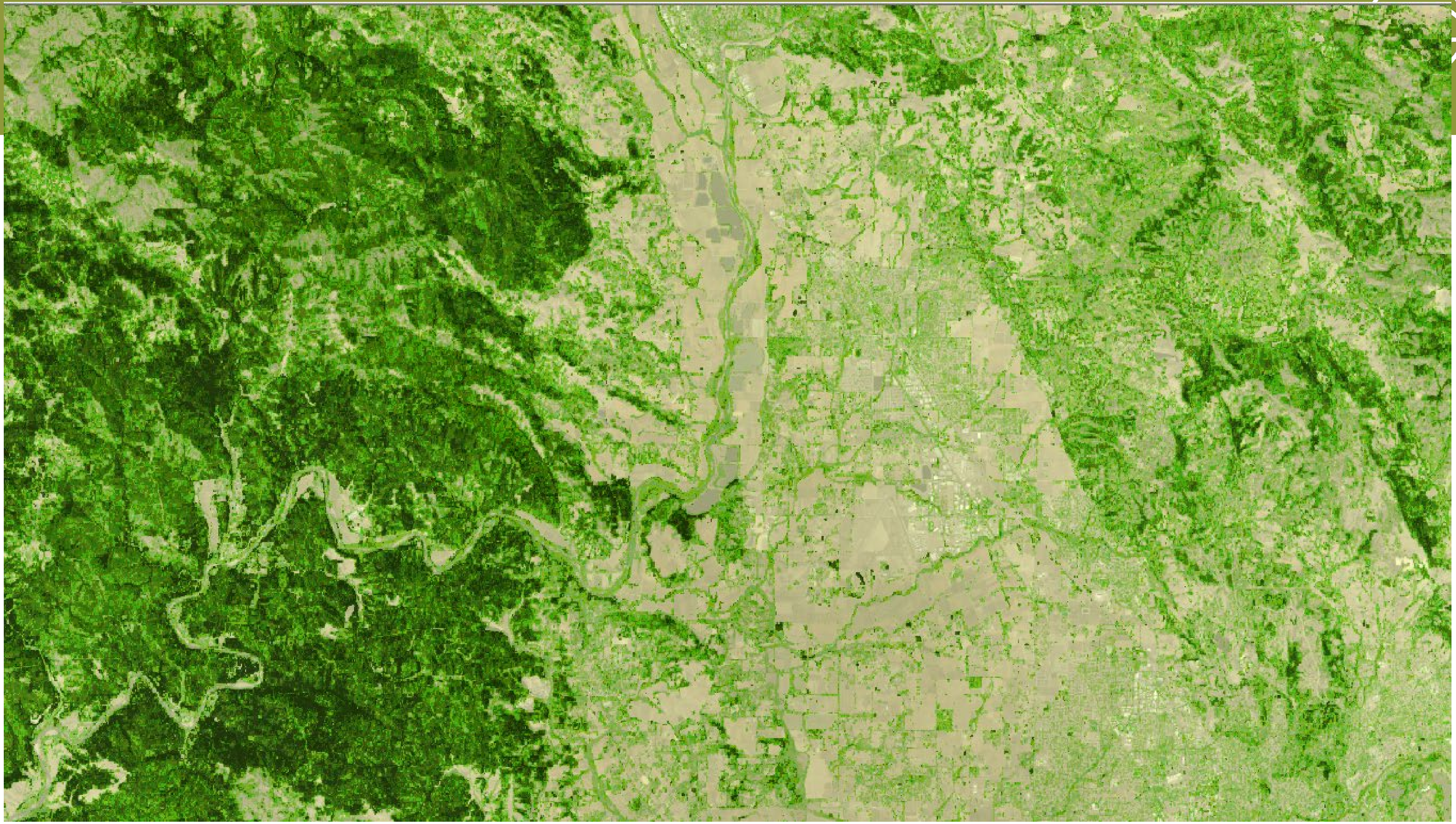
Watersheds Derived From Lidar Data

Vegetation Height

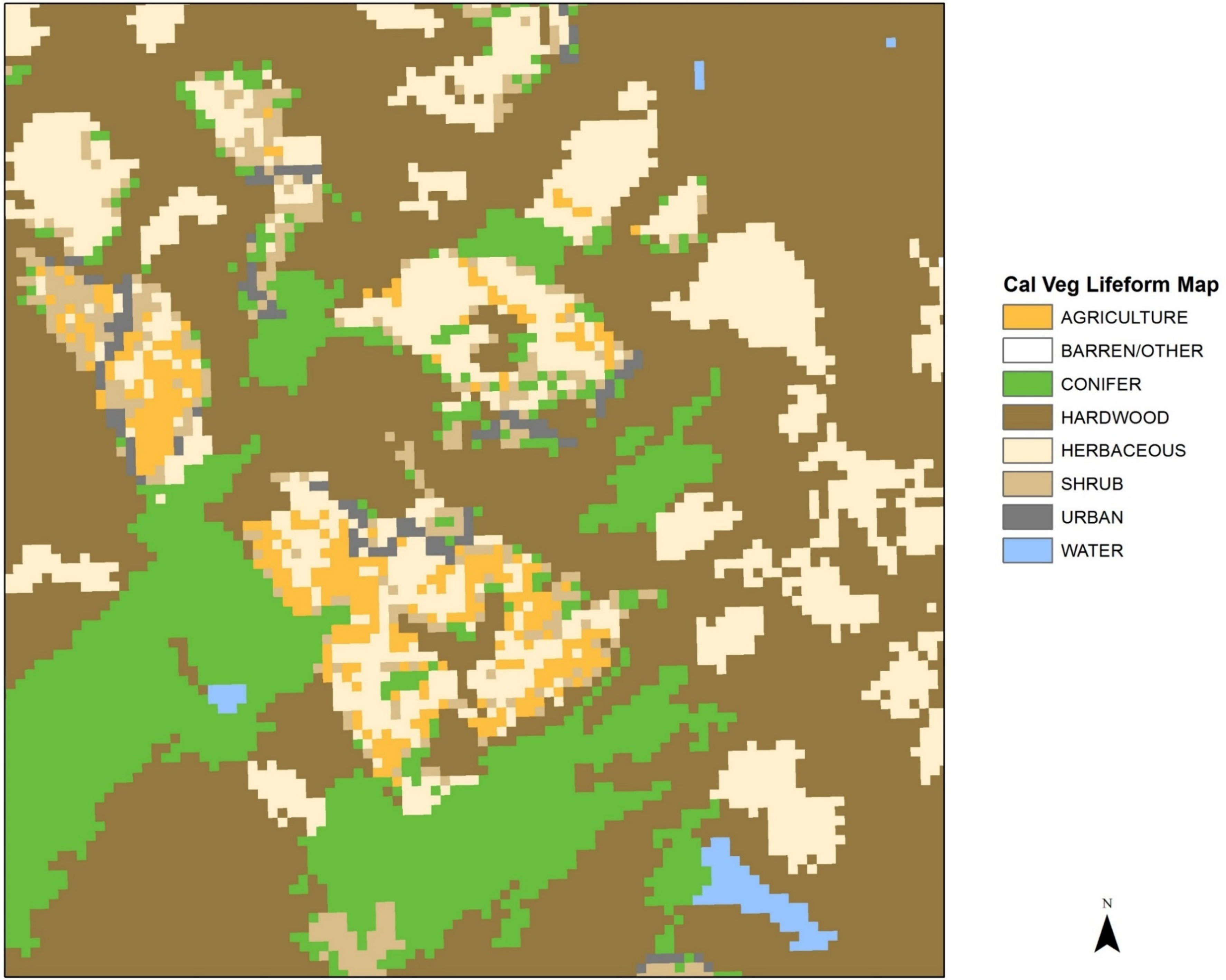
Tall

Short

Stream Centerlines



Lidar Derived Above Ground Biomass



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CONCLUSIONS

- **Semiautomated techniques work well in a large county like Sonoma**
  - Add detail
  - Reduce costs
  - Shorten map production timeline
- **Making the data (veg map, LiDAR, ancillary datasets) easily accessible and digestible helps to build support for the products**
- **More field work is always better, and private land counties are a challenge**