Mount Mansfield: Mapping the Alpine Tundra

Using Object-Based Image Analysis to Extract Alpine Tundra Features on Vermont's Highest Mountain

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The Pennsylvania State University

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1.0 Project Introduction

This project created a shapefile and associated files that represent the alpine tundra features on Mount Mansfield in Vermont. The data created provides a footprint of the alpine tundra land cover on and along the ridges of Mount Mansfield. This project defined alpine tundra by three (3) features: Bare Rock, Alpine Vegetation (non-evergreen), and Subalpine Krummholz (evergreen). The coverage of the alpine tundra spans the Sunset Ridge Trail, the Maple Ridge Trail, and the portion of the Long Trail from the Mount Mansfield Forehead to the Mount Mansfield Adam's Apple.

This project created the shapefile through an object-based image analysis (OBIA). Data sources included high-resolution 4-band imagery (Red, Green, Blue, Infrared) from the Vermont Imagery Program (0.2 meters, 0.5 meters) collected in 2013 during leaf-off conditions and the National Agriculture Imagery Program (NAIP) (1 meter) collected in 2014 during leaf-on conditions, and high-resolution elevation data (Normalized Digital Surface Model, Digital Elevation Model, Slope) from the Vermont Lidar Program (0.7 meters) collected in 2014 during leaf-off conditions.

2.0 Problem

Current low resolution, pixel-based national land cover data sets do not capture the **size**, **shape**, or **spatial arrangement** of alpine tundra features on Mount Mansfield. This project used object-based image analysis on Vermont's high-resolution imagery and elevation data to map Mount Mansfield's alpine tundra features for use on local scales and by local communities. The solution created a baseline land cover map for the alpine tundra for use on local scales and by local stakeholders. The project also provided a cost and schedule-efficient solution (all completed through software vice field work). Applications of the output include but are not limited to estimating the area of the alpine tundra, establishing a baseline for change detection, and incorporating the data into future GIS, remote sensing, and interdisciplinary studies.

3.0 Background

Vermont's highest peak, Mount Mansfield (Latitude: 44° 32' 38" N, Longitude: 72° 48' 52" W), reaches a maximum elevation of 4,393 feet (1339 meters). Figure 1 provides an overview of the mountain's location and appearance.

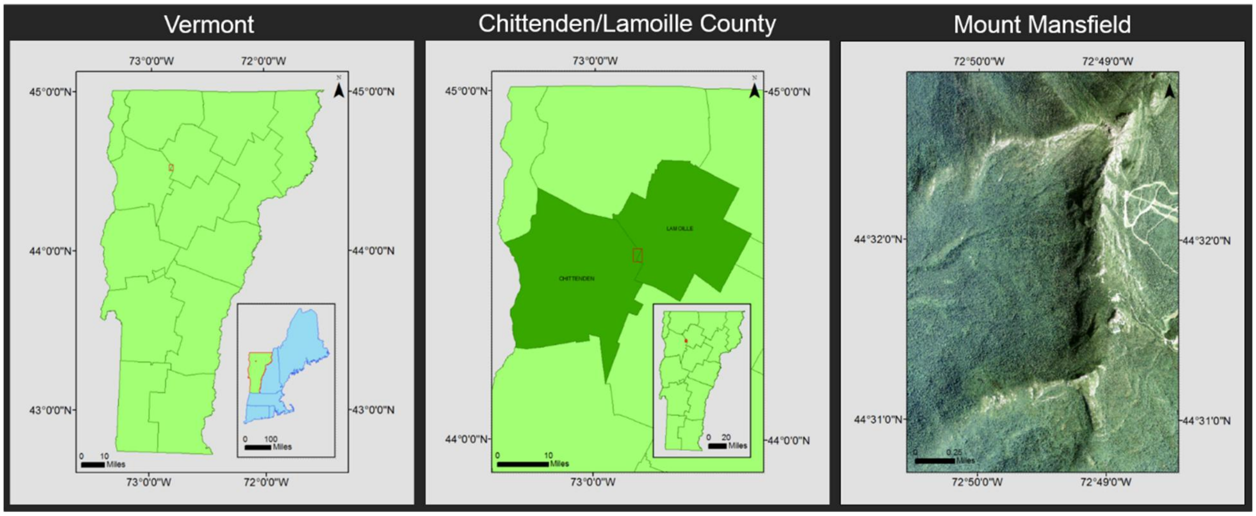

Figure 1: Vermont's location within New England (left), Mount Mansfield's location within Chittenden and Lamoille counties (center), and the extent of Mount Mansfield as shown in 1-meter 2014 National Agriculture Imagery Program imagery (right).

National level land cover data sets, specifically the National Land Cover Database (NLCD) mapped by the Multi-Resolution Land Characteristics Consortium, provides 30-meter spatial resolution land cover data for the United States (MRLC, n.d.). However, the NLCD data set does not provide enough granularity to identify the **size**, **shape**, or **spatial arrangement** of Mount Mansfield's features. Figures 2-4 demonstrate that while the NLCD 2011 data does capture the overall shape of Mount Mansfield, it does not provide enough granularity for local scale (State/County/Town level) analyses (MRLC, n.d.).

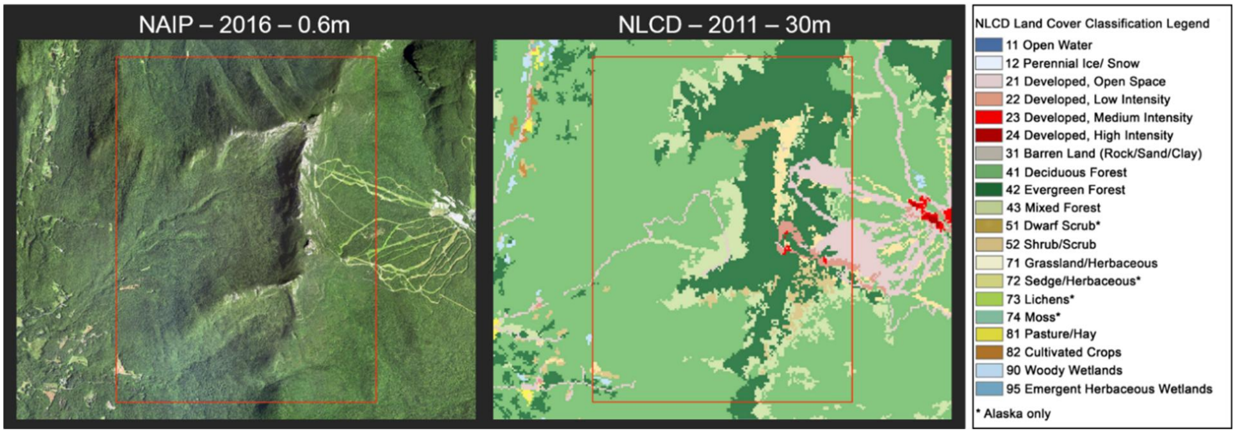

Figure 2: The entirety of Mount Mansfield as shown in the 0.6-meter 2016 NAIP imagery (left), the NLCD 2011 representation of the mountain (center), and the NLCD 2011 legend (right). The red rectangle identifies the Mount Mansfield study area. The NLCD coverage captures the overall shape of the mountain.

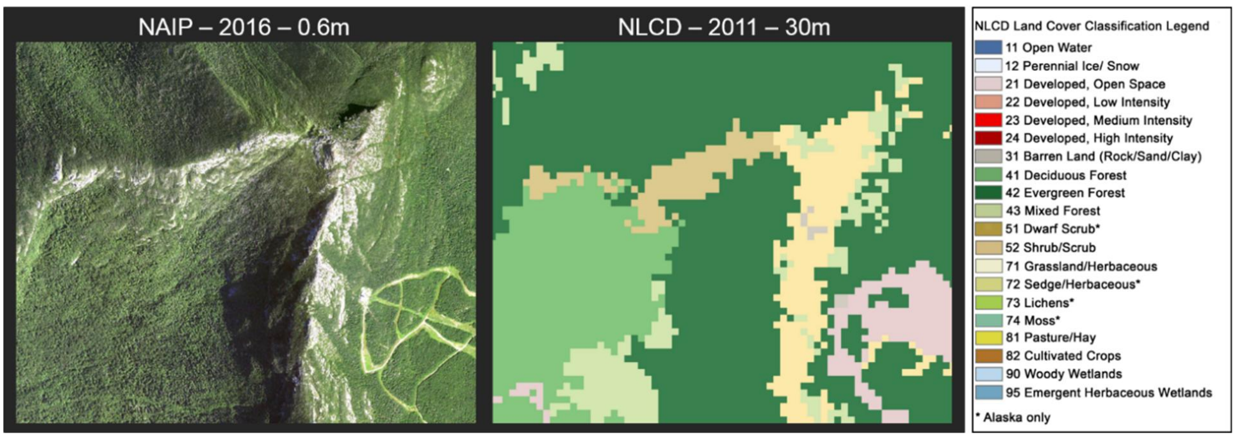

Figure 3: The northern half of Mount Mansfield as shown in the 0.6-meter 2016 NAIP imagery (left), the NLCD 2011 representation of the mountain (center), and the NLCD 2011 legend (right). The NLCD coverage still captures the overall shape of the mountain, but it does not capture the variation within the overall shape.

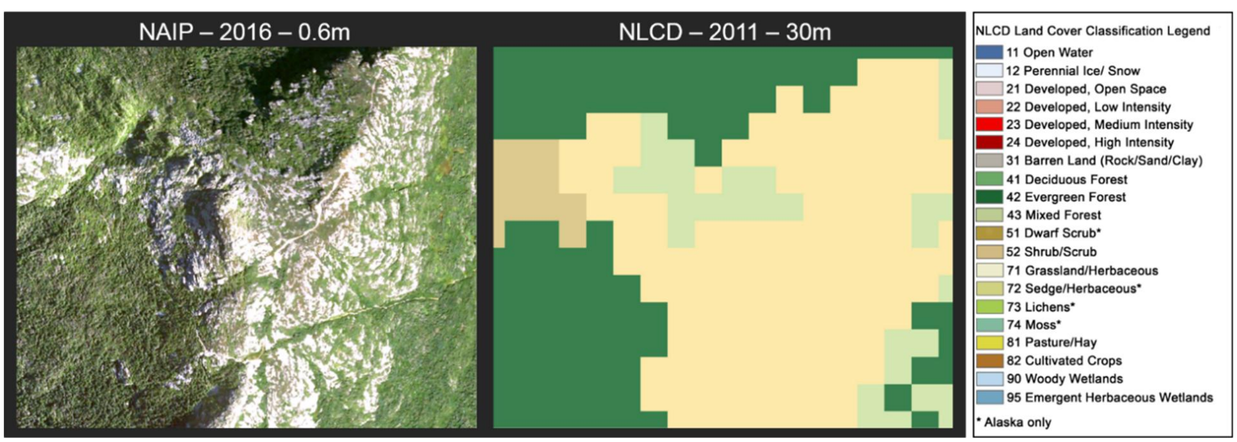

Figure 4: The Chin of Mount Mansfield as shown in the 0.6-meter 2016 NAIP imagery (left), the NLCD 2011 representation of the mountain (center), and the NLCD 2011 legend (right). The NLCD coverage does not capture the rapidly varying features and terrain when zoomed in to a more localized scale.

4.0 Land Cover Classification

This project mapped and delineated alpine tundra, as defined by three feature types: Bare Rock, Alpine Vegetation, and Subalpine Krummholz. Figure 5 shows a closeup of an area along the Long Trail (near the intersection with Sunset Ridge Trail) that samples each feature type of interest.

Figure 5: An area facing the Mount Mansfield Chin (left) with a closeup view of the three features of interest: Bare Rock, Alpine Vegetation, and Subalpine Krummholz (right).

While the Bare Rock, Alpine Vegetation, and Subalpine Krummholz made up the features of interest, they are not the only features on the mountain. Other feature types include:

- Building
- Radio/TV Tower
- Auto Road/Parking Lot
- Gravel Construction Road
- Coniferous Tree (non-alpine)
- Deciduous Tree
- Ski Trail
- Car

In order to scope the analysis and focus on the features of interest, this project grouped all other features into a class named Other.

5.0 Project Workflow

The project followed a four-stage remote sensing workflow:

- Data acquisition – Download the relevant imagery and elevation data sets (No software required)
- Data preprocessing – Adjust the data sets to fit the appropriate map projection and study area size (ArcMap 10.4.1)
- Data processing – Create the shapefile containing the mapped and delineated features of interest (eCognition Developer 9.3)
- Accuracy assessment – Determine the quantitative and qualitative accuracy of the output shapefile (ArcGIS Pro 2.0)

Figure 6 shows the four stages in the workflow and the major components of each stage.

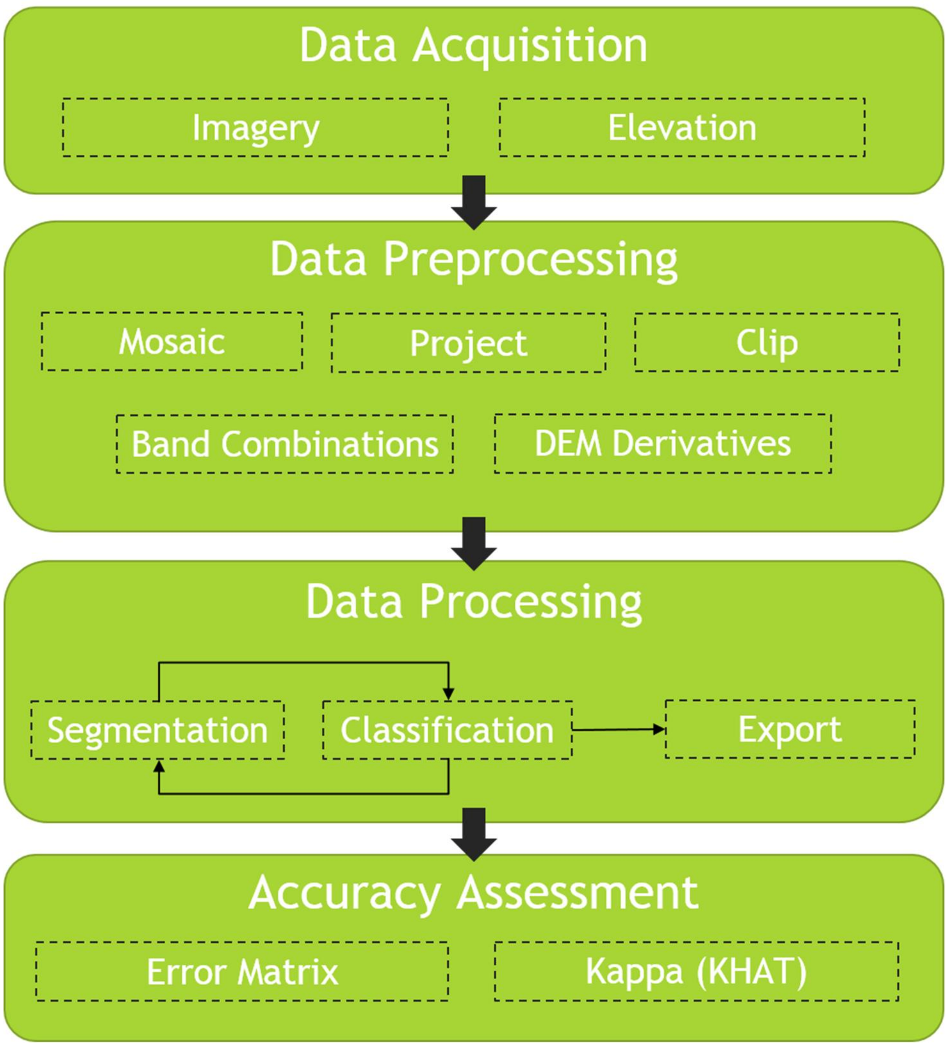

Figure 6: The four stages of the project included data acquisition, data preprocessing, data processing, and accuracy assessment.

6.0 Data Sets

This project obtained all imagery and elevation data from the Vermont Open Geodata Portal (State of Vermont, 2019). Imagery data sets included Eastern Chittenden County, Northwestern Vermont, and Statewide NAIP (Vermont Center for Geographic Information, 2013a, 2013b, 2015). Each imagery data set contained four spectral bands: Red, Green, Blue, and Infrared.

Figure 7 shows a sample of each imagery data set for an area over the Mount Mansfield Chin.

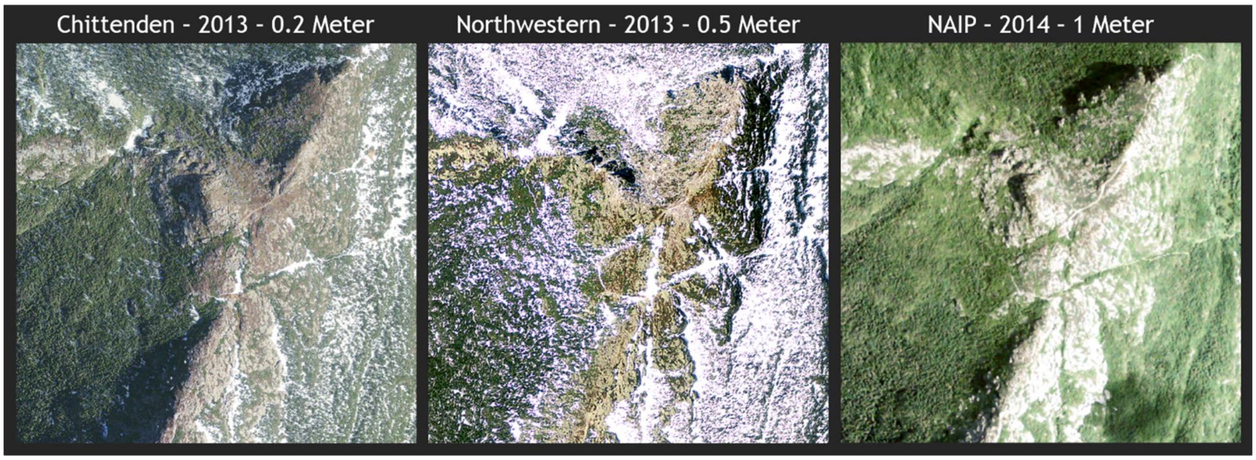

Figure 7: 4-band imagery data sets included Chittenden County (left), Northwestern Vermont (center), and Statewide NAIP (right).

Elevation data sets included Normalized Digital Surface Model, Hydro Enforced Digital Elevation Model, and Slope derived in ArcGIS Pro from the Digital Elevation Model (Vermont Center for Geographic Information, 2017, 2018a).

Figure 8 shows a sample of each elevation data set for an area over the Mount Mansfield Chin.

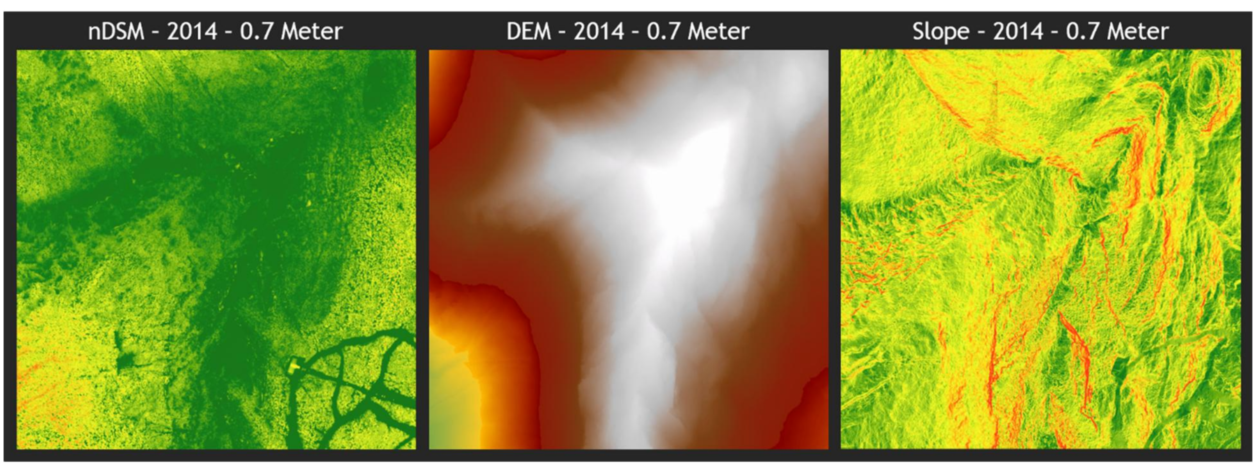

Figure 8: Elevation data sets included nDSM (left), DEM (center), and Slope (right).

7.0 Image Interpretation Key

This project followed the elements of image interpretation and created an image interpretation key (O'Neil-Dunne & Schuckman, 2018a, 2018b). The image interpretation key characterized the features of interest according to how they appeared relative to image tone, image texture, shadow, pattern, association, shape, size, and site. The key provided a comparison of feature characteristics that allowed the project to identify similarities and differences between the features. It highlighted the differences between the alpine tundra features of interest (Bare Rock, Alpine Vegetation, Subalpine Krummholz) in a way that shaped the eCognition rule set used to map and delineate these features.

Figures 9-11 show the visual part of the image interpretation key for the features of interest in True Color imagery (Red/Green/Blue bands), Color Infrared imagery (Infrared/Red/Green bands), and the Normalized Difference Vegetation Index (NDVI) representations. The NDVI color ramp ranges from red (low NDVI) to yellow (medium NDVI) to green (high NDVI).

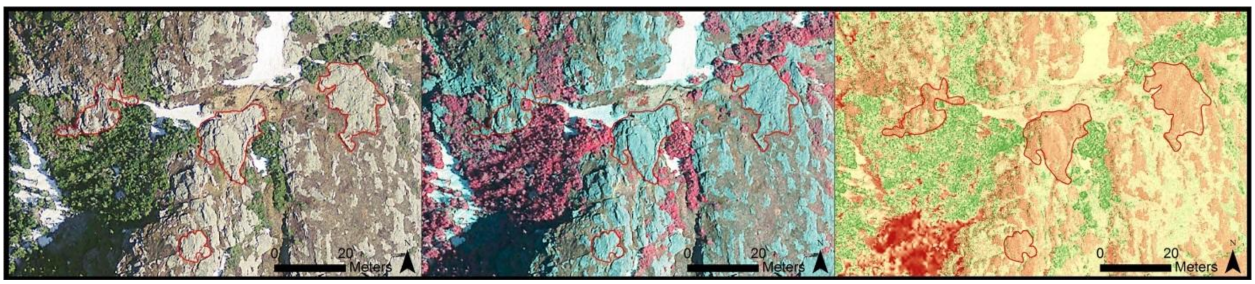

Figure 9: Bare Rock features shown in True Color (left), Color Infrared (center), and Normalized Difference Vegetation Index (right). Sample land cover features highlighted in red polygon boundaries.

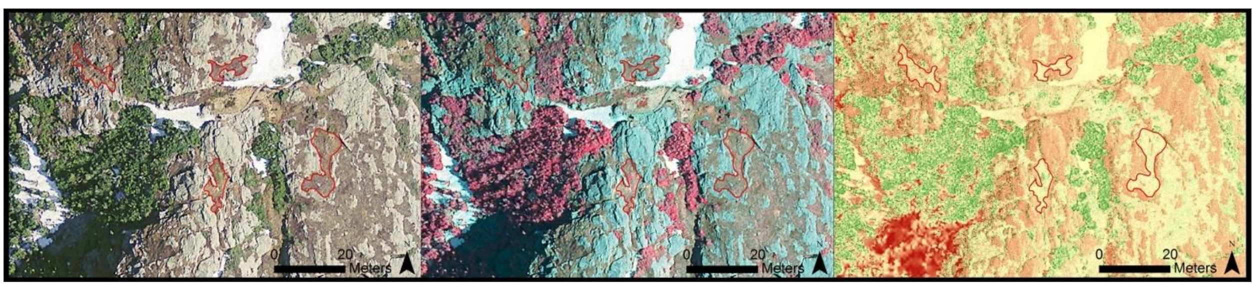

Figure 10: Alpine Vegetation features shown in True Color (left), Color Infrared (center), and Normalized Difference Vegetation Index (right). Sample land cover features highlighted in red polygon boundaries.

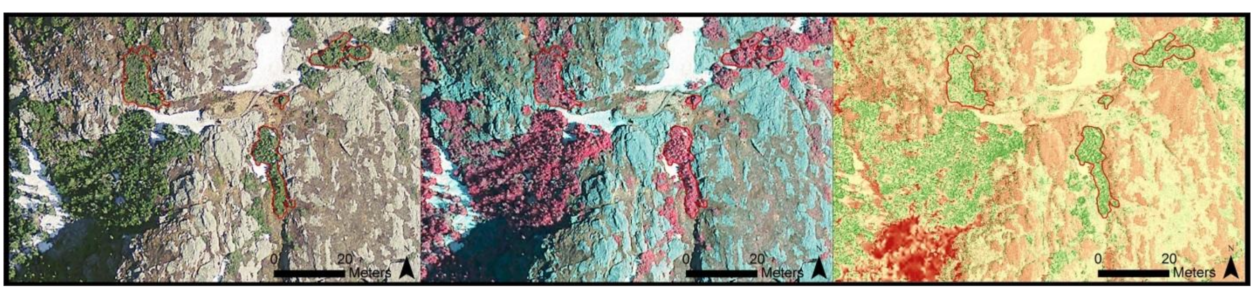

Figure 11: Subalpine Krummholz features shown in True Color (left), Color Infrared (center), and Normalized Difference Vegetation Index (right). Sample land cover features highlighted in red polygon boundaries.

8.0 Data Analysis

This project used eCognition Developer software to map, delineate, and export the alpine tundra features of interest through object-based image analysis (Trimble, n.d.). Figure 12 provides an overview of the eCognition rule set workflow used for this project.

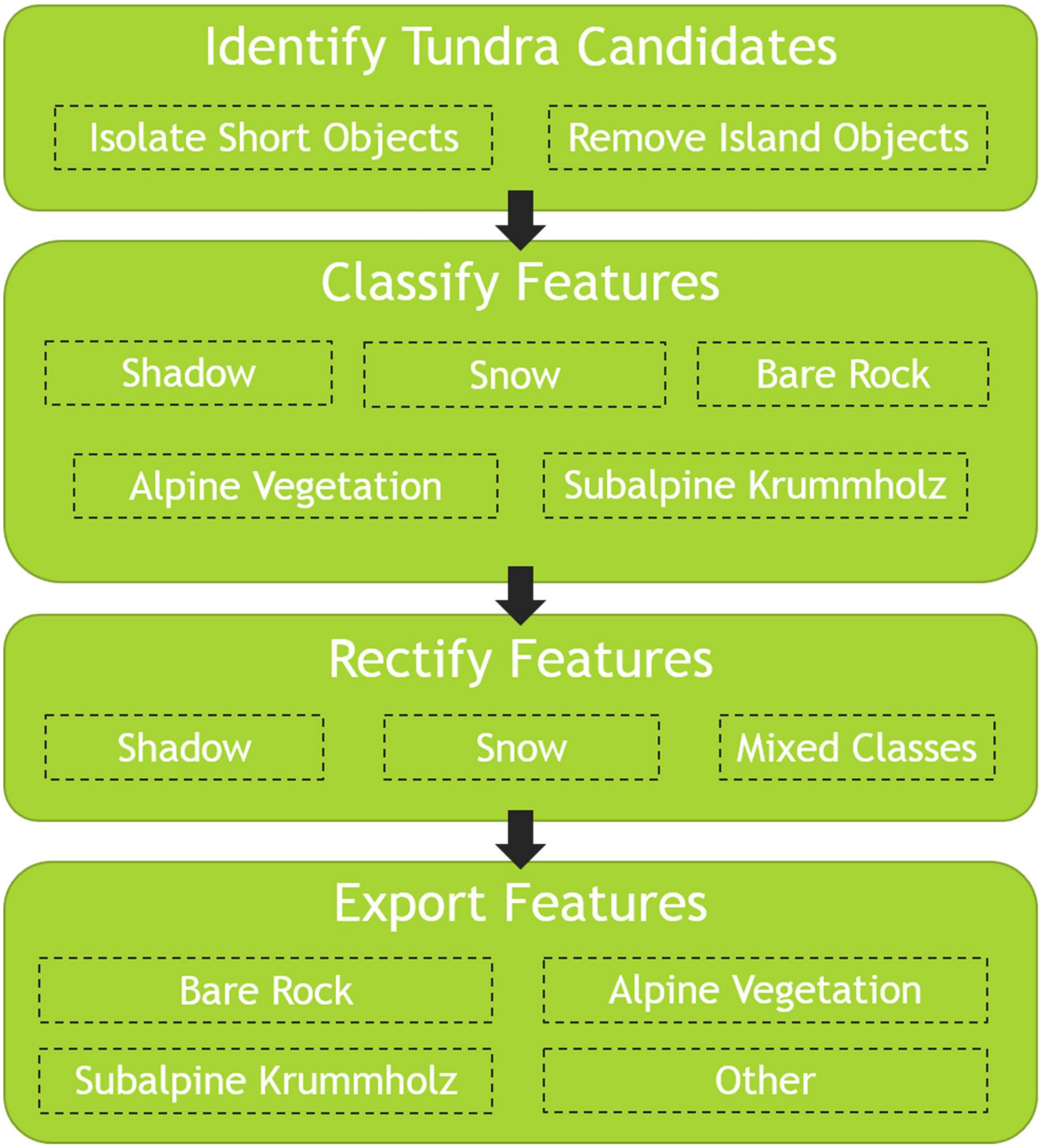

Figure 12: The four stages of the eCognition rule set included identifying the tundra candidates, classifying features, rectifying features, and exporting features.

The rule set workflow shows features (Snow, Shadow, Mixed Classes) beyond those of interest that required rectification. Note that Mixed Classes consist of either a mix of Bare Rock/Alpine Vegetation or a mix of Alpine Vegetation/Subalpine Krummholz.

Figure 13 shows a sample of the mountain containing both shadow and snow.

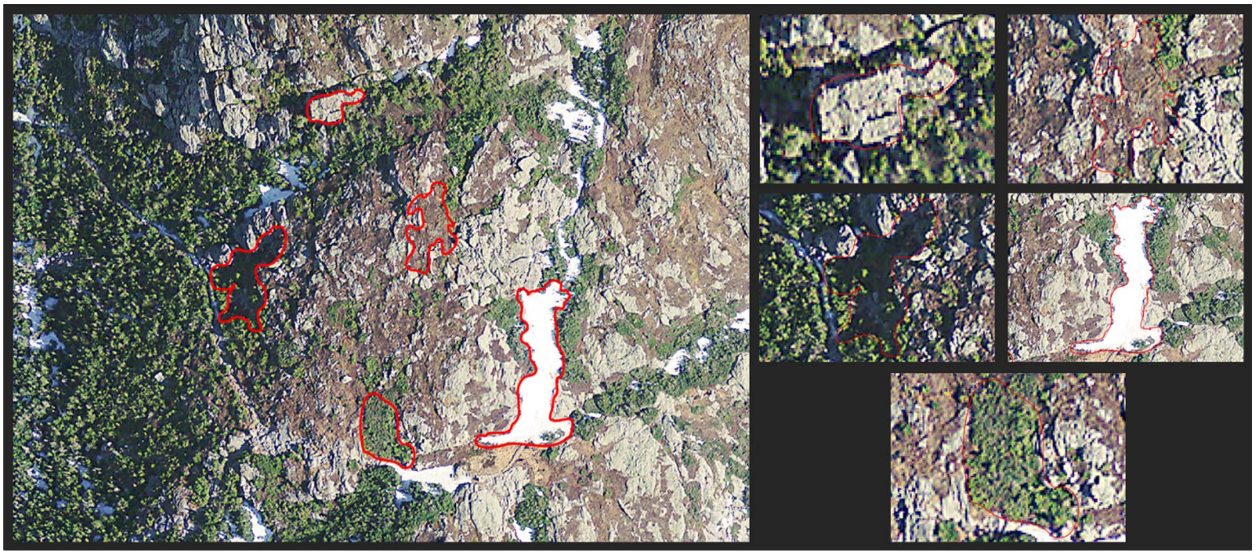

Figure 13: A portion of Mount Mansfield showing the features of interest along with shadow and snow (left) and the zoomed-in versions of the same features (right).

NDVI played the most critical role in the feature classification. Figure 14 defines NDVI mathematically – a normalized ratio of the Infrared band reflectance and Red band reflectance, with a value between -1 and 1 – and shows the NDVI ranges discovered for the alpine tundra features on Mount Mansfield.

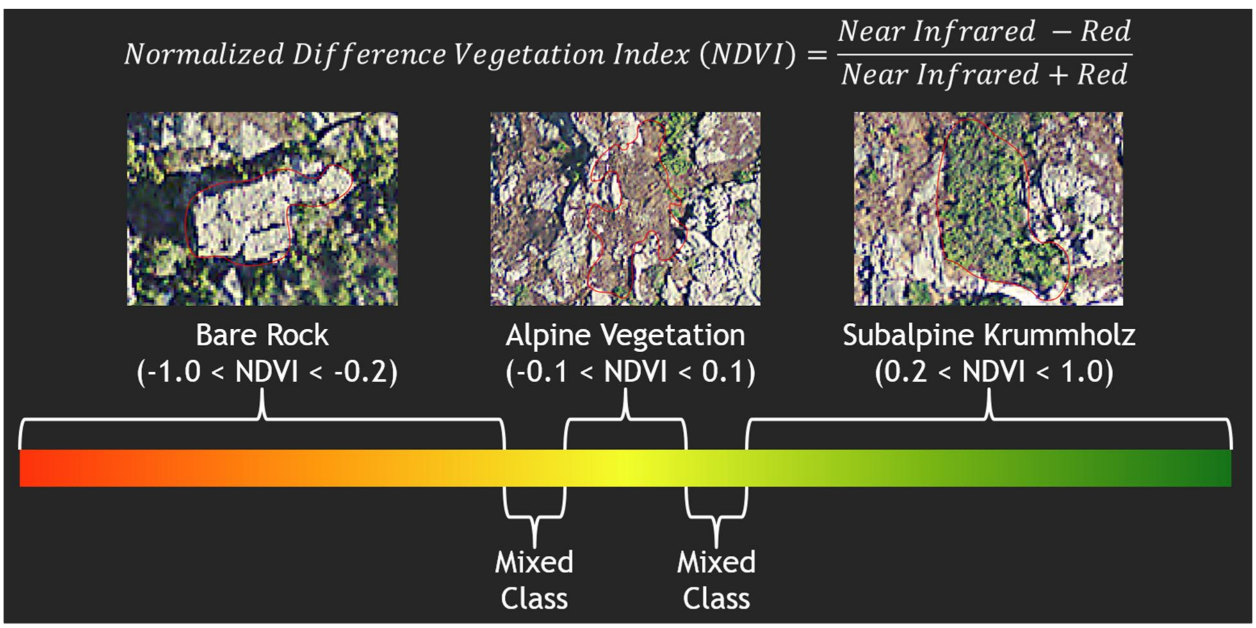

Figure 14: NDVI definition and the NDVI ranges for the Bare Rock, Alpine Vegetation, and Subalpine Krummholz features on Mount Mansfield.

Note that the NDVI ranges presented in Figure 14 do not represent not universal values. The Alpine Vegetation class will not always contain values between -0.1 and 0.1; the range applies for the particular set of imagery on the specific image acquisition date. The same applies for the Bare Rock and Subalpine Krummholz classes. Though not universal, the ranges observed do represent directionally accurate values (i.e. for similar lighting conditions in early May, Bare Rock will have lower NDVI values than Alpine Vegetation, and Alpine Vegetation will have lower NDVI values than Subalpine Krummholz NDVI).

9.0 Results

The eCognition rule set exported the classes to a shapefile for use in GIS software packages. Figures 15 and 16 show the exported shapefile and color scheme legend, respectively.

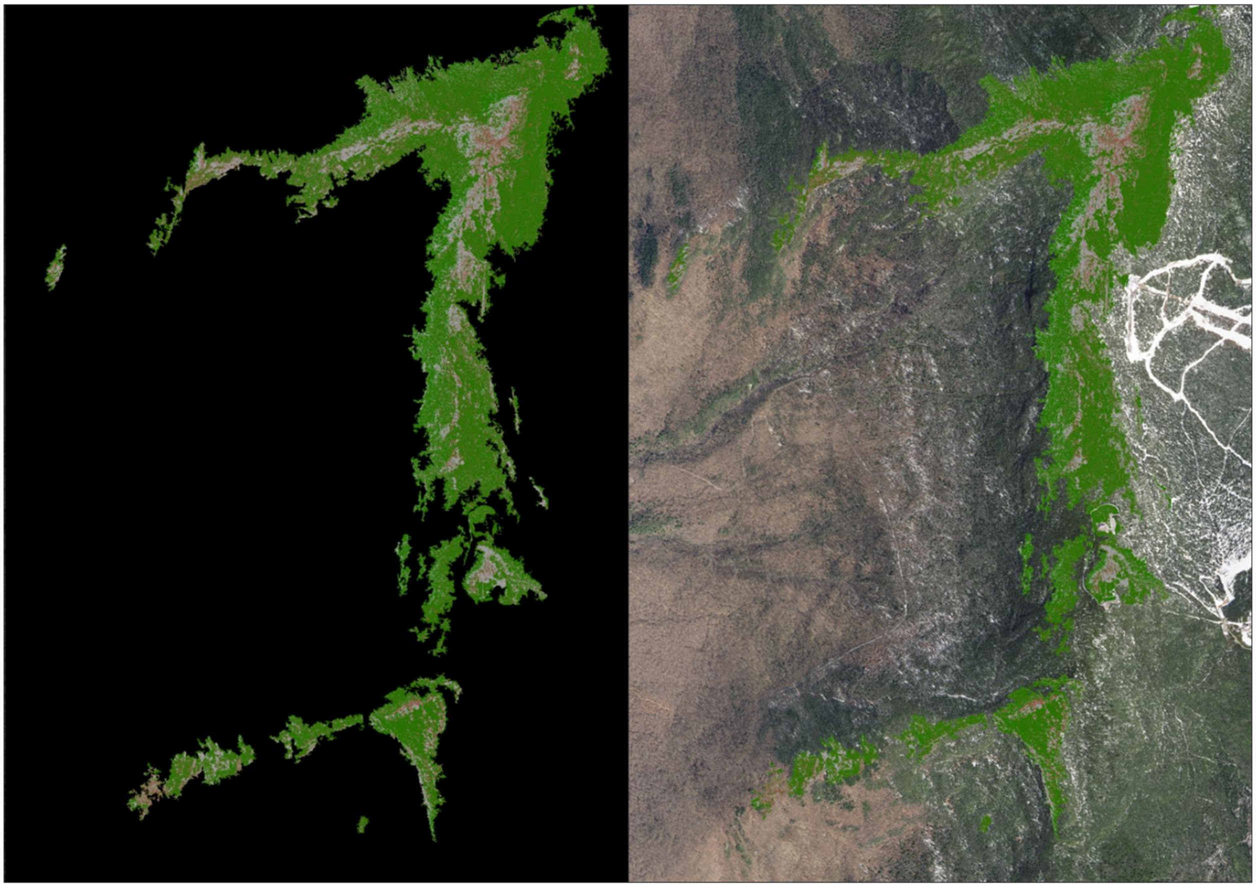

Figure 15: The Mount Mansfield alpine tundra shapefile shown on against a solid background (left) and overlaid on an imagery basemap (right).

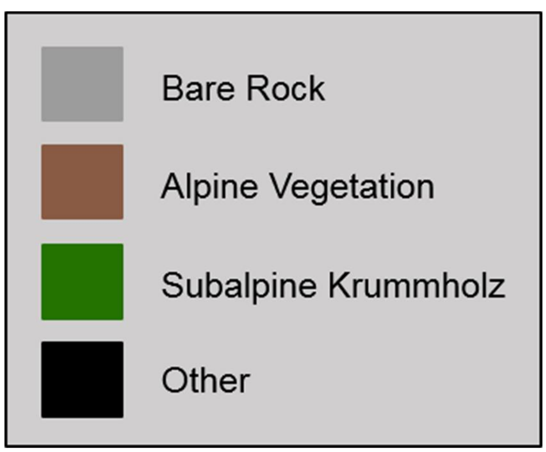

Figure 16: Legend for the alpine tundra shapefile. The colors in the legend reflect the actual feature colors at the time of the imagery used in the analysis (early May).

10.0 Accuracy Assessment

This project computed both quantitative and qualitative accuracy assessments. For the quantitative accuracy assessment, the project used the formula provided by Congalton and Green (2009) to compute the number of accuracy assessment points. With inputs of 4 classes, 95^{th} percentile confidence, and 5% precision, the formula required 624 points. The project used an equalized stratified sampling approach for the point distribution (156 points per class). Figure 17 shows the accuracy assessment point distribution overlaid onto the output shapefile.

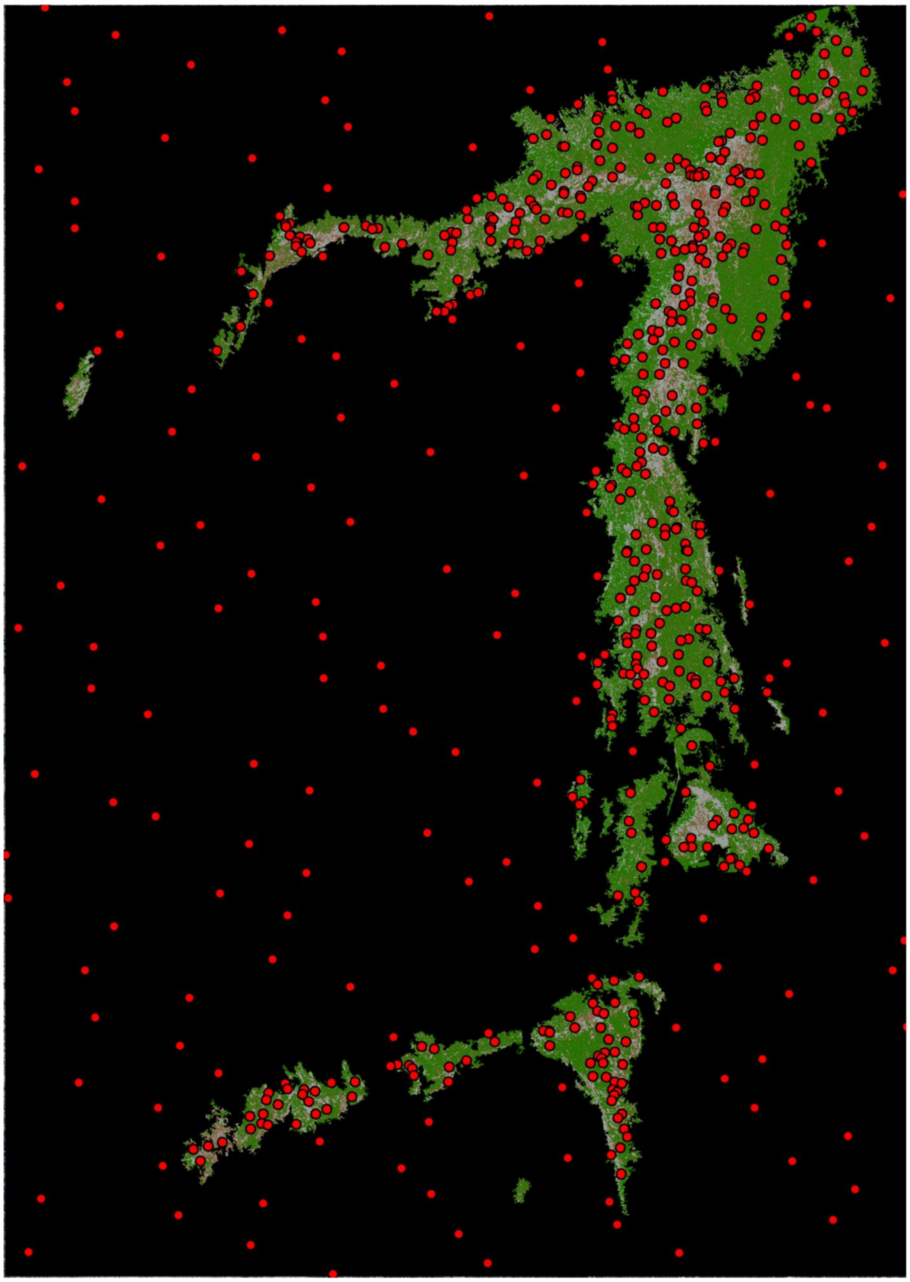

Figure 17: Distribution of accuracy assessment points created from a stratified random sampling approach, overlaid onto the Mount Mansfield land cover shapefile.

The project used the accuracy assessment points to compute an error matrix and measure the Overall Accuracy, User's Accuracy, Producer's Accuracy, and Kappa (KHAT) value. Figure 18 shows the error matrix.

		Reference Data						
		Bare Rock	Alpine Vegetation	Subalpine Krummholz	Other	Row Total	User's Accuracy	Kappa
Classified Data	Bare Rock	104	6	41	5	156	66.67%	
	Alpine Vegetation	18	33	92	13	156	21.15%	
	Subalpine Krummholz	10	10	123	13	156	78.85%	
	Other	0	0	15	141	156	90.38%	
	Column Total	132	49	271	172	624		
	Producer's Accuracy	78.79%	67.35%	45.39%	81.98%		64.26%	
	Kappa							0.52

Figure 18: Error matrix showing the Overall Accuracy, Producer's Accuracy, User's Accuracy, and Kappa (KHAT) value.

The complexity of the land cover (variation on size, shape, and spatial arrangement of features) prevents the quantitative accuracy assessment from providing a universal assessment for all parts of the study area. For this reason, the project created a qualitative accuracy assessment, which visually compared the input layers to the resulting Mount Mansfield shapefile. Figures 19-24 show the qualitative accuracy assessment images for the different parts of the study area (Sunset Ridge Trail, Long Trail, Maple Ridge Trail).

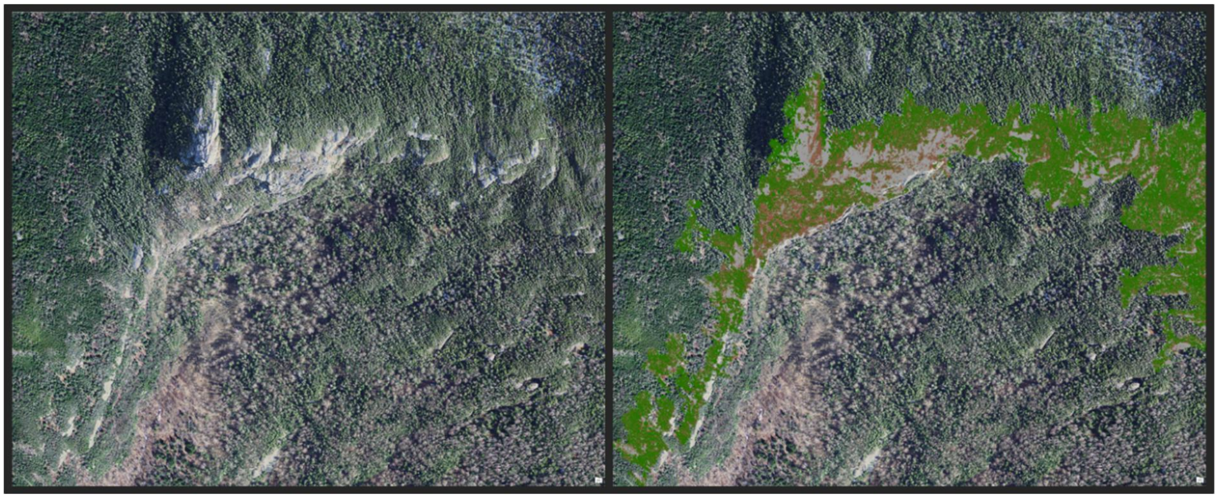

Figure 19: Comparison of the basemap (left) and the output shapefile (right) near the start of the Sunset Ridge Trail.

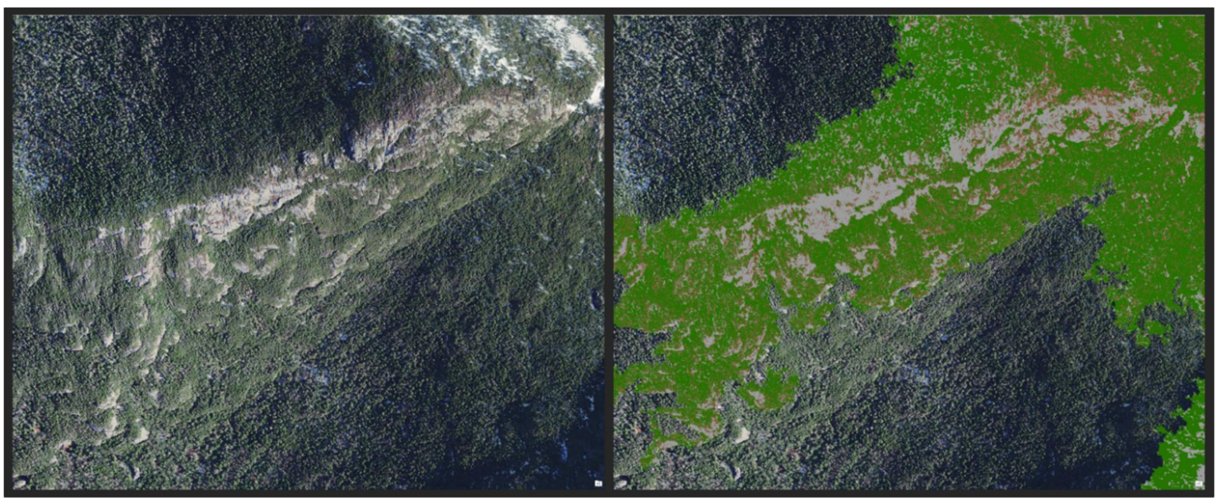

Figure 20: Comparison of the basemap (left) and the output shapefile (right) farther east on the Sunset Ridge Trail.

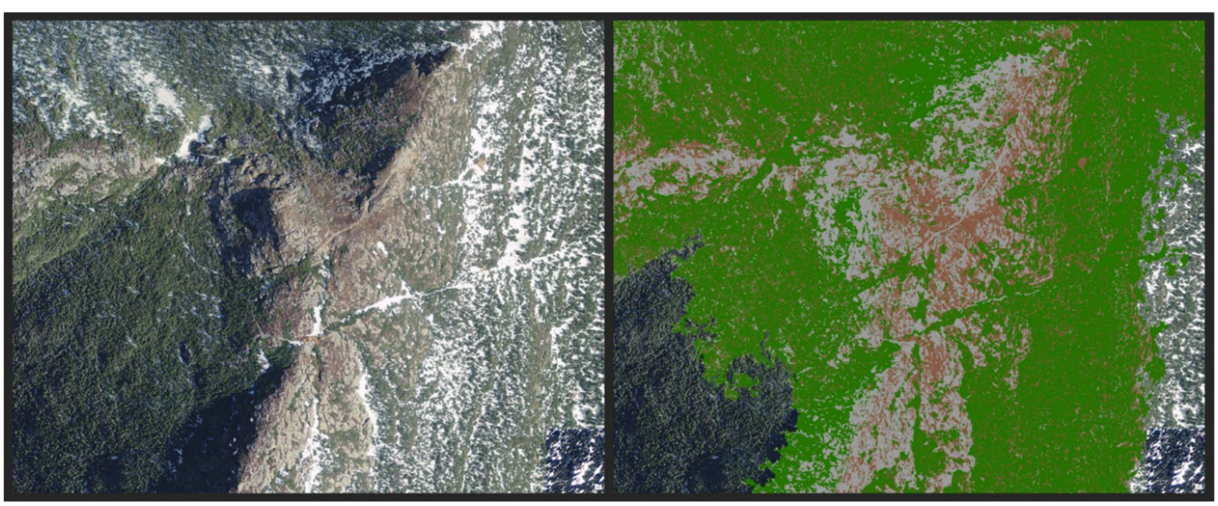

Figure 21: Comparison of the basemap (left) and the output shapefile (right) near the Chin.

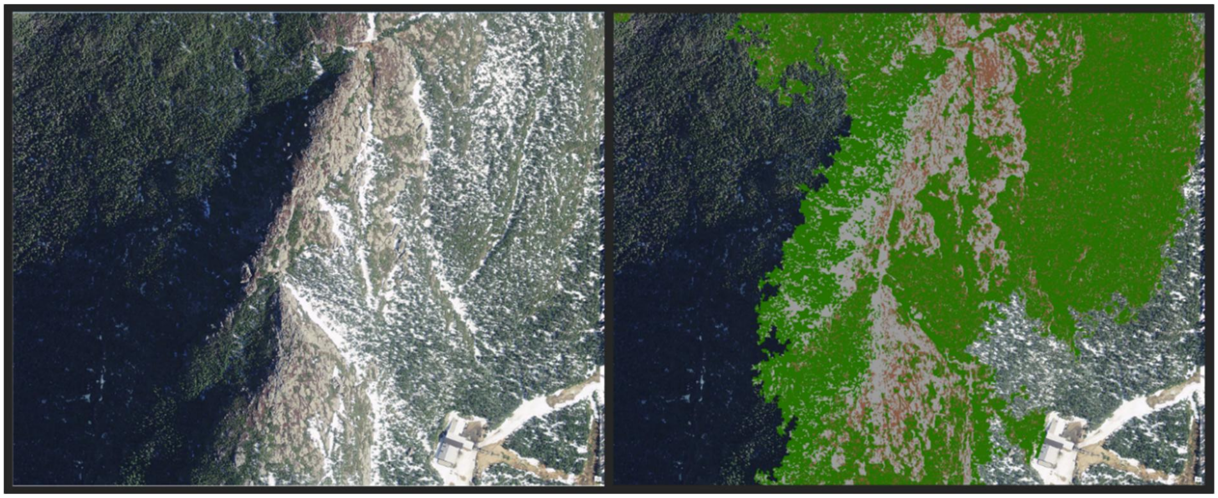

Figure 22: Comparison of the basemap (left) and the output shapefile (right) on the Long Trail near the Cliff House.

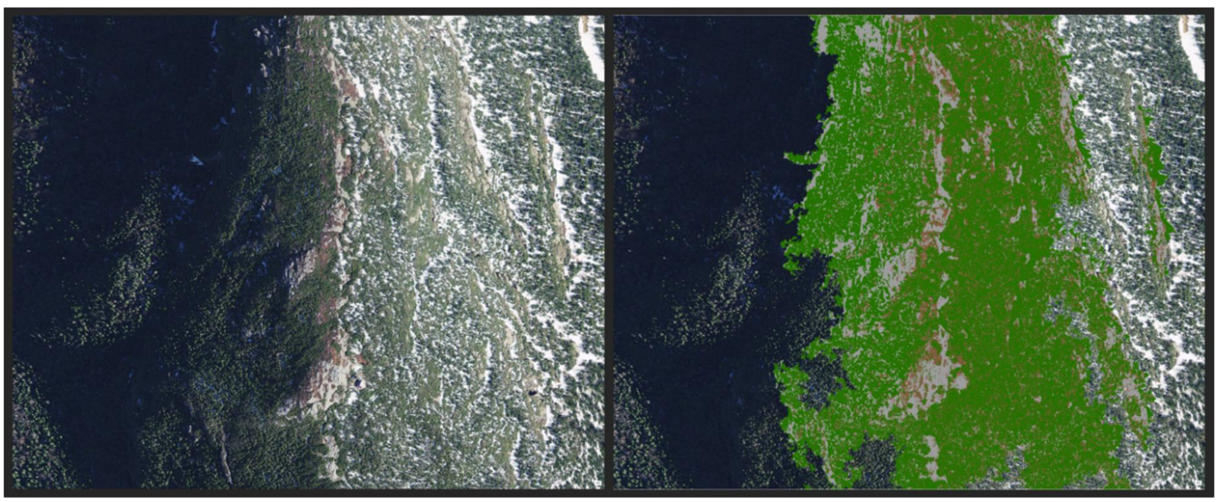

Figure 23: Comparison of the basemap (left) and the output shapefile (right) farther South on the Long Trail.

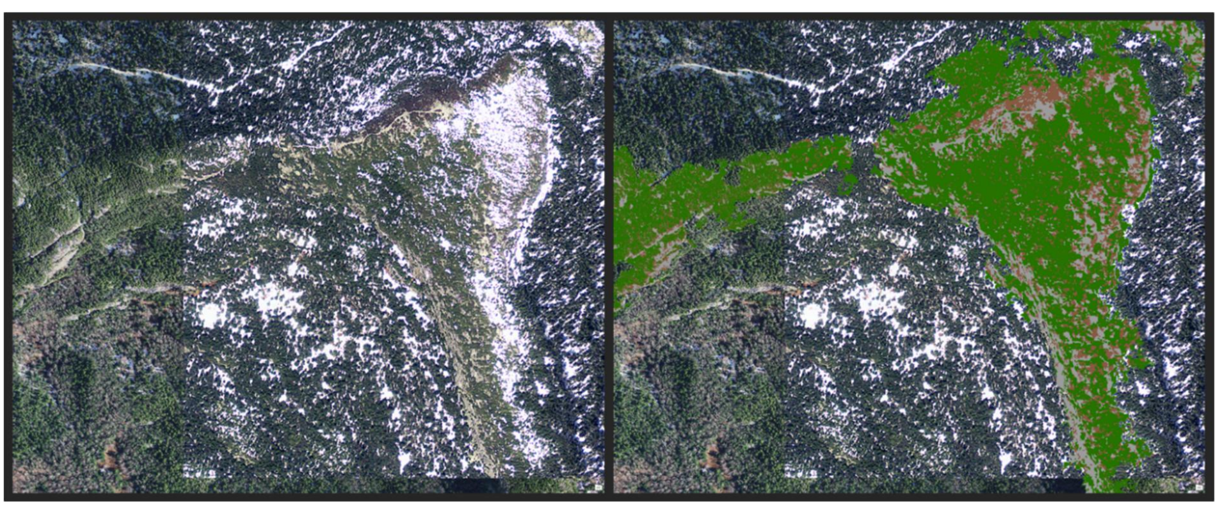

Figure 24: Comparison of the basemap (left) and the output shapefile (right) near the Forehead.

11.0 Data Availability

The Mount Mansfield project data was submitted to the Vermont Center for Geographic Information (VCGI) and VCGI published it to the Vermont Open Geodata Portal.

The files for this project include:

- Feature Geometry (.shp)
- Index File (.shx)
- dBASE Table (.dbf)
- Coordinate System (.prj)
- Metadata (.xml)
- Spatial Index (.sbn, .sbx)
- Character Encoding (.cpg)

Note that the high-resolution input data for this project contributed to a large output file size. The feature geometry file is 110 MB, and the dBASE Table is 80 MB (it contains 321,726 records). In addition, the shapefile is projected into NAD83 State Plane Vermont FIPS 4400 Meters (EPSG: 32145). The metadata file contains a comprehensive documentation of the data, analysis, and results.

Links to the data, metadata, and a Medium.com article detailing the project are listed below.

Data:
https://vcgi.maps.arcgis.com/home/item.html?id=f945467d78f640d697a0950635777429

Metadata:
http://maps.vcgi.vermont.gov/gisdata/metadata/LandLandcov_MTMANSFIELDTUNDRA.htm

Medium Article:
https://medium.com/vcgi/mount-mansfield-mapping-the-alpine-tundra-751a9f3d7c5d

For those interested in obtaining a copy of the eCognition rule set (.dcp file), I can provide it via email if you contact me at the email address listed below.

Please direct questions about the data, metadata, article, and/or rule set to my personal email address: calekochenour@gmail.com.

12.0 Conclusion

This project identified a problem that national level data sets (e.g. the National Land Cover Database) do not capture the **size**, **shape**, or **spatial arrangement** of alpine tundra features on Mount Mansfield. The project solution used object-based image analysis on Vermont's high-resolution imagery and elevation data to create a land cover data set that captured complexity of the alpine tundra and produced a data set for use on a local scale and by local stakeholders. Figure 25 provides a visual summary of the problem and the project solution.

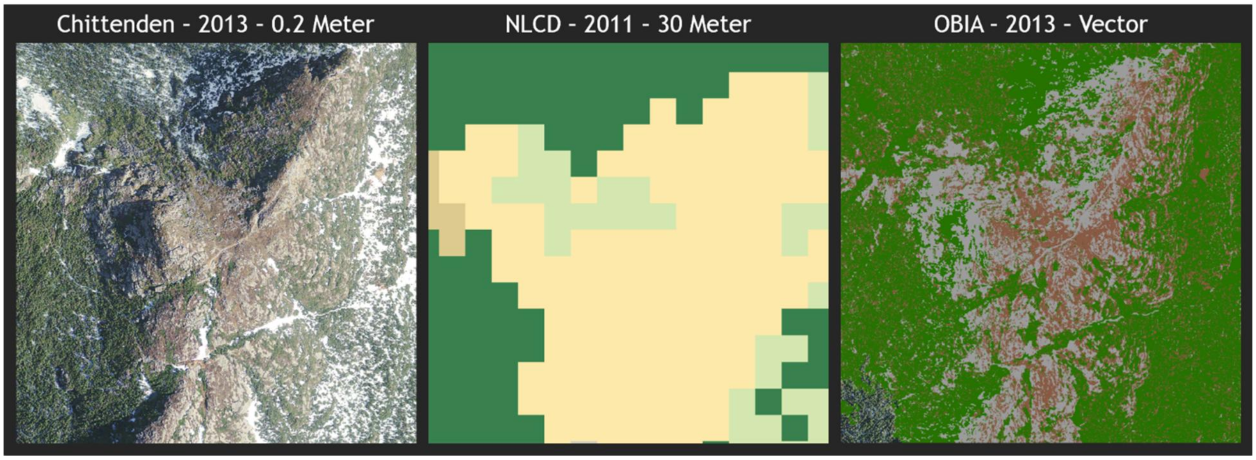

Figure 25: An area near the Mount Mansfield Chin as shown in 0.2-meter Vermont aerial imagery (left), 30-meter National Land Cover Database (center), and the result of this project's object-based image analysis (right).

I want to thank Jarlath O'Neil-Dunne, who advised me throughout this project. His time, expertise, and guidance played a significant role in the success of my analysis.

13.0 Future Research

This project focused on the concept of land cover complexity. The analysis defined complexity as the variation in **size**, **shape**, and **spatial arrangement** of features in a particular study area. Study area complexity increases as feature variation in any category increases. Highly complex land cover (large variation in size, shape, and spatial arrangement) exists in similar alpine environments throughout the Northeastern United States. Examples include other study areas in Vermont (Camel's Hump, Mount Abraham), New York (Adirondack Mountains), New Hampshire (White Mountains), and Maine (Mount Katahdin, Sugarloaf Mountain). Each of these locations in the Northeast contain Bare Rock, Alpine Vegetation, and/or Subalpine Krummholz features in the alpine environment.

Future analyses could baseline these land cover features with a similar method used to capture the features on Mount Mansfield. The analytical framework created by the Mount Mansfield eCognition rule set – use high-resolution imagery and elevation data to isolate tundra candidates, classify tundra features, and export the land cover shapefile – could apply to each of these study areas. The success of the analysis to capture the complexity of these additional study areas would depend on the granularity of the statewide imagery and elevation data available, ideally no coarser than 1-meter spatial resolution. While the eCognition rule set ranges and thresholds would differ with study area and imagery/elevation acquisition date, the framework and method for the Mount Mansfield study area would provide a starting point.

There is also an opportunity to conduct a similar analysis on Mount Mansfield, with more recent and higher resolution imagery, acquired in 2018 at 0.15-meter spatial resolution. The Vermont Center for Geographic Information (2018b, 2018c) published the data and metadata to the Vermont Open Geodata Portal **after** I completed the land cover classification described in the project. Since this imagery was acquired in 2018 under similar leaf off conditions (early May acquisition date), a similar land cover mapping could be completed for the new data. A new project could compare the output shapefiles to determine land cover change in the 5-year time span (May 2013 to May 2018). Note that a mapping of the 2018 data (and subsequent change mapping) would depend in large part on the imagery differences, unless newer and updated elevation layers (nDSM, DEM, Slope) were available to accompany the 2018 imagery.

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