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HUMBOLDT STATE UNIVERSITY SPONSORED PROGRAMS FOUNDATION

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Title: *Using High Resolution Satellite Imagery and Feature Extraction Software for Vegetation Mapping at the Whiskeytown National Recreation Area, Redding, California*

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ABSTRACT

This work was done in response to a Federal Government program to reduce risk to life and property by more effectively managing hazardous fire fuels. A crucial step of vegetation management is the production of a vegetation map. We mapped the Whiskeytown Unit of the Whiskeytown-Shasta-Trinity National Recreation Area. Vegetation was classified and mapped to the Association-Alliance level, the Alliance level and, for some classes, to the mixed alliance level to facilitate cross walk to fuel types. Recent advances in satellite imaging capabilities (1-meter spatial resolution) and pattern recognition software that considers neighborhoods of picture elements facilitated the compilation of this electronic map and database.

The previously developed, vegetation classification at Whiskeytown National Recreation Area served as the basis for making the vegetation map. We modified this classification to reflect actual conditions in the study area. We produced three versions of the vegetation map of the Whiskeytown Unit. The Association-Alliance map offers maximum classification detail with 38 classes (31 plant associations, 5 alliances, 1 Disturbed class and a Barren class). Because we sometimes experienced confusion by the contextual classifier when defining associations, we aggregated to the alliance level (20 alliances, Disturbed, and Barren classes) and finally to an appropriately mixed alliance level of classes that we defined as "Mapping Units" (13 alliances, 3 mixed alliances called Mapping Units, and a combined Barren - disturbed class).

Results of mapping at the vegetation association-alliance level indicated that two abundant classes covered 24 percent of the landscape: the Canyon live oak/whiteleaf manzanita association and the Mixed conifer alliance in near equal proportion. Six classes covered between 5 and 9 percent each for a total of 44 percent of the land area. The remaining thirty classes were rarer, covering 32 percent of the land area. In the alliance level map, four alliances (Canyon live oak forest, Ghost pine woodland, Mixed conifer forest, Ponderosa pine forest) covered between 11 and 17 percent of the landscape each for a total of 56 percent of the land area. Another four alliances covered between 5 and 9 percent of the landscape for a total of 30 percent. The remaining 14 least abundant alliances covered 14 percent of the land area. In the Mapping Unit level map, four Mapping Units (Canyon live oak forest, Ponderosa pine forest, Mixed conifer forest, Mixed pine – mixed oak) covered between 11 and 24 percent of the land area each for a total of 64 percent of the landscape. The remaining ten, less abundant Mapping Units covered 14 percent of the land area.

In order to assess the accuracy of the vegetation map that we have compiled for the Whiskeytown Unit, we sampled the mapped vegetation polygons in the field. A sampling protocol is provided as required by this Task Agreement. We allocated approximately 500 plots according to the NPS standard allocation percentages, producing a plot distribution that considers class abundance such that more abundant classes receive more sample plots. This protocol assumes a production rate of approximately 10 plots per day and a budget to cover approximately 50 days.

INTRODUCTION

A clear understanding of landscape dynamics requires knowledge of existing vegetation cover that is geographically explicit. Maps have historically provided this information and recent advances in computer technology have placed maps and their associated databases into a dynamic systems environment. This merger of computerized databases and graphic functionality is well known as a geographic information system (GIS, United State Geological Survey 2006).

Information about vegetation cover has been provided historically by aerial photographs but is increasingly being provided by satellite imagery in electronic form, reducing image acquisition costs and facilitating integration with GIS (Lillesand et al. 2004). During the past 20 years, satellite imagery has only provided moderate vegetation detail at the sub-formation/mixed series level (for example, needle-leaf, closed canopy, mixed pine forest) primarily because of limited spatial resolution (30-meter pixels). Recent advances in satellite imaging capabilities have provided 4-meter spatial resolution, multispectral images and 1-meter resolution panchromatic (black-and-white) images (Space Imaging 2006). It is now possible to map vegetation from satellite imagery at a level of detail formally reserved for medium scale, color aerial photographs when the 4-meter imagery is merged with the 1-meter imagery to create a 1-meter resolution, multispectral image.

In addition to improvements in the spatial resolution of satellite imagery, new feature extraction software has been developed that enables automated classification of geographic patterns of image pixel, brightness values in multiple wavelength bands (Visual Learning Systems 2006). Previous methods have only allowed classification of individual, multispectral, pixel brightness values regardless of neighborhood values (Lillesand et al. 2004). These older methods produced a grid of classified pixels rather than the more traditional polygon map that humans normally draw (Fox 2003). The new software allows for the creation of polygons based upon patterns of image pixels in a fashion similar to those drawn manually but with the increased consistency of automated methods (McGovern et al. 2004).

The goal of this project was to produce maps of the vegetation in the Whiskeytown Unit of the Whiskeytown-Shasta-Trinity National Recreation Area. This mapping was done in response to the Wildland-Urban Interface Initiative, a federal government program to reduce risk to life and property by more effectively managing hazardous fire fuels. A crucial step of vegetation management is production of a vegetation map that is consistent with the methodology, specifications and standards established by the United States Geological Survey-National Park Service, Vegetation Mapping Program (USGS 1994). We mapped to the alliance level (and sometimes the mixed alliance level) to facilitate cross walks to fuel types. We also mapped to the association level when possible.

PROJECT AREA

Vegetation mapping was restricted to the Whiskeytown Unit of the Whiskeytown-Shasta-Trinity National Recreation Area (Figure 1).

Figure 1. The Project Area was defined by the Whiskeytown Unit of the Whiskeytown - Shasta - Trinity National Recreation Area in North Central California.

The topography of the area can generally be described as rolling to steep hills with steeply graded, high velocity watercourses. Most slopes are in excess of 20 percent. Elevations above mean sea level range from 244 meters on the south boundary at Clear Creek to 1900 meters on Shasta Bally Mountain.

The climate varies considerably with the seasons and elevations. Typically, summers are hot and dry, and winters are cool with moderate rainfall. Thirty-eight degrees Celsius readings often occur during the months of May through October, with occasional sub-freezing temperatures from November through March. The mean annual temperature is 14° C., as recorded at the weather station located at Whiskeytown headquarters. Significantly cooler temperatures are experienced at higher elevations. The average annual precipitation at the weather station at park headquarters is 1524 mm. Seventy-five to ninety percent of the total annual rainfall occurs between November 1 and April 30.

The natural vegetative communities at Whiskeytown are varied, providing shelter and sustenance to a large variety of resident and migratory wildlife, including some endangered species, as well as providing natural settings for recreation. The biological resources of the area have been profoundly influenced by human activities.

METHODS

The National Park Service purchased the Ikonos imagery used for this project. Three source images were acquired by the Ikonos satellite on July 25, 2003 as directed by Space Imaging Incorporated, the company that programs and maintains the satellite. Space Imaging produced an ortho rectified, digital image mosaic of the Whiskeytown Unit on September 4, 2003 (detailed description in the Appendix). The digital image file includes four multispectral bands at 4-meter spatial resolution and one panchromatic band at 1-meter resolution. We merged the 1-meter resolution panchromatic image mosaic with the 4-meter resolution multispectral image mosaic to retain the discrimination power of the multispectral image (especially the combination of the visible red spectral band and the very near infrared band) while taking advantage of the defining power of the 1-meter image to identify individual tree crowns. We experimented with three methods for multi-resolution merging and found the principal components transformation method to produce the best results (Leica Geosystems 2003).

We evaluated two traditional per-pixel classifiers (Lillesand et al. 2004) for extracting vegetation classes and found them ineffective with the fine resolution imagery used. For example, dark pixels occurring in the shadows were always put into the same "shadow" class regardless of what type of tree cover or steep terrain feature was providing the shadow.

We then began to use a spatial pattern recognition software package called Feature Analyst (Visual Learning Systems 2006) to identify groups of pixels associated with various vegetation categories. Since we were not sure how finely Feature Analyst could differentiate plant associations, we began with an unsupervised approach in which we estimated the number of vegetation communities present and let the software define them. Initial results with 20 classes showed extreme diversity within polygons, indicating that the landscape was so heterogeneous that many more classes would be necessary. When we used 60 classes for the unsupervised method, the computer took 72 hours of CPU (central processing unit) time and then shut down before completing the work. The unsupervised approach was frustrating because we were

stretching the computers resources. Another drawback of unsupervised classification is that the polygons formed do not have labels other than class numbers where similar vegetation mosaics have the same number. So, even if were able to get a reasonable result, we were still far from a final classification with all classes labeled according to composition.

After two phone calls and extended discussions to get advice from the company that created the software (Visual Learning Systems) and considering our goals in this work, we decided on a supervised approach to classification that used training areas of pixels representing specific plant communities (both vegetation associations and alliances). From our understanding of the functionality of the software, the supervised approach seemed more appropriate for what we were doing, mapping the landscape into vegetation classes that had already been defined in previous work (Stuart et al. 2003). This way we could limit the number of classes to 38 (the result of analysis of the classes developed previously, see the results section of this report) and give the software more information on the spatial heterogeneity of each vegetation class.

This supervised procedure based on the 1-meter resolution image produced a final result but the polygons were extremely convoluted and complex and the map still took 36 hours of processing time to complete. Since we needed to edit training area locations to improve the map through several drafts, we needed a way to speed the processing. We experimented with using an image with pixels larger than 1-meter, up to 4-meters (the original multispectral image resolution before the multi-resolution image merge) and found the best results with a 2-meter, resolution merged, multispectral image.

Attempts to use the training areas previously defined without editing their location proved frustrating in that the previous areas were defined on moderate resolution Landsat imagery having 30-meter pixels. Locations defined with the old, course-resolution imagery were not located precisely enough to train the feature analyst software with the new 2-meter imagery. We had to visually edit and define the precise location of 50 training areas (some classes had more than one training area) before we were able to obtain good results with Feature Analyst on the Ikonos image.

VEGETATION CLASSIFICATION

The previously developed, vegetation classification at Whiskeytown National Recreation Area (Stuart et al. 2003) served as the basis for making the vegetation map. The classification resulted in 22 alliances and 49 associations and types. However, several concerns about the original vegetation classification developed in the preparation of the map. Examples of these were:

1. The *Quercus berberidifolia – Arctostaphylos patula* type did not exist. The contract botanists had misidentified *Quercus chrysolepis* as *Quercus berberidifolia.* This left us with 48 association and types.

2. We had too many types for interpretation by managers and some associations and types were too finely defined and needed to be merged with other associations or types. For example, it became apparent that there was little difference between the *Lithocarpus densiflorus* var. *densiflorus*| *Toxicodendron diversilobum* and the *Lithocarpus densiflorus* var. *densiflorus – Cornus nuttallii/Toxicodendron diversilobum* association. We ended up merging the two into the *Lithocarpus densiflorus* var. *densiflorus – Cornus*

nuttallii/Toxicodendron diversilobum association. We were able to reduce the number of association and types to 30 after merging (Table 1).

3. Some vegetation types had not been included in the original classification. We added six new vegetation types after reviewing the data and consulting with park personnel. The new types were the:
    a. Chamise alliance,
    b. Red fir alliance,
    c. Mixed conifer alliance,
    d. Black oak alliance,
    e. Ghost pine – interior live oak – Brewer oak association, and
    f. Ponderosa pine – Douglas-fir – canyon line oak association.

    This resulted in 36 vegetated classes for the map.

4. Two bare or scarcely vegetated types were not in the classification, but occupied significant area in the park. We labeled these as Barren or Disturbed producing a total of 38 classes (Table 1).

Table 1. Vegetation labels used in the map of associations and other major types.

Vegetation Associations and Types from Classification plus Newly Created Vegetation Types	Associations and other types
Quercus chrysolepis - Quercus kelloggii/Toxicodendron diversilobum association	Black oak - canyon live oak/toyon - poisonoak association
Quercus kelloggii - Quercus chrysolepis/Heteromeles arbutifolia - Toxicodendron diversilobum association	"
Quercus kelloggii/Toxicodendron diversilobum association	"
Quercus kelloggii/Heteromeles arbutifolia - Toxicodendron diversilobum association	"
Quercus kelloggii/Arctostaphylos viscida association	Black oak/whiteleaf manzanita association
Quercus douglasii/Cercis occidentalis type	Blue oak/redbud association
Quercus garryana var. breweri - Cercocarpus betuloides association	Brewer oak - birchleaf mountain-mahogany association
Quercus chrysolepis - Acer macrophyllum/Achnatherum occidentale type	Canyon live oak - bigleaf maple/needle grass association
Quercus chrysolepis/Toxicodendron diversilobum association	Canyon live oak/poisonoak association
Quercus chrysolepis/Styrax officinalis association	Canyon live oak/snowdrop bush association
Quercus chrysolepis/Arctostaphylos viscida association	Canyon live oak/whiteleaf manzanita association
Pseudotsuga menziesii - Quercus chrysolepis - Acer macrophyllum/Toxicodendron diversilobum association	Douglas-fir - canyon live oak - bigleaf maple/poisonoak association

Vegetation Associations and Types from Classification plus Newly Created Vegetation Types	Associations and other types
Pseudotsuga menziesii - Lithocarpus densiflorus var. densiflorus association	Douglas-fir - tanoak/iris association
Pseudotsuga menziesii - Lithocarpus densiflorus var. densiflorus/Aralia californica association	"
Quercus kelloggii - Pinus sabiniana/Styrax officinalis - Toxicodendron diversilobum type	Ghost pine - black oak/snowdrop bush - poisonoak association
Pinus sabiniana - Quercus chrysolepis/Arctostaphylos viscida association	Ghost pine - canyon live oak/whiteleaf manzanita association
Arctostaphylos patula - Chrysolepis sempervirens/Arctostaphylos nevadensis association	Greenleaf manzanita - bush chinquapin/pinemat manzanita association
Chrysolepis sempervirens - Lithocarpus densiflorus var. echinoides association	"
Quercus wislizeni/Toxicodendron diversilobum association	Interior live oak/poisonoak association
Quercus wislizeni/Toxicodendron diversilobum/Centaurea solstitialis association	Interior live oak/poisonoak/yellow starthistle association
Quercus wislizeni/Arctostaphylos viscida association	Interior live oak/whiteleaf manzanita association
Pinus attenuata - Mixed oak/Arctostaphylos viscida association	Knobcone pine - mixed oak/whiteleaf manzanita association
Pinus attenuata/Ceanothus lemmonii association	Knobcone pine/Lemmon ceanothus association
Abies concolor - Pinus lambertiana - Pinus ponderosa/Lithocarpus densiflorus var. *echinoides* association	Mixed conifer/shrub tanoak - greenleaf manzanita association
Pinus ponderosa - Abies concolor/Arctostaphylos patula - Chrysolepis sempervirens type	"
Pinus ponderosa - Pinus lambertiana/Lithocarpus densiflorus var. *echinoides* association	"
Pinus ponderosa - Pinus lambertiana/Arctostaphylos patula - Lithocarpus densiflorus var. *echinoides* association	"
Pinus ponderosa/Lithocarpus densiflorus var. *echinoides* association	"
Pinus ponderosa - Abies concolor/Lithocarpus densiflorus var. *echinoides* association	"
Pinus ponderosa - Pinus lambertiana/Lithocarpus densiflorus var. *echinoides* association	"
Quercus garryana var*. garryana - Quercus kelloggii/Toxicodendron diversilobum* association	Oregon white oak - black oak/poisonoak association
Pinus ponderosa - Quercus kelloggii/Arctostaphylos viscida - Toxicodendron diversilobum type	Ponderosa pine - black oak/whiteleaf manzanita - poisonoak association

Vegetation Associations and Types from Classification plus Newly Created Vegetation Types	Associations and other types
Pinus ponderosa - Lithocarpus densiflorus var. *densiflorus - Quercus chrysolepis/Toxicodendron diversilobum* type	Ponderosa pine - tanoak - canyon live oak/poisonoak association
Pinus ponderosa - Quercus chrysolepis/Arctostaphylos viscida association	"
Pinus ponderosa - Lithocarpus var. *densiflorus* association	"
Quercus chrysolepis - Arctostaphylos patula association	Shrub canyon live oak - greenleaf manzanita - shrub tanoak association
Quercus chrysolepis - Lithocarpus densiflorus var. *echinoides* association	"
Quercus chrysolepis/rock association	Shrub canyon live oak/rock association
Lithocarpus densiflorus var. *echinoides/Pteridium aquilinum* association	Shrub tanoak/bracken fern association
Lithocarpus densiflorus var. *echinoides/Arctostaphylos nevadensis* type	Shrub tanoak/pinemat manzanita association
Lithocarpus densiflorus var. *densiflorus/Toxicodendron diversilobum* type	Tanoak - mountain dogwood/poisonoak association
Lithocarpus densiflorus var. *densiflorus - Cornus nuttallii/Toxicodendron diversilobum* association	"
Alnus rhombifolia/Carex nudata association	White alder type
Alnus rhombifolia association	"
Alnus rhombifolia/Leucothoe davisiae association	"
Alnus rhombifolia/Pteridium aquilinum association	"
Arctostaphylos viscida - Heteromeles arbutifolia - Toxicodendron diversilobum type	Whiteleaf manzanita - toyon - poisonoak association
Arctostaphylos viscida - Adenostoma fasciculatum association	Whiteleaf manzanita - chamise association
Quercus berberidifolia-Arctostaphylos patula type	wrong type -- misidentified by contract crews
new	Chamise alliance
new	Black oak alliance
new	Mixed conifer alliance
new	Ghost pine - interior live oak - Brewer oak association
new	Ponderosa pine - Douglas-fir - canyon live oak association
new	Red fir alliance
new	Barren
new	Disturbed

RESULTS AND DISCUSSION

We produced three versions of the vegetation map of the Whiskeytown Unit. The Association map offers maximum classification detail with 38 classes (31 plant associations, 5 alliances, 1 Disturbed class and a Barren class, Table 2). Because we sometimes experienced confusion by the contextual classifier when defining associations, we aggregated to the alliance level (20 alliances, Disturbed, and Barren, Table 2) and finally to an appropriately mixed alliance level of classes that we defined as "Mapping Units" (13 alliances, 3 mixed alliances, and a combined Barren - disturbed class, Table 2).

Table 2. Cross listing of three levels of thematic mapping detail: associations-alliances were merged into alliances and some of the alliances were merged into mapping units. Class ID numbers relate to the digital maps at the associations-alliances level.

Class ID	Mapping Units	Alliances	Associations-Alliances
37	Barren - disturbed	Barren*	Barren*
38	"	Disturbed*	Disturbed*
34	Blue oak woodland	Blue oak woodland	Blue oak/redbud association
4	Brewer oak shrubland	Brewer oak shrubland	Brewer oak - birchleaf mountain-mahogany association
32	Canyon live oak forest	Canyon live oak forest	Canyon live oak - bigleaf maple/needle grass association
31	"	"	Canyon live oak/poisonoak association
29	"	"	Canyon live oak/snowdrop bush association
28	"	"	Canyon live oak/whiteleaf manzanita association
27	Chamise shrubland	Chamise shrubland	Chamise alliance
36	Deciduous oak forest	Black oak forest	Black oak - canyon live oak/toyon - poisonoak association
11	"	"	Black oak alliance
35	"	"	Black oak/whiteleaf manzanita association
13	"	Oregon white oak woodland	Oregon white oak - black oak/poisonoak association
26	Douglas-fir forest	Douglas-fir forest	Douglas-fir - canyon live oak - bigleaf maple/poisonoak

Class ID	Mapping Units	Alliances	Associations-Alliances
			association
25	"	"	Douglas-fir - tanoak/iris association
20	Interior live oak woodland	Interior live oak woodland	Interior live oak/poisonoak association
19	"	"	Interior live oak/poisonoak/yellow starthistle association
18	"	"	Interior live oak/whiteleaf manzanita association
14	Mixed conifer forest	Mixed conifer forest	Mixed conifer alliance
15	Mixed conifer shrubland	Mixed conifer shrubland	Mixed conifer/shrub tanoak - greenleaf manzanita association
24	Mixed pine - mixed oak	Ghost pine woodland	Ghost pine - black oak/snowdrop bush - poisonoak association
23	"	"	Ghost pine - canyon live oak/whiteleaf manzanita association
22	"	"	Ghost pine - interior live oak - Brewer oak association
17	"	Knobcone pine woodland	Knobcone pine - mixed oak/whiteleaf manzanita association
16	"	"	Knobcone pine/Lemmon ceanothus association
33	Montane chaparral	Canyon live oak shrubland	Shrub canyon live oak - greenleaf manzanita - shrub tanoak association
30	"	"	Shrub canyon live oak/rock association
21	"	Greenleaf manzanita shrubland	Greenleaf manzanita - bush chinquapin/pinemat manzanita association
6	"	Tanoak shrubland	Shrub tanoak/bracken fern association
7	"	"	Shrub tanoak/pinemat manzanita association
12	Ponderosa pine forest	Ponderosa pine forest	Ponderosa pine - black oak/whiteleaf manzanita -

Class ID	Mapping Units	Alliances	Associations-Alliances
			poisonoak association
9	"	"	Ponderosa pine - Douglas-fir - canyon live oak association
10	"	"	Ponderosa pine - tanoak - canyon live oak/poisonoak association
8	Red fir forest	Red fir forest	Red fir alliance
5	Tanoak forest	Tanoak forest	Tanoak - mountain dogwood/poisonoak association
3	White alder temporarily flooded forest	White alder temporarily flooded forest	White alder alliance
1	Whiteleaf manzanita shrubland	Whiteleaf manzanita shrubland	Whiteleaf manzanita - chamise association
2	"	"	Whiteleaf manzanita - toyon - poisonoak association
Number of Categories	17	22	38

* Barren is a non-vegetation class.
*Disturbed is a mostly barren class with very sparse grass cover.

The Barren and Disturbed types were functionally similar and merited being merged into a new type labeled Barren-disturbed. We created 3 other mapping units out of a total of 7 alliances. The 3 mapping units were defined based on similar species composition, physiognomy, ecological function, and resource management concerns. The new units were defined as:

1. Deciduous oak forest = Black oak forest + Oregon white oak woodland. The Oregon white oak woodland had nearly as much cover of black oak (23.9%) as it did Oregon white oak (26.8%). Furthermore, the Oregon white oak woodland was often nearby or intermixed with black oak communities.

2. Mixed pine – mixed oak = Ghost pine woodland + Knobcone pine woodland. These alliances had scattered pines over a dense cover of mixed oaks and whiteleaf manzanita. The spectral signature of the manzanita and oaks overwhelmed any contribution of the widely spaced, thin canopies of the pines. These two alliances are physiognomically very similar and ecosystem processes are undoubtedly dominated by the oaks and whiteleaf manzanita. The vegetation classification presents nearly identical relative cover values in the Knobcone pine and Ghost pine woodlands for pines (7.8% versus 8.4%) and for whiteleaf manzanita (22.3% vs. 21.4%). Furthermore, both types had relative covers of mixed oaks and toyon of 32.8% and 52.6%, respectively.

3. Montane chaparral = Canyon live oak shrubland + Greenleaf manzanita shrubland + Tanoak shrubland. This mapping unit is found on and around Shasta Bally. The physiognomy of these alliances is essentially identical, all being of similar heights and canopy cover. The dominant shrubs in each alliance have evergreen, sclerophyllous leaves of similar size and shape and the alliances differ only in the relative cover of the predominant species. One area might be dominated by shrub tanoak with lesser amounts of the shrub form of canyon live oak, greenleaf manzanita, or bush chinquapin. Another area, on the other hand, might have more leaf cover of canyon live oak with lesser amounts of the other species. The landscape represents a constant physiognomic form, but with a multidimensional continuum of changing patterns of cover of the predominant evergreen shrub species. Shrubs have the highest relative cover with 78%, with trees having 17%, and herbs with 5%. The dominant shrubs in decreasing order of relative cover are the shrub variety of tanoak (35%), greenleaf manzanita (14%), the shrub form of canyon live oak (10%), bush chinquapin (9%), and pinemat manzanita (6%).

Results of mapping at the vegetation association - alliance level of detail are shown in Figure 2. Land area by class is summarized in Table 3 for the 38 classes defined. Two classes covered 24 percent of the landscape: the Canyon live oak/whiteleaf manzanita association and the mixed conifer alliance in near equal proportion. Six classes covered between 5 and 9 percent each for a total of 44 percent of the land area. The remaining thirty classes were rarer, covering 32 percent of the land area.

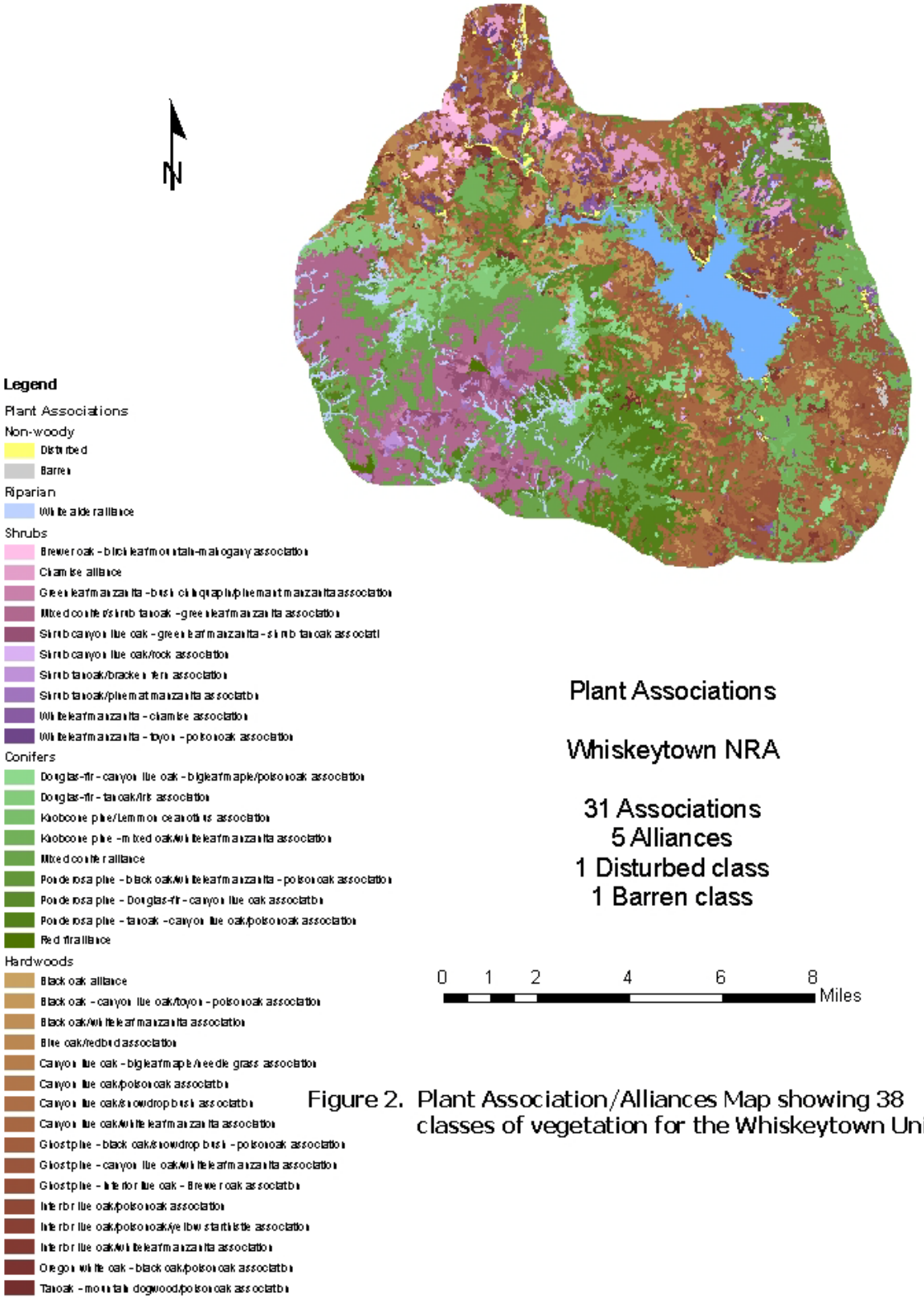

Figure 2. Plant Association/Alliances Map showing 38 classes of vegetation for the Whiskeytown Unit.

Table 3. Area summary statistics for plant Associations-Alliances

Thirty-eight Plant Associations - Alliances	Number of Polygons	Land Area of all Polygons (hectares)	Percentage	Mean Area per Polygon (hectares)
Barren	74	217.0	0.8	2.9
Black oak - canyon live oak/toyon - poisonoak association	365	1,464.6	5.3	4.0
Black oak alliance	3	6.6	0.0	2.2
Black oak/whiteleaf manzanita association	127	333.9	1.2	2.6
Blue oak/redbud association	15	57.7	0.2	3.8
Brewer oak - birchleaf mountain-mahogany association	23	222.6	0.8	9.7
Canyon live oak - bigleaf maple/needle grass association	131	564.1	2.1	4.3
Canyon live oak/poisonoak association	25	82.5	0.3	3.3
Canyon live oak/snowdrop bush association	117	251.2	0.9	2.1
Canyon live oak/whiteleaf manzanita association	401	3,632.0	13.3	9.1
Chamise alliance	93	610.9	2.2	6.6
Douglas-fir - canyon live oak - bigleaf maple/poisonoak association	131	482.8	1.8	3.7
Douglas-fir - tanoak/iris association	130	974.7	3.6	7.5
Ghost pine - black oak/snowdrop bush - poisonoak association	207	1,204.7	4.4	5.8
Ghost pine - canyon live oak/whiteleaf manzanita association	242	2,412.6	8.8	10.0
Ghost pine - interior live oak - Brewer oak association	101	448.1	1.6	4.4
Disturbed	65	149.8	0.5	2.3
Greenleaf manzanita - bush chinquapin/pinemant manzanita association	49	104.3	0.4	2.1
Interior live oak/poisonoak association	46	155.7	0.6	3.4
Interior live oak/poisonoak/yellow starthistle association	19	62.4	0.2	3.3
Interior live oak/whiteleaf manzanita association	115	325.8	1.2	2.8
Knobcone pine - mixed oak/whiteleaf manzanita association	256	2,377.7	8.7	9.3
Knobcone pine/Lemmon ceanothus association	43	83.6	0.3	1.9
Mixed conifer alliance	155	3,050.6	11.1	19.7
Mixed conifer/shrub tanoak - greenleaf manzanita association	91	2,543.7	9.3	28.0
Oregon white oak - black oak/poisonoak association	32	91.0	0.3	2.8
Ponderosa pine - Douglas-fir - canyon live oak association	162	1,677.1	6.1	10.4
Ponderosa pine - black oak/whiteleaf manzanita - poisonoak association	49	135.6	0.5	2.8
Ponderosa pine - tanoak - canyon live	269	1,701.1	6.2	6.3

Thirty-eight Plant Associations - Alliances	Number of Polygons	Land Area of all Polygons (hectares)	Percentage	Mean Area per Polygon (hectares)
oak/poisonoak association				
Red fir alliance	5	49.7	0.2	9.9
Shrub canyon live oak - greenleaf manzanita - shrub tanoak associati	34	267.1	1.0	7.9
Shrub canyon live oak/rock association	49	90.2	0.3	1.8
Shrub tanoak/bracken fern association	15	96.6	0.4	6.4
Shrub tanoak/pinemat manzanita association	24	55.2	0.2	2.3
Tanoak - mountain dogwood/poisonoak association	31	48.7	0.2	1.6
White alder alliance	207	792.6	2.9	3.8
Whiteleaf manzanita - chamise association	101	262.6	1.0	2.6
Whiteleaf manzanita - toyon - poisonoak association	145	304.6	1.1	2.1

Results of mapping at the vegetation alliance level of detail are shown in Figure 3. Land area by alliance is summarized in Table 4 for the 22 alliances defined. Four alliances (Canyon live oak forest, Ghost pine woodland, Mixed conifer forest, and Ponderosa pine forest) covered between 11 and 17 percent of the landscape each for a total of 56 percent of the land area. Four Alliances covered between 5 and 9 percent of the landscape for a total of 30 percent. The remaining 14 least abundant alliances covered 14 percent of the land area.

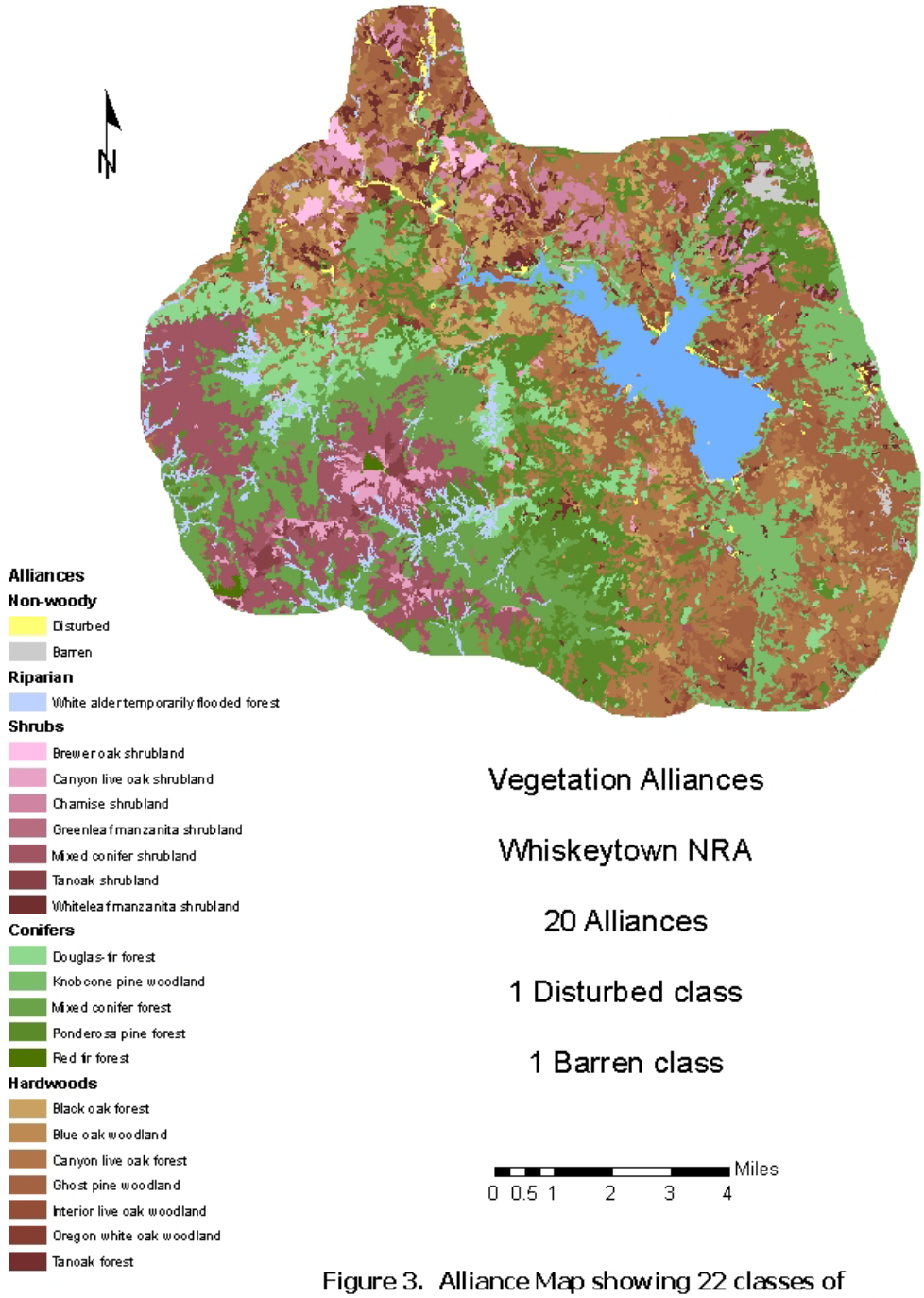

Figure 3. Alliance Map showing 22 classes of vegetation for the Whiskeytown Unit.

Table 4. Area Summary Statistics for Alliances

Alliances	Number of Polygons	Land Area of all Polygons (hectares)	Percentage	Mean Area per Polygon (hectares)
Barren	74	217.0	0.8	2.9
Black oak forest	411	1,805.2	6.6	4.4
Blue oak woodland	15	57.7	0.2	3.8
Brewer oak shrubland	23	222.6	0.8	9.7
Canyon live oak forest	500	4,529.8	16.6	9.1
Canyon live oak shrubland	81	357.3	1.3	4.4
Chamise shrubland	93	610.9	2.2	6.6
Douglas-fir forest	223	1,457.5	5.3	6.5
Ghost pine woodland	312	4,065.4	14.9	13.0
Disturbed	65	149.8	0.5	2.3
Greenleaf manzanita shrubland	49	104.3	0.4	2.1
Interior live oak woodland	170	543.9	2.0	3.2
Knobcone pine woodland	260	2,461.3	9.0	9.5
Mixed conifer forest	154	3,050.6	11.2	19.8
Mixed conifer shrubland	91	2,543.7	9.3	28.0
Oregon white oak woodland	32	91.0	0.3	2.8
Ponderosa pine forest	383	3,376.7	12.4	8.8
Red fir forest	5	49.7	0.2	9.9
Tanoak forest	31	48.7	0.2	1.6
Tanoak shrubland	31	151.8	0.6	4.9
White alder temporarily flooded forest	206	792.6	2.9	3.8
Whiteleaf manzanita shrubland	225	567.1	2.1	2.5

Results of mapping at the Mapping unit level of classification detail are shown in Figure 4. Land area by mapping unit is summarized in Table 5 and charted in Figure 5. Four mapping units (Canyon live oak forest, Ponderosa pine forest, Mixed conifer forest and Mixed pine – mixed oak) covered between 11 and 24 percent of the land area each for a total of 64 percent of the landscape. Three mapping units (Douglas-fir forest, Deciduous oak forest, and Mixed conifer shrubland) covered between 5 and 9 percent of the land area for a total of 22 percent. The remaining ten, less abundant mapping units covered 14 percent of the land area.

We believe this mapping unit level of detail provides the best characterization of the landscape considering a desire for functionally defined classes that distinguish significant differences in vegetation character.

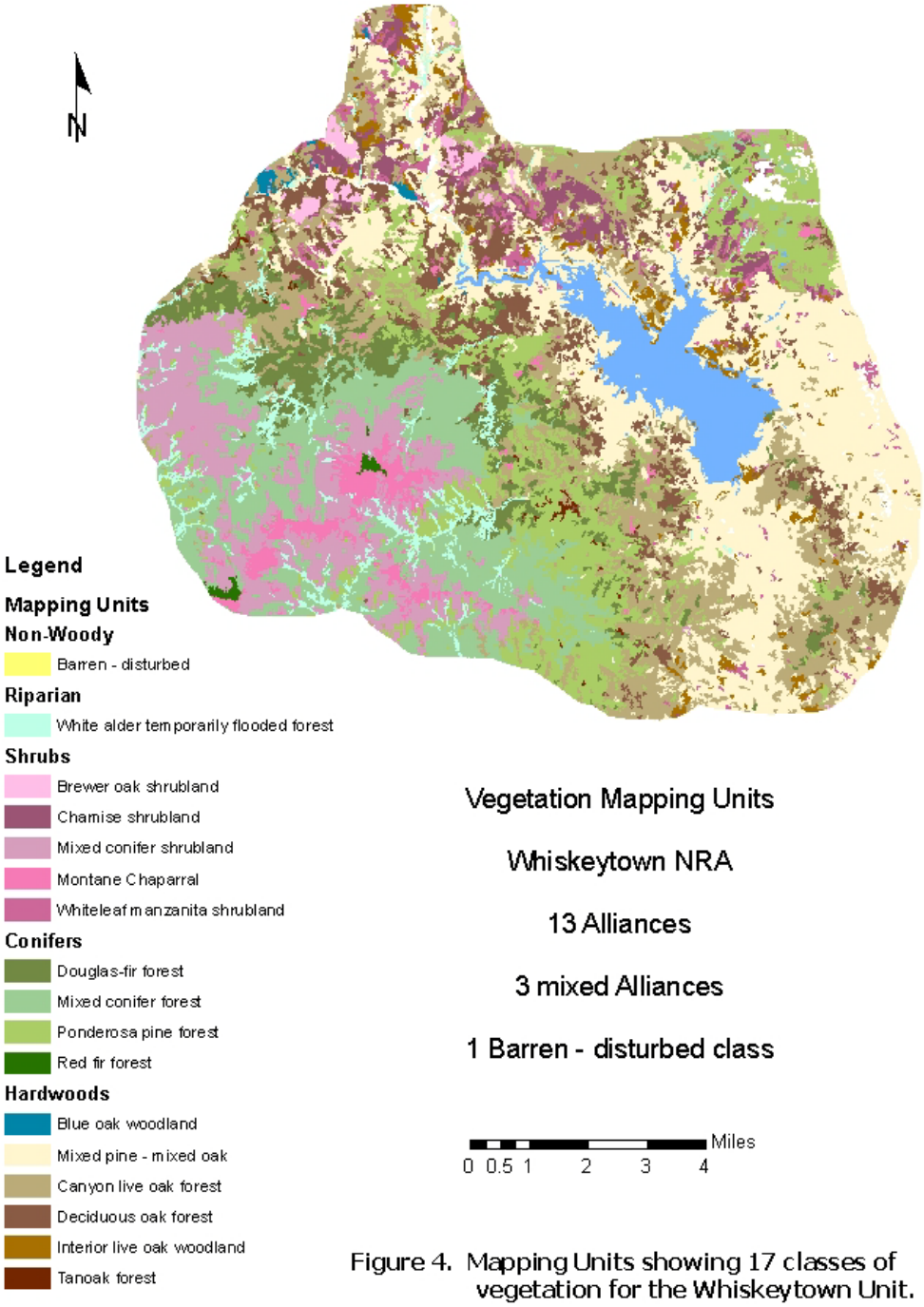

Figure 4. Mapping Units showing 17 classes of vegetation for the Whiskeytown Unit.

Table 5. Area summary statistics for Mapping Units

Mapping Unit Name	Number of Polygons	Land Area of all polygons (hectares)	Percentage of Land Area	Mean Area per Polygon (hectares)
Barren - disturbed	118	366.8	1.3	3.1
Blue oak woodland	15	57.7	0.2	3.8
Brewer oak shrubland	23	222.6	0.8	9.7
Canyon live oak forest	500	4529.8	16.6	9.1
Chamise shrubland	93	610.9	2.2	6.6
Deciduous oak forest	417	1896.2	7.0	4.5
Douglas-fir forest	223	1457.5	5.3	6.5
Interior live oak woodland	170	543.9	2.0	3.2
Mixed conifer forest	154	3050.6	11.2	19.8
Mixed conifer shrubland	91	2543.7	9.3	28.0
Mixed pine - mixed oak	229	6526.7	23.9	28.5
Montane Chaparral	108	613.3	2.3	5.7
Ponderosa pine forest	383	3376.7	12.4	8.8
Red fir forest	5	49.7	0.2	9.9
Tanoak forest	31	48.7	0.2	1.6
White alder temporarily flooded forest	206	792.6	2.9	3.8
Whiteleaf manzanita shrubland	225	567.1	2.1	2.5

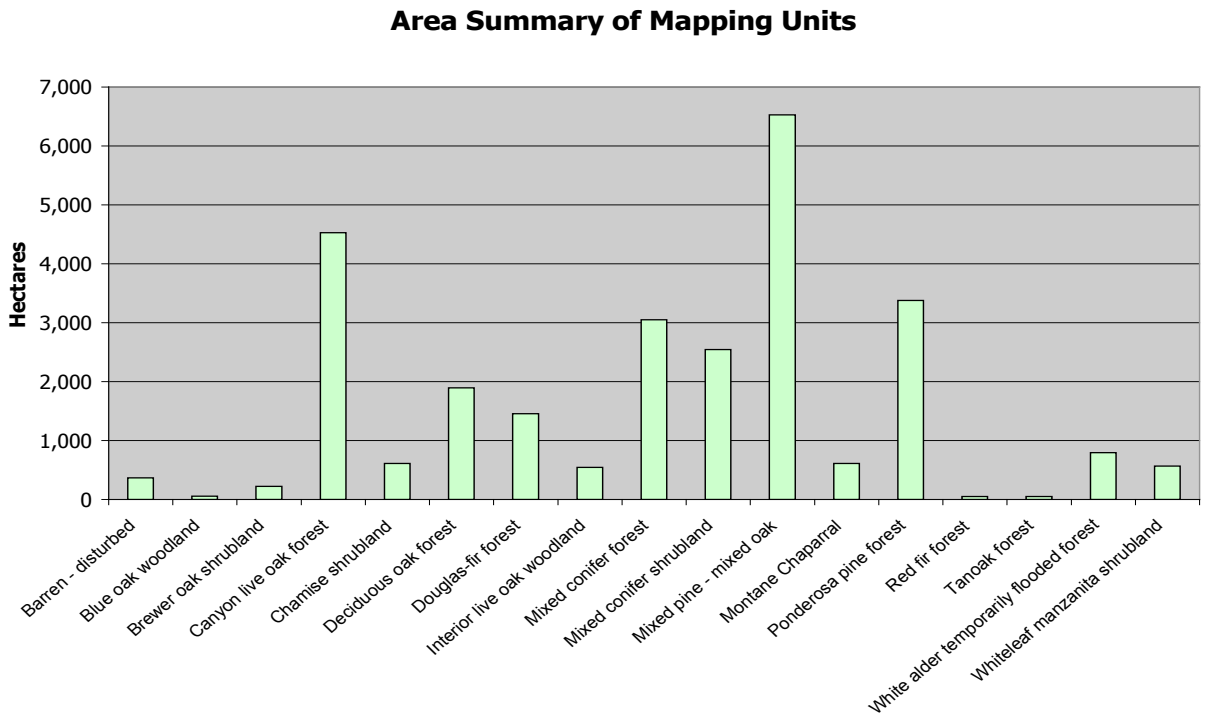

Figure 5. Bar chart of land area by mapping unit.

PROTOCOL FOR ASSESSING THE ACCURACY OF THE VEGETATION MAP

This Task Agreement required delivery of a written protocol for assessing the accuracy of the final map. That protocol is provided in this section of the final report.

In order to assess the accuracy of the vegetation map that we have compiled for the Whiskeytown Unit, we will need to sample the mapped vegetation polygons in the field. The following sampling protocol is consistent with the United States Geological Survey – National Park Service (USGS-NPS) Vegetation Mapping Standard (USGS-NPS 1994) in that we propose to follow the standard except that funding will likely be insufficient to collect the number of samples required per vegetation type.

The actual number of samples taken will depend on the actual production rate of our field crew as detailed in this statement. We present three possible funding levels: $32,00 to provide at least 500 samples, $80,000 to likely meet USGS-NPS standard sample size requirement assuming a production rate of 10 plots per day, and $100,000 to more adequately insure compliance with the standard, assuming a production rate of only eight plots per day.

At the low funding level, we will execute a stratified random sample of mapped polygons throughout the mapped area such that the proportion of plots assigned to each mapped vegetation type is consistent with the NPS standard. The percentage of plots that will be assigned to each mapped vegetation type is shown in Table 6. We calculated three plots for scenario E (78 plots total) since we produced one very rare vegetation class (Scenario E) with three polygons and three plots will allow us to visit all sites as required by the standard.

Table 6. Percentage of plots taken per class of mapped vegetation type. After USGS 1994.

Class of Vegetation Type	NPS Standard # of Plots	Number of Classes on Final Map	Percentage of Plots
Abundant, NPS Scenario A	30	29	39
Relatively Abundant, Scenario B	20	6	26
Relatively Rare, Scenario C	20	1	26
Rare, Scenario D	5	1	6
Very Rare, Scenario E	Visit all sites (3 plots)	1	3

Sampling will be accomplished using a ***relevé*** approach such that the field crew will enter a polygon according to coordinate location (determined by GPS navigation) and begin to assess the vegetation within the polygon as they walk to the approximate geographic center of the polygon. The exact position of the crew is not nearly as important as the crew's assessment of the vegetation type characterized by the polygon (that is, assuming they are far enough from the polygon boundary to avoid edge effects). Dominant overstory and understory plant species will be recorded by cover class, determined by ocular estimation. Because of minor inclusions that are smaller than the minimum mapping unit (MMU) and variation within polygons defined by the feature analyst-image classification methods, exceptions to the majority vegetation type

within a polygon will exist. The field crew will determine the best location to characterize the majority of the vegetation within the polygon and label accordingly.

The estimated cost per day (10-hour day) to place two workers in the field is shown in Table 7.

Table 7. Cost per day for the field crew.

Item	*Cost*
Vehicle	$43
Gas & oil	$35
Wages, person 1	$100
Wages, person 2	$100
Benefits	$30
Per diem & lodging	$160
Supervision	$60
Misc. office costs	$5
Foundation indirect cost	$80
Total cost	$613

The productivity of the field crew will depend upon various factors such as plot location and access parameters. We have developed three cost scenarios for sampling with varying production rates (Table 8).

Table 8. Estimated sampling costs at three production rates: 12, 10 and 8 plots per day.

Production at 12 plots per day			*Production at 10 plots per day*			*Production at 8 plots per day*		
Cost	# of plots	# of days	Cost	# of plots	# of days	Cost	# of plots	# of days
$613	12	1	$613	10	1	$613	8	1
$3,065	60	5	$3,065	50	5	$3,065	40	5
$6,130	120	10	$6,130	100	10	$6,130	80	10
$9,195	180	15	$9,195	150	15	$9,195	120	15
$12,260	240	20	$12,260	200	20	$12,260	160	20
$18,390	360	30	$18,390	300	30	$18,390	240	30
$24,520	480	40	$24,520	400	40	$24,520	320	40
$30,650	600	50	$30,650	500	50	$30,650	400	50
$36,780	720	60	$36,780	600	60	$36,780	480	60
$61,300	1200	100	$61,300	1000	100	$61,300	800	100
$91,950	1800	150	$91,950	1500	150	$91,950	1200	150
$122,600	2400	200	$122,600	2000	200	$122,600	1600	200
$153,250	3000	250	$153,250	2500	250	$153,250	2000	250

The map contains 38 vegetation classes. If we allocate 511 plots according to the NPS standard allocation percentages, we will produce the plot distribution shown in Table 9. This assumes a production rate of approximately 10 plots per day and a budget of approximately $32,000.

Table 9. Number of vegetation types, samples per type and total samples to be obtained across the map to be produced. Assumes a funding level of $32,000 and a production of approximately 10 plots per day.

Class of Vegetation Type	*Number of Types in the Map*	*Sample plots per Type*	*Total Sample Plots Proposed*
Abundant, NPS Scenario A	29	15	435
Relatively Abundant, Scenario B	6	10	60
Relatively Rare, Scenario C	1	10	10
Rare, Scenario D	1	3	3
Very Rare, Scenario E	1	3	3
TOTAL	38		511

With a budget of $32,000.00, we will be able to sample approximately 500 plots, allocated among the classes of vegetation types defined (Table 9). This sample will be proportionally consistent with the USGS-NPS accuracy assessment standard but short of the number of plots required to fully meet the standard.

In order to fully meet the USGS-NPS accuracy assessment standard, we would need to sample approximately 1,000 plots as detailed in Table 10. Sampling 1,000 plots will require approximately 100 days (production rate of 10 plots per day) and cost approximately $61,000. While the larger sample would most likely meet the standard completely, it may not be possible to complete the work within one summer's field season, complicating and prolonging the assessment more than is practical in our opinion.

Table 10. Estimated number of vegetation types, samples per type and total samples to be obtained across the map to be produced if the USGS-NPS Accuracy Assessment Standard is met.

Class of Vegetation Type	*Number of Types in the Map*	*Required Samples per Type*	*Total Samples Required*
Abundant, NPS Scenario A	29	30	870
Relatively Abundant, Scenario B	6	20	120
Relatively Rare, Scenario C	1	20	20
Rare, Scenario D	1	5	5
Very Rare, Scenario E	1	3	3
TOTAL	38		1018

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Internet location - http://biology.usgs.gov/npsveg/aa/aa.html

Visual Learning Systems
2006. Image Analyst Software, Internet location-
http://www.featureanalyst.com/index.htm

APPENDIX. Detailed Information about the satellite images used for mapping.

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Company Information

Address

Space Imaging
12076 Grant Street
Thornton, Colorado 80241
U.S.A.

Contact Information

On the Web: http://www.spaceimaging.com
Customer Service Phone (U.S.A.): 1.800.232.9037
Customer Service Phone (World Wide): 301.552.0537
Customer Service Fax (World Wide): 301.552.3762
Customer Service Email: info@spaceimaging.com
Customer Service Center hours of operation:
Monday - Friday, 7:00am - 11:00pm Eastern Standard Time

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Product Order Metadata

Creation Date: 09/04/03
Product Work Order Number: 00079639
Product Order Number: 118966
Customer Project Name: Whiskeytown Mosaic
Ground Station ID: PGS
Product Order Area (Geographic Coordinates)
Number of Coordinates: 176
Sensor Type: Satellite
Sensor Name: IKONOS-2
Processing Level: Orthorectified
Image Type: PAN/MSI
Interpolation Method: Cubic Convolution
Multispectral Algorithm: None
Stereo: Mono
Mosaic: Yes
Seam Feathering: No
Tonal Adjustment: Yes
Map Projection: Universal Transverse Mercator
UTM Specific Parameters
Hemisphere: N
Zone Number: 10
Datum: NAD83
Product Order Pixel Size: 1.00 meters
Product Order Map Units: meters
MTFC Applied: Yes
DRA Applied: Yes
Media: CD

Product Media Format: CD
File Format: GeoTIFF
  TIFF Tiled: No
  Bits per Pixel per Band: 11 bits per pixel
Multispectral Files: Separate Files

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Source Image Metadata

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Product Image ID: 000
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Scan Azimuth: 180.04 degrees
Scan Direction: Reverse
Panchromatic TDI Mode: 13
Nominal Collection Azimuth: 3.2258 degrees
Nominal Collection Elevation: 72.24467 degrees
Sun Angle Azimuth: 144.5598 degrees
Sun Angle Elevation: 65.66101 degrees
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Percent Cloud Cover: 0

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Product Image ID: 000
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  Along Scan: 0.85 meters
Scan Azimuth: 0.04 degrees
Scan Direction: Forward
Panchromatic TDI Mode: 13
Nominal Collection Azimuth: 350.0238 degrees
Nominal Collection Elevation: 79.55445 degrees
Sun Angle Azimuth: 144.8943 degrees
Sun Angle Elevation: 65.74453 degrees
Acquisition Date/Time: 2003-07-25 19:19 GMT
Percent Cloud Cover: 0

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Product Image ID: 000

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Scan Direction: Reverse
Panchromatic TDI Mode: 13
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Nominal Collection Elevation: 84.54680 degrees
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Sun Angle Elevation: 65.83419 degrees
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Percent Cloud Cover: 0

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  Y Components: 1
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    Coordinate: 2
    Latitude: 40.7161279916 degrees
    Longitude: -122.7300835941 degrees
    Coordinate: 3
    Latitude: 40.7152545729 degrees
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    Longitude: -122.4774469293 degrees
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  UL Map Y (Northing): 4507280.38 meters
Pixel Size X: 1.00 meters
Pixel Size Y: 1.00 meters
Product Order Map Units: meters
Columns: 21456 pixels
Rows: 19588 pixels

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Product Component Metadata

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    Longitude: -122.7307930883 degrees
    Coordinate: 2
    Latitude: 40.7161279916 degrees
    Longitude: -122.7300835941 degrees
    Coordinate: 3
    Latitude: 40.7157601909 degrees
    Longitude: -122.6027970783 degrees
    Coordinate: 4
    Latitude: 40.5393086214 degrees
    Longitude: -122.6038411360 degrees
Component Map Coordinates (in Map Units)
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  UL Map Y (Northing): 4507280.38 meters
Pixel Size X: 1.00 meters
Pixel Size Y: 1.00 meters
Product Order Map Units: meters
Columns: 10752 pixels
Rows: 19588 pixels

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Product Image ID: 000
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Thumbnail File Name: po_118966_rgb_0000100_ovr.jpg
Country Code: US
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    Longitude: -122.6038293277 degrees
    Coordinate: 2

Latitude: 40.7157601502 degrees
Longitude: -122.6027852389 degrees
Coordinate: 3
Latitude: 40.7152545729 degrees
Longitude: -122.4760697983 degrees
Coordinate: 4
Latitude: 40.5388061239 degrees
Longitude: -122.4774469293 degrees
Component Map Coordinates (in Map Units)
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UL Map Y (Northing): 4507280.38 meters
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Pixel Size Y: 1.00 meters
Product Order Map Units: meters
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