California State University, Chico

Methods For Vegetation Mapping in the Cascade/Sierra Nevada Foothills: A Case Study of Big Chico Creek Watershed, Chico, California.

Project

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Abstract

Vegetation mapping has become a mainstay of ecological research. Current regional vegetation maps (i.e. USGS GAP maps) lack either the grain or extent needed to conduct landscape level studies. Currently, efforts are being made to map fine-scale vegetation from remotely sensed images over a larger geographic area. One such project is being conducted by Dr. Todd Keeler-Wolf of the California Fish and Game, vegetation mapping laboratory and the California Native Plant Society (CNPS). This project will map the vegetation complexity of the Cascade/Sierra Foothills at the vegetation association level covering an elevation band of 60-625 meters between Shasta and Kern counties. In order for such studies to be feasible methods for mapping vegetation rapidly and accurately must be derived.

This project is a pilot study for creating alliance level vegetation datasets from remotely sensed imagery using a geographic information system (GIS). A grant from the Bidwell Environmental Institute (BEI) financed the creation of this pilot study. The project site, located within the Big Chico Creek watershed in Chico, CA, represents a transition zone between granitic Sierran land forms to the south and the volcanic Cascadian land forms to the north. This transverse canyon, which encompasses over 4,507 continuous hectares, represents an environmental gradient (Whittiker 1965) from the Sacramento River Valley to the southern Cascade foothills. The project areas utility is furthered by its accessibility from city and state owned lands and highly variable vegetation distribution. Although studies like this have been done in the past (Throne et

al 2004) none have been done to fine-scale vegetation detail in the Northern Californian Cascades.

Another focus of this pilot study was to utilize data that could either be obtained at nominal or no cost. This was accomplished by interpolating vegetation cover from a 2005 National Agriculture Imagery Program (NAIP) 1 meter resolution air photos which are available under public domain. ESRI's ArcGIS software and a Waicom Digitizing monitor were used to derive vegetation polygons in a heads-up-digitizing process[1] similar to that of Throne (et al. 2004), by having the aerial photo be a screen backdrop to which other ancillary datasets could be overlaid to provide interpretation assistance. The air photo interpretation process was supplemented by using side looking radar in the form of a 5 meter resolution Digital Terrain Model (DTM) and a Digital Surface Model (DSM) radar data sets from Intermap Inc. to produce a vegetation height model (Xu, et al. 2006). Using the side looking radar is more expensive than using the readily available 30 meter USGS Digital Elevation Model (DEM) with the Shuttle Radar Topographic Mapping 30 meter DTM data as outlined in Xu et al. (2006), however the utility of a higher resolution vegetation height model for mapping at the alliance level justifies the cost.

Based on relevant literature (Throne et al.) and CNPS protocols, a Minimal Mapping Unit (MMU) of 1 hectare (10,000m^2) was used for the majority of the study area. The resulting polygons (n=872) from the air photo interpretation were attributed with both primary and secondary vegetation classes. The primary vegetation class reflects the polygons alliance level classification according to the Manual of California

[1] Heads-up-digitizing requires that vegetation polygons are interpreted on the air photo within the Arc GIS software package

Vegetation (MCV) (Sawyer and Keeler-Wolf 1995). The secondary vegetation class reflects either understory vegetation (i.e. grass or shrubs) or other observable canopy species. Digitizing vegetation polygons from air photos requires that astute attention is paid to in tone, texture, and color to differentiate between alliance types.

An air photo interpretation key was made using a GPS unit to collects reference points that reflected each alliance type. It is worth mentioning that knowledge obtained form these preliminary field visits is paramount to understanding the complex vegetation alliances of the Sierra Nevada foothills. Using the air photo interpretation key polygons were created for a vegetation types if over 50% of that polygons area was covered. An alliance with two vegetation types (i.e. Live/Blue Oak) indicates that both species have equal presence within the polygon. If a subspecies was observed, but not over 50% cover it was listed in the secondary cover attribute.

Currently the Big Chico Creek Vegetation Map contains 872 vegetation polygons representing 23 different alliance types. A final error assessment of the map proved that accurate vegetation datasets can be produced for aerial photographs. The methods used to produce this dataset can be replicated to produce similar datasets for the rest of the Sierra Nevada foothills.

CHAPTER I

INTRODUCTION

Project Organization

This project is organized into three chapters. The first chapter introduces the reader to the project by clearly stating the objectives, defining the problem, and defining the area of study. The first chapter also contains a review of relevant literature. The second chapter outlines how the project was conducted. This technical design includes the rationale for the project as well as an outline of data acquisition and the construction of a data dictionary. The third and final chapter contains the findings of the project along with a discussion of these results.

Objectives

The aim of this project is to: (a) build a fine-scale vegetation map at the alliance level of California State University, Chico's Big Chico Creek Ecological Reserve (BCCER; BCCER 2008)), and the City of Chico's upper section of Bidwell public park (City of Chico 2008) and the adjoining Bidwell Ranch mitigation property from digital ortho color aerial photography; (b) field test the derived map to ensure accuracy; and, (c) establish a vegetation database legacy in a GIS form for the Big Chico Creek watershed of which the study properties are apart. The legacy data will be available to others who wish to conduct research within the project area. The data will provide a basic understanding of the ecosystems within the project area as well as aid in the establishment of long-term species and ecosystem monitoring plots.

The Problem

Creating accurate and appropriate vegetation maps is one of the first steps in conducting ecological research. Recent advances in GIS allow researchers to map vegetation using fine-grained remotely sensed data (Throne et al. 2004; Xu and Pu 2003). Vegetation cover can be seen as an expression of both underlying abiotic variables such as slope, aspect, solar radiation, soils, and hydrology, and disturbance (i.e. fire, logging, earth slides, flooding, etc.). This project will focus on the use of the abiotic variables and remotely sensed radar and visible data, expressed as raster datasets, to help interpret the existing vegetation cover from aerial photographs, where appropriate disturbance data covering fire and past logging influences will be employed. Methodologies used in this project, particularly the classification system, will allow the final map to be incorporated into the preexisting California Native Plant Societies (CNPS) database, and the larger Cascade/Sierra Nevada Foothills project (California Fish and Game). The expansion of larger regional databases will aid geographers, ecologists, and natural resource managers by allowing them to conduct more detailed studies across a broader landscape.

Study Area

The study area, located 39º 46’ 20” N 121º 46’ 54” W in Chico, CA, represents a transition zone between granitic Sierran land forms to the south and the volcanic Cascadian land forms to the north. The Big Chico Creek watershed as a transverse canyon can also be seen as an environmental gradient (Whittiker 1965) from the Sacramento River Valley to the southern Cascade foothills of Mt. Lassen. The study areas utility as a pilot location is furthered its accessibility from the city of Chico and state owned lands and highly variable vegetation distribution.

The project area is comprised of the Big Chico Creek Ecological Reserve, Upper Bidwell Park, and Bidwell Ranch encompassing over 4,507 continuous hectares of land. The boundary line for the project area was created by using four previously existing boundaries: (1) the California Department of Fish and Game watershed; (2) Upper Bidwell Park; (3) Bidwell Ranch; and (4) Big Chico Creek Ecological Reserve. Merging these boundaries to create the project area ensures that the final data set is useful to more than one party. For the purpose of this project the merged boundary will be referred to as the project area (Fig. 1). The larger study area also follows a current shift to map along environmentally meaningful boundaries. In this instance, much of the Big Chico Creek lower to middle watershed was captured in the projects study area.

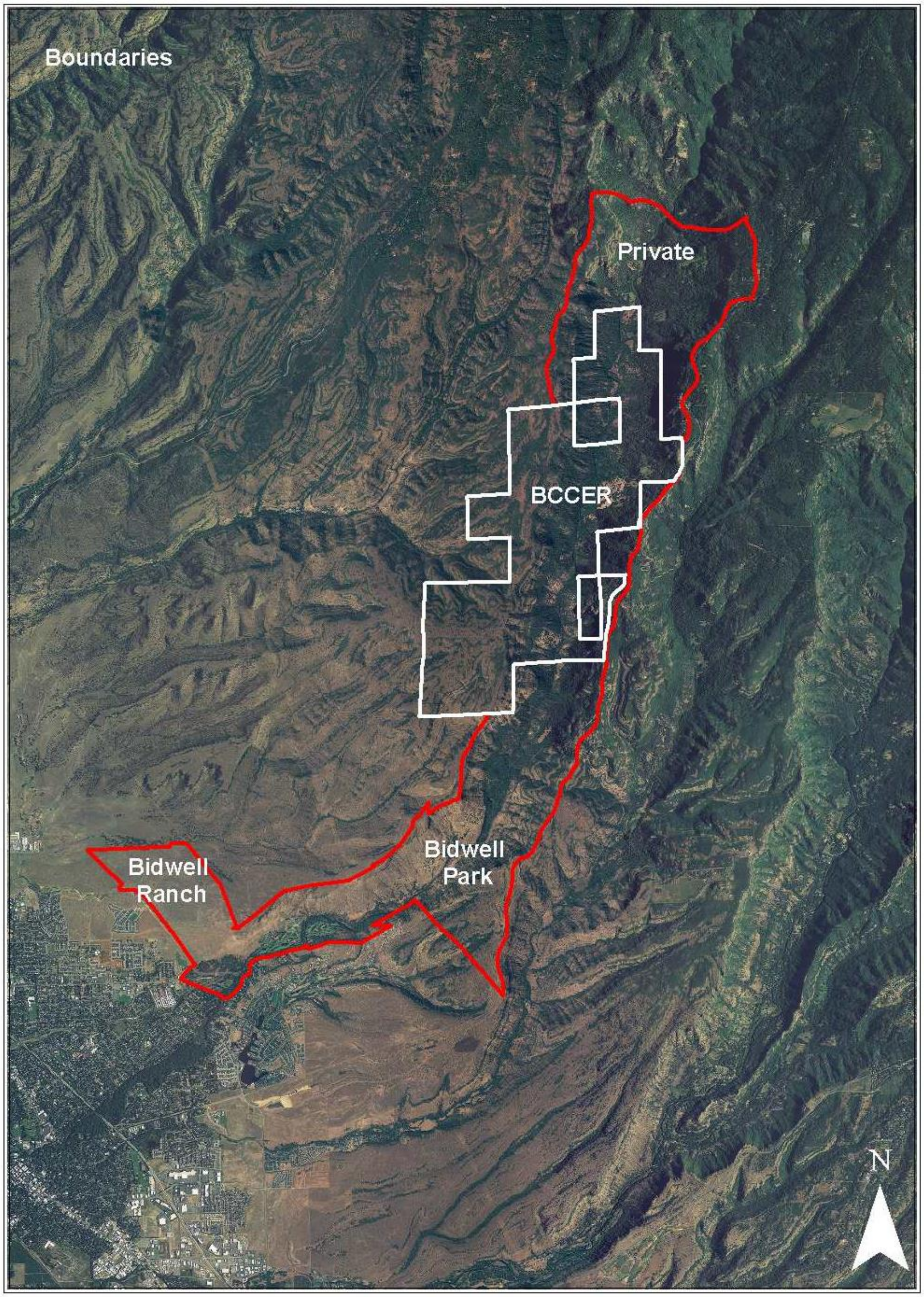

Figure 1

BACKGROUND

In 1997 Dr. Don Holtgrieve organized funding to purchases the 4,000 acres of land that became the California State University, Chico Big Chico Creek Ecological Reserve (BCCER). By organizing funding through grants Dr. Holtgrieve, along with his colleague Susan Gibbs (then head of the Big Chico Creek Watershed Alliance), developed and submitted grant applications to agencies such as the US Fish and Wildlife Service California Fish and Game, US Fish and Wildlife Foundation, and the Packard Foundation. The resulting grants, managed by the University Foundation, allowed the BCCER to be purchased in two sales at market value (Holtgrieve 2007). The reserve is owned by the California State University Chico Research Foundation, and is managed by the Bidwell Environmental Institute (REF), which is now be renamed the Institute for Sustainable Development.

Along with the BCCER the project area also consists of portions of the adjacent Upper Bidwell Park and Bidwell Ranch. Bidwell Park was deeded to the City of Chico by Annie Bidwell in 1905. Since then, the City of Chico has purchased land adjoining Annie Bidwell's original grant. Currently, Bidwell Park encompasses 1,485 contiguous hectares (City of Chico 2007). Bidwell Ranch was recently purchased by the City of Chico. This adjacent area lies directly north of Upper Bidwell Park and contains the Chico vernal pool complex (REF), a habitat that is utilized by *Limnanthes floccosa ssp. california* (Butte County Meadowfoam) which is endemic to Butte County. In order to preserve this unique habitat, the City of Chico plans to use the site as a mitigation bank for local developers. Mitigation Banks allows developers to offset a portion of the environmental cost of their projects by helping preserve pristine natural landscapes.

Land Use

A key concept in geography is studying how humans interact with their landscape. This human environmental interaction can be observed through changes in land use over time. The first humans to interact with the study area were the indigenous Native Americans. The Konkow, or Northwestern Maidu, used the study area primarily for hunting and fishing as well as gathering acorns from the native oaks. Signs of this interaction can still be seen within the study area in the form of mortar holes and by the presence of stone tools (BCCER 2007).

Later settlement of the study area by non-indigenous peoples subjected the landscape to both logging and cattle grazing, as well as accidental wildfires. These two activities influenced the current vegetation arrangement of the canyon and continued until the BCCER and Upper Bidwell Park were established (BCCER 2007). This human environmental interaction has influenced the canyon's vegetation into the expression we see today.

Other influences on vegetation patterns in the canyon are natural and non-natural disturbance regimes. The disturbance regime that is commonly related to vegetation is fire. Ponderosa pine forests have been shaped by fire regimes long before European colonization (REF). These fires were often small surface fires that burned off understory vegetation without affecting the range and distribution of the mature pine forest (Keely 2001). The modern trend to suppress low intensity fires coupled with the effects of historic logging have influenced the current vegetation distribution in the study area (Mott 2007). This background information, as well as a review of the relevant literature, helped inform the project as to how to capture this heterogeneous and dynamic vegetation distribution in a vegetation dataset.

LITRATURE REVIEW

Intro

Geographers and landscape ecologists study the earth's surface and the processes which reshape it. This literature review uses sources from both disciplines in order to place importance on the production of vegetation maps. Another group, nature reserve managers, are tasked with understanding how these ecological processes affect landscape change, and then making use of this knowledge to actively manage the surrounding landscape. This task is becoming increasingly hard as the amount of natural landscapes shrinks due to development by humans, and as anthropogenic impacts, such as climate change, alter landscapes that have previously been set aside for conservation (Lindenmayer et al. 2008).

To help nature reserve managers manage current reserves, as well as effectively site new ones, ecologists use vegetation maps and datasets first catalogue existing conditions of biologic resources, and later to quantify these changes against a known baseline (i.e. the previous existing conditions; Lindenmayer et al. 2008). One way to aid nature reserve manages in managing multiple environmental indicators is the production of vegetation maps and datasets (Fairbanks 2000). The creation of ecological data sets for natural resource management requires an understanding of both geography and ecology. This project seeks to apply this knowledge by creating a vegetation map and corresponding data set using the tools of GIS and remote sensing.

Geography and Ecology (Vegetation Science)

Vegetation mapping has its roots in both geography and landscape ecology (REF). Both sciences agree that an understanding of the distribution of plant communities, as well as how they change, is a key component of ecological research. Landscape ecology provides the foundation for natural resource management (Simmering et al. 2006; Weins 2005; Gutzwiller 2002; Liu and Taylor 2002), as well as being commonly recognized as the provider of a theoretical foundation for nature conservation (Simmering et al. 2006; Hansson and Angelstam 1991). This theoretical foundation is further strengthened by the work of geographers who supplement studies in ecology by including anthropogenic influences in landscape observation. The works of early biogeographers, and later contributions by physical and human geographers, have influenced the way contemporary geographers and landscape ecologists interpret landscapes and ecological processes.

Understanding ecological process allows observations of changes in our natural environment to be used to predict future changes to ecological communities. Our understanding of ecological process is grounded in previous studies on ecological communities (Clements 1916); plant communities (Gleason 1917, 1922, 1926); pattern and process of plant communities (Watt 1947); equilibrium theory of island biogeography (MacArthur and Wilson's 1967); community continuum-environmental gradients (Whittaker 1972); disturbance (Turner 1993, 1989); and ecological process observation via spatial pattern (McGarigal and Marks 1995). These studies show a continual progression towards understanding complex landscapes from studying individuals and their species interactions, compiling that knowledge to the landscape scale, and then quantifying this change though the use of new tools (such as spatial models and statistical packages).

Studying landscape level change requires the development of new methods including spatial models to predict vegetation cover (Simmering et al. 2006, Xu et al. 2006, Hupy et al. 2005, Faribanks et al. 2000, Faribanks 2000, Ohmann and Spies 1998, Frederiksen and Lawson 1992, Davis and Goetz 1990), vegetation maps (Throne et al 2004, Kuchler 1974). To use these methods, or developing new ones one must focus on three words: process, pattern, and scale.

Scale, Process, and Pattern

The study of ecology is grounded in the observation ecological patterns. To define these patterns ecologists use the paradigms of spatial scaling and ecological process. The production of vegetation maps requires that each of these constructs be observed simotaiously so that the spatial pattern, in this case vegetation distribution, can be detected.

Scale

A key component to observing ecological processes is realizing that it is scale dependent. Changing the extent, (size of the study area); grain (the finest level of spatial extent) often referred to as Minimal Mapping Unit (MMU); can change the observations of ecological process (Weins 1989). Weins (1989) makes another important observation when he compares the ecologist's conception of scale to that of a geographer. Ecologists see 'large scale' as pertaining to the size of the study area, while geographers see 'large scale' in reference to map scales, which are expressed as ratios (ie. 1:24,000) which represent resolution. This may explain the disparity between these two sciences until recently.

The link between scale and ecological pattern was not realized by early biogeographers and ecologists. Historic studies in ecology and biogeography were conducted, with little attention give to the effects of scale (Wiens 1989). The resulting studies could not be compared because ecological patterns observed at one scale rarely were repeated at another. To make matters worse, bigogeographers and ecologists were defining scale in conflicting ways.

Sayre (2005) further explains the miscommunication between ecologists and geographers in his article, *Ecological and geographical scale: parallels and potential for integration*. Sayre attempts to unite the fields of geography and ecology by focusing on the need for each field to include scale in their research topics. Sayre shows that studies in human geography have the same fundamental problems as those in physical geography and ecology in that scale of the study often influences the results. The solution for this problem, according to Sayre, is for human geographers to use the scale model provided by ecologists.

Once spatial scale was defined, and agreed upon, studies showed that the extent and grain of a study could influence the results. This notion is furthered by Turner (et al. 1989) who state that processes observed at one scale are rarely repeated at another. Using multiple scales to observe spatial phenomenon can only be achieved if fine grain data (i.e. 1 ha or smaller MMU) is collected for the entire study area. Only then can researchers compare and combine results in studies using different scales, eventually allowing data to be scaled-up for studies of larger regions.

To ensure that the proper scale is used researchers are encouraged to sample at the finest grain possible. Results can then be scaled up (types of oak trees can be defined as oaks, then further defined as trees. However if data was just collects as trees one could not define separate oak species). Turner (et al. 1998) shows that the use of fine grained data alone does not ensure that the spatial pattern will be captured as the distributions of species occur at different spatial extents. While grain size will ensure interoperability between data sets, scale will dictate how the ecological process is observed (Wines 1989).

It has been recognized that the shifting mosaic steady-state concept of vegetation distributions is problematic as a general function of landscapes. First, the concept seems to be applicable only when disturbances are small and frequent in a large area of homogeneous habitat (Pickett 1985). Second, large areas may be more likely than small areas to exhibit a stable mosaic (Turner 1993; Conell and Sousa 1983; DeAngelis and Waterhouse 1987; Zedler nd Goff 1973). Showing that scale must constantly be considered when studying ecological process. Landscapes that appear to be highly fragmented at larger scales appear homogeneous at smaller scales. We must then view ecological processes within the context of scale.

Process

Understanding ecological processes is a key component in addressing ecological pattern. Ecological process represents environmental change that occurs within a landscape as reflected by the change in individuals with that landscape. An environmental change, such as temperature, availability of moisture, or disturbance regimes, can often be observed as a change in vegetation due to the low mobility and sensitivity of plant species. These changes in environment, or ecological process, drives plant community dispersal (Addicott 1987). The ways in which biogeographers and ecologists thought about ecological process have continued to change.

Ecologists have not always seen ecological process as a continual manipulator of landscape pattern. Instead, focus was placed on the idea of landscape reaching an equilibrium, or climax community (Egerton 1973; Bormann and Likens 1979; Connell and Sousa 1983; Weins 1984; DeAngelis and Waterhouse 1987; Turner 1993). Once a community reached it climax state it would stay suspended there until a disturbance reset the cycle. This theory was challenged by those who believed that communities were constantly evolving.

As Sprugel (1991) writes, “The idea of a landscape suspended in dynamic equilibrium by balancing disturbance and recovery is attractive because it provides some sense of constancy even in the presence of persistent change” (Sprugel 1991). The idea of dynamic equilibrium may be too simple an explanation of ecosystem dynamics. Different disturbances can lead to different responses. The idea of an ecosystem as a ‘shifting steady state’ (Bormann and Likens 1979) presents researchers with a moving target because landscapes are constantly being changed by disturbance and the ecological responses (Delcourt and Delcourt 1991). Studies in ecology must then be seen as a snapshot of the landscape at any given time. Ecologists and geographers realize that ecological process, or the frequency of the change in a landscape, is a critical factor in landscape observation.

Along with frequency of change, researchers must also consider the historic uses of the land and how past land use practices affect the current arrangement is vegetation.

The distinction between urban, agricultural, and forested land controls how we observe natural and anthropogenic processes. For example landscapes can be altered by disturbances such as fires, insect attacks, and windstorms (Baker 1989; Pickett and White 1985).

Pattern

After scale and process are understood one can detect ecological patterns. Ecological processes can become recognizable through observations in spatial pattern, such as vegetation (McGarigal and McComb 1995; Turner 1989). This "quantification of spatial pattern is necessary to link the effects of landscape heterogeneity with ecological function and to use remotely sensed data to measure change in large spatial units" (Turner 1989). Turner has noted that studies in "patch size (Gardner et al. 1987), fractal dimension (Krummel et al. 1987), edges (Turner 1987b), diversity (Romme 1982; Romme and Knight 1982), and indices of dominance or contagion can all be used to quantify landscape pattern" (Turner 1989).

Vegetation Mapping Methods

The methods we use to map vegetation distributions are changing in response to the ever-changing classification systems. Previous studies have estimated vegetation cover one of three ways: manually interpreting aerial photographs (Nowak et al. 1996; Kuchler 1974): digitally interpreting air photos (Throne et al. 2004); interpolating vegetation cover using abiotic variables (Ohmann and Spies 1997). These methods are used because conducting field work is not cost effective for covering large forested areas (Xu et al. 2006). This review will focus on air photo interpretation and spatial modeling as remote sensing techniques to be used in vegetation mapping.

Spatial Models

To ensure that ecological processes are represented at the appropriate scale, landscape ecologists have developed the spatial model. Spatial models show the interactions between ecological processes and the spatial distribution of ecological variables. These distributions can be seen as a pattern observed across the landscape often represented as raster pixels or vector polygons on the computer screen. The interpretation of pixels and polygons for researchers to see spatial patterns requires the production of vegetation maps otherwise known as vegetation models.

Since spatial models require large amounts of data, recent advances in computer technology, remote sensing, and GIS make it easier to obtain and manipulate spatial data. However, these technical advances are only useful if the underlying ecological process is understood. Therefore our understanding of ecological process dictates the accuracy of our spatial models (Baker 1989). To achieve accuracy, we need sound methodologies which carefully consider the extent and grain when modeling ecological process.

Remote sensing/GIS

To make use of classification systems the production of vegetation mapping is necessary. This exercise links the tablature data collected to spatial geometry. Giving you a species range or distribution. Baker's (1989) article, *A review of models of landscape change*, illustrates the concerns of ecologists during the early 90s when GIS were just starting to be utilized to study ecologic processes. Although the article is dated given the advances in GIS since its publication, it is still relevant to developing current ecologically focused GIS databases.

GIS provides an excellent tool set for observing ecological process since vegetation distributions are constantly changing the dynamics of plant communities

(Addicott 1987). To observe these changes we can rely on modern technology, such as GIS and remote sensing. According to Fairbanks (2000):

> "GIS, remote sensing, and statistical analysis make it possible to study the inter-relationship of scale, pattern, and process, and how they relate to the grain and extent of landscape measurement and observation within hierarchically nested systems"

Although technology enables us to study this phenomenon much work is still needed to collect the necessary supporting field data. Methodologies for data collection, such as the ones outline later in this project, will allow the efforts of researches to grow exponentially as more studies are conducted.

Use of Vegetation Maps as a building block for other Studies (Natural resource management)

Summation of Literature

The sciences of geography and ecology agree on the need for a defined scale for landscape level studies. Using finer grain size will allow researchers to compare and combine results in studies of differing scales and extents. This will eventually allow data to be scaled-up for studies of larger regions (Throne et al. 2004).

We realize the species distributions are governed by 'ecological neighborhoods,' or in our case, vegetation alliances (Addicott 1987). We can derive a reflection of ecological process by using GIS and remotely sensed data. Capturing this process is only possible if a series of vegetation maps are produced at defined time intervals. The production of vegetation maps over time will allow researchers to observe other ecological processes as they constantly change the vegetation distribution in and around the study area.

CHAPTER II

Experimental design

Introduction

This project is a pilot study for creating alliance level vegetation datasets from remotely sensed imagery using a GIS. Although studies like this have been done in the past, (Throne et al 2004) none have been done in the Cascade foothills landscape. This study places importance on the ability of the final vegetation map to fit within preexisting lager scale maps produced by the California Native Plant Society (CNPS) and other federal, state, and local databases. This will be accomplished by using the Manual of California Vegetation (MCV) classification system to define vegetation polygons (Keeler-Wolf 1995). This classifications system is used by the CNPS and also contains crosswalks to other commonly used systems, allowing the data to be later scaled up and included in regional datasets.

Typically, vegetation maps are generated by either (1) producing spatial models to predict vegetation, or (2) using air photos to interpret vegetation cover. This study will be unique in its use of abiotic variables, expressed as GIS data layers, to aid in air photo interpretation. This can be seen as using a spatial model as part of an air photo interpretation key. These abiotic variables are used in conjunction with CNPS rapid assessment field plots and existing vegetation maps in GIS format to further aid researchers in interpolating vegetation cover form National Agriculture Imagery Program (NAIP) aerial photographs. Methods derived from Xu et al. (2006), Throne et al. (2004) and Gong (2002) are used as a basis for constructing vegetation polygons from remotely sensed data.

Rational

A previous study conducted by Throne (et al. 2004) used the United States Geological Survey's (USGS) Digital Ortho Quarter Quadrangle (DOQQ) imagery to map Napa County's vegetation distribution. Polygons were drawn in a 'heads-up digitizing' format to classify vegetation using the MCV classification system (Sawyer and Keeler-Wolf 1995). The study successfully mapped the counties vegetation by creating 28,456 polygons with a Minimal Mapping Unit (MMU) of under 1 ha.. Throne's study was able to discern 15 more vegetation types than the previous map by CalVeg and 22 more vegetation types than Gap Analysis Programs' (GAP) map (Throne et al. 2004).

The vegetation map of the Big Chico Creek watershed will use Digital Surface Model (DSM), Digital Terrain Model (DTM), and high resolution (1m) color aerial orthorectifid imagery to aid in air photo interpolation (Fig. 2). This project hopes to produce a vegetation map that maintains the 'realistic looking vegetation polygons' similar to Throne's et al. study while mapping a more heterogeneous landscape.

Methods of Analysis

Spatial Scale

This project is designed so that it encompasses three differing spatial scales, beginning with the watershed. Although the study area boundary is not entirely derived from watershed boundaries, it represents a large section of the Big Chico Creek watershed, as defined by the USGS hydrologic units, as its outer boundary. This allows for an expansion of the project for whole watershed analysis to be conducted by connecting it to the California Native Plant Society's (CNPS) preexisting framework. Sampling within watersheds is practical because it provides a range of environmental

Figure 2 DTM DSM AND Airphoto

variability that is constrained to an ecologically meaningful, yet manageable, boundary. Additionally, "sampling within watersheds can help control for the effects of broader scale patterns in climate, fire history and land use history" (Meentemeyer and Moody 2000). Mapping at this scale ensures an ecologically meaningful project extent.

The second scale further subdivides the project area into alliances of vegetation using the Manual of California Vegetation (MCV) alliance divisions. Aliances represent dominant species, or codominant species which largely influence surrounding vegetation and species composition. Because these alliances represent not only plant communities, but also the species associated with them, this scale lets ecological process dictate the boundaries.

The final division of scale is the Minimal Mapping Unit (MMU), or the grain size of our data. The MMU is derived from the resolution of the data. Five meter Digital Terrain Model (DTM) and Digital Surface Model (DSM) data will allow us to comfortably map vegetation in 10m grid squares using terrain and canopy characteristics. Vegetation polygons are constructed with a one hectare MMU. This one hectare MMU was further subdivided when ecologically meaningful communities could be detected, such as grasslands or riparian zones. The use of these three spatial scales allows for a vegetation maps that captures fine grained data (MMU) that can be scaled up to fit within course grained regional studies.

Data Collection Procedures

Sampling strategy is a critical element of field-based landscape ecology **(**Meentemeyer and Moody 2000, Stohlgren et al. 1997). Data collection for this project expanded upon the methodologies of Throne et al. (2004) by augmenting them with color imagery, and Digital Terrain Model (DTM) and Digital Surface Model (DSM) radar data.

This study also differs from Throne et al. (2004) due to the extensive use of point data in the form of CNPS rapid assessment, releve inventory, and alliance level field surveys. The use of existing field CNPS rapid assessment field surveys as well as the higher quality data allows new methods to be used to produce a vegetation dataset for the project area.

Point Data

It must be clearly noted that first hand knowledge of the study area was a crucial factor in completing this project. Field visits were captured as point data using a Global Positioning System (GPS). GPS points were assigned a number corresponding to a field note. Field notes were composed of (1) species present within one hectare of the point, (2) alliance, (3) secondary canopy species, (4) level of cover (ie woodland, sevana, forest, etc.).The field notes and GPS points were then synthised in a GIS to act as an aerial interpretation key.

To begin several field surveys were conducted by the air photo interpreter accompanied by a field biologist (Scott Gregory) to learn how to identify the different plant species of the study area (List of all identified plant species). During these visits a Garmin E-Trex Legend GPS was used to record changes in vegetation at the alliance level by creating waypoints. These changes in vegetation were often linked to environmental variables (slope aspect elevation) or changes in substrate.

For each field survey a waypoint was created using the GPS augmented by accompanying notes in a field notebook. These notes and waypoints would later be combined in the lab using GIS to create a point shapefile with the field notes in the attribute table. This process also worked the other way around. If a vegetation polygon could not be classified for a given area the UTM would be recorded, then to a field survey would be conducted to classify the unknown area. This process was driven by changes in the environment, not a pre determined sampling strategy. The GPS points and accompanying field surveys were then imputed into the GIS and acted as a photo interpretation key.

The collection of point data also allows for statistical analysis and accuracy assessment to occur. The Big Chico Creek project will use tabulated vegetation data collected by the CNPS and a geography class (GEOG 444), as well as data collected from the study area by the researchers to provide a basis for statistical analysis and accuracy assessment (*see accuracy assessment*).

GIS

Interpretation of vegetation polygons was implemented using ESRI ArcGIS 9.1, ESRI ArcView 3.3 and a Waicom backlit digitizer on a Dell Optiplex GX 620I in the CSU, Chico Geography Department Computer Lab. The use of a GIS allows raster data (air photos, DSM, and DTM) and vector data (points, and vegetation polygons) layers to be accessed and overlaid in one software package. Advances in digitizing tablets now allow for vegetation polygons to be digitized on a touch sensitive screen in which air photos are displayed in the background. This process is commonly referred to as 'heads up digitizing'. The heads up digitizing process allows air photo interpretation to occur more rapidly.

Available Data

The following data sets were available to augment air photo interpretation of vegetation polygons:

Table 1. Data dictionary for BCCER and Upper Bidwell Park vegetation legacy database

Theme name	Feature type	Data Source	Scale/projection	Accuracy	Attribute items used	Attribute item source if known
Vegetation	Poly	CSU Chico	1:3,000 UTM Zone 10, NAD83	Minimal Mapping Unit: 1 hectares	Cover I, string Cover II, string	Based on 2005 aerial photography
NAIP_2005_Butte	Imagery	National Aerial Imagery Program, USDA	1 meter resolution UTM Zone 10, NAD 83	Horizontal: 2-3 meters	Not required	Photography taken April 2005 for entire county
Study boundary	Poly	BCCER, City of Chico	1:10,000 UTM Zone 10, NAD83	Horizontal: 1 meter	Not required	BCAG
Calwater	Poly	California Interagency Watershed Mapping Committee	1:100,000 UTM Zone 10, NAD83	See XML for details	Catchment code	USGS
CDF_Fire	Poly	California Department of Forestry and Fire Protection	1:24,000 UTM Zone 10, NAD 83	Hoizontal: 30 meters	Date	Not known
Soils	Poly	National Resource Conservation Service	1:10,000 UTM Zone 10, NAD 83	Horizontal: 10 meters	Name/series	Aerial photography and field survey
CNPS_GEOG_Veg_points	Points	California Native Plant Society Sierra Foothills Project Dean Fairbanks	UTM Zone 10, NAD 83	Horizontal: 3-7 meters	Alliance	Field Survey 2005-2006
Maslin_veg	Points	BCCER Paul Maslin	1:? UTM Zone 10, NAD83	Horizontal: 10 meters	Veg_type	General Field Survey
Senock_ponderosa_sites	Points	Dept. of Geosciences, Randy Senock	UTM Zone 10, NAD83	Horizontal: 3-7 meters	Location	General Field Survey

Murphy_springs	Points	Dept. of Geosciences, Michael Murphy	UTM Zone 10, NAD83	Horizontal: 3-7 meters	Location	Masters Thesis Field Survey
Elevation	Raster	Intermap Technologies, Colorado Springs, CO	5 meter resolution UTM Zone 10, NAD83	Horizontal: 5 meter Vertical: 1 meter	Elevation cell value, ratio	Radar

Construction of Vegetation Polygons

Vegetation polygons were produced by interpolating vegetation cover from a 2005 National Agriculture Imagery Program (NAIP) 1m² air photo. Using ESRI's ARC GIS 9 and Waicom Digitizing monitor vegetation polygons were derived in a heads up digitizing process similar to the one used by Throne (et al. 2004). The air photo interpretation process was supplemented by using the DTM and DSM radar data from Intermap Inc. to produce a vegetation height model (Xu, et al. 2006). The resulting polygons were attributed with both primary and secondary vegetation classes. The primary vegetation class reflects the polygons classification according to the MCV. The secondary vegetation class reflects either underlying vegetation (ie grass or shrubs) or other observable canopy species. Digitizing vegetation polygons from air photos requires that astute attention is paid to in tone, texture, and color to distinguish alliance types. This knowledge is then supplemented with data from abiotic variables such as slope, aspect, and elevation to further discern between vegetation types.

Based on relevant literature (Throne et al. 2004) and CNPS protocols, a minimal mapping unit (MMU) of 1 hectare (10,000m^2) was used for the majority of the study area. A polygon was created for a vegetation alliance if over 50% of the area was covered by that vegetation type. An alliance with two vegetation types (i.e. Live/Blue Oak) indicates that both species have equal presence within the polygon. If a subspecies was observed, but not over 50% cover it was listed in the secondary cover attribute.

To the extent possible the MMU was revised to a finer resolution ($100m^2$) for some habitat types such as riparian, springs, vernal pools. This change in MMU was necessary to capture theses unique vegetation distributions in our database because of their importance to the canyons ecosystem, vulnerability to anthropogenic disturbance, ability to act as environmental indicators. Changing the MMU in such cases is also is consistent with methods used by Throne (et al. 2004).

Digitizing Process

A digitizing session consisted of an MXD file with the DSM/DTM regression (to show vegetation height) and NAIP imagery displayed on the Wacom monitor. It is worth noting that the Wacom monitor produced a more accurate map due to the higher pixel count than a standard computer monitor. The increased resolution allowed a digitizing RF of 1:3000 to be used, a scale not possible on other computer monitors. The resolution of the screen combined with the NAIP imagery allowed air photo interpreters to identify vegetation at the individual level (i.e. as small as an individual Manzanita).

There were pitfalls to using the Wacom digitizing tablet. The tablet also was so accurate that it captured every small vibration in ones hand while digitizing. After adjusting both the sensitivity of the tables, and the pixels per inch in GIS editor tool bar a pleasant medium for digitizing polygons was reached. However, it was still necessary to convert the final shapefile into a coverage to ‘smooth’ the final vegetation polygons to create a ‘natural looking’ vegetation map. Also, the digitizing process produced small empty polygons as an artifact of the auto complete polygon function of the ARC GIS editor toolbar. Such polygons were deleted and filled when the final polygons were converted into a coverage.

Classification System

In order to map the complex vegetation of California the California Native Plant Society (CNPS) has derived its own sampling strategies and classification system. The *Rapid Assessment Protocol* (CNPS 2004) was derived to allow CNPS volunteers collect quantitative vegetation data in a standardized format. This standardized data collection format allows the CNPS to consolidate the information from across the state into one database. To further standardize the process a consistent classification system, *A Manual of California Vegetation* (MCV; Sawyer and Keeler-Wolf 1995), was adopted. The MCV not only provides standardization within the CNPS, it also has cross-walks to other commonly used classification systems such as the National Vegetation Classification Standard (NVCS; Throne et al 2004).

Other vegetation maps and datasets have used the MCV to classify their findings. Most recently, Throne (et al 2004) decided to use the MCV classification system for four reasons; (1) it is consistent with National Vegetation Classification Standard (NVCS) at the alliance level; (2) using this classification system extends the evolving NVCS to Mediterranean-climate ecosystem; (3) the MCV is an objective and repeatable classification system; and (4) the system allows new vegetation types to be proposed for inclusion.

Another important aspect of the MCV and CNPS's *Rapid Assessment Protocol* is the distinction between vegetation alliances and associations. The MCV defines an association as comprising of both the canopy and understory species. The association is a finer grained classification level which accounts for the change of shrub and herb species within consistent canopy species. A courser grain of classifying vegetation is the alliance (Sawyer and Keeler-Wolf 1995). The *Rapid Assessment Protocol* defines a vegetation alliance as limited to the canopy species, not taking any scrub or herb species into account (CNPS 2004). Vegetation interpretation for arial imagery best suited to the alliance classifications level as shrub and herb species are seldom visible in aerial photos.

Anouther benefit of using the MCV classification system to define vegetation alliances is the fact that the MCV in a continually evolving classification system. This ensures that it can easily be tailored to different environments and changes in vegetation mapping methods, as well as allowing unique expressions of vegetation to be included in later editions of the manual. As the authors state the MCV has become a standard classifications system, allowing fine scale studies to be included in larger regional maps (Throne et al 2004).

This project used MCV classification system at the alliance level to record primary and secondary vegetation cover classes. The primary vegetation cover class represents a dominant species, or group of species found within the canopy of a polygon. An alliance was coded to a polygon if it represented over 50% of that polygons cover.

The secondary cover class represents either an associated canopy species (i.e. Blue Oak/Live Oak) or visible understory vegetation (i.e. grassland). While some understory species were observed it is worth noting that these do not represent associations as defined in the MCV. The secondary cover classes are included to add further detail to the vegetation dataset where possible. To add further detail, polygon names also reflect the density of the canopy structure. This is done by using forest (most dense), woodland, (less dense), and savanna (open canopy) tags to describe each polygon.

Statistics

The data from the 68 vegetation plots from CNPS Sierra Foothills project and GEOG 444 Spring 2006 fieldwork exercise were converted into a presence/absence and percent cover matrices using Microsoft Excel and ESRI's ARC View GIS. These matrices were ordinated using PC-ORD to assist in the vegetation interpretation process (McCune and Mefford 2005). Data from these matrices were used to create clusters of dominant vegetation types at the species level. These clusters were then overlayed as field points on the imagery to help distinguish between species with similar tone/textures.

Error assessment

A two part error assessment was conducted on the post product ion map to ensure that the accuracy of the map was within acceptable scientific standards. The first component of the error assessment was to circulate that map to parties that were familiar with the study areas vegetation. While the circulation of the map does not statistically prove that maps value the positive responses from the interested parties indicated to the project team that a statistical error assessment was warranted.

To check the accuracy of the map an error matrices was constructed using a stratified random sampling method similar to the on described by Congalton (1988). This method allows the user to create strata, or classes, in which the random samples are chosen from. This ensures that smaller strata, such as black oak in our project, are included in the sample population.

Since the 68 points from CNPS and GEOG 444 were collected before the production of the map they are seen as independent samples. In order to use the stratified random sampling error assessment this point data will be augmented by selecting the remaining random points using GIS form the vegetation database. It is important to note that the field observations used to validate the map contain a certain level of error. Just as one may introduce error into the map when digitizing polygons the same can be done by improperly coding points used in the accuracy assessment.

When mapping at the alliance level it is particularly hard to capture changing alliances at the ground level. The gradual change between vegetation can not be captured in a single point. Therefor using the above mentions random sampling approachcould introduce as much erro into the data set as digitizing the original polygons. Furthermore, when more than one person is asked to define vegetation at the alliance level discrepancies are sure to ensue. It is this researcher's opinion that new methods are needed to assess error in such subjective situations. Ultimately, the beset form of error assessment was the consensus of the individuals who were originally consulted during the project.

Limitations

Studies of environmental phenomenon are subject to changing ecological conditions. Thus, weather and seasonality will hamper researcher's efforts to accurately capture the presence of species within ecosystems. Furthermore, all of the plant communities defined in the study are constantly changing within the ecosystem as a response to disturbance regimes. This shifting steady state mosaic of vegetation shows that this study will be a snap-shot of the vegetation at one point in time. Further vegetation maps will be needed to show how this ecosystem evolves over time.

The process of digitizing polygons also changes from person to person. Mapping in this fashion defiantly requires cartographers to make educated guesses about vegetation cover. In areas of dense heterogeneous canopy (ie Mixed Oak) it is almost impossible to distinguish different Oak species from each other. After multiple field visits to the “mixed Oak” areas it was concluded that no oak species was dominant, thus ‘Mix Oak” is the appropriate label for such polygons. Some of the finer grained polygons are more of a reflection of observations made in the field instead of recognizable patterns interpreted in the digitizing process.

Another problem encountered during this project was the lack of accessibility to may portions of the study area. The excellent trail system of Upper Bidwell Park is consolidated into three unevenly distributed fire roads as one crosses the parks northern boundary. Even the presence of fire roads cannot be counted on to access the majority of the project area. In some instances the steep canyon walls impede access to even the most determined individuals. This lack of access is evident in the distribution of field surveys and error assessment points. Thankfully much of the inaccessible terrain was composed of scrub oak, one of the easiest to identify in the aerial imagery.

As stated above, conducting an error assessment at the alliance level was quite challenging. This is mainly because point data does not accurately capture landscape level change. Further studies on the vegetation of the project area will be the ultimate validation for the maps accuracy. A study which uses the legacy data from this project to produce a spatial model of the project areas vegetation would further validate the methods used in this study.

Findings

The final vegetation map represents how advances in technology can affect our ability to observe ecological process. The availability of NAIP imagery should be seen as a superior alternative to using DOQQ's due to the ability to use color to distinguish between vegetation types. The project area was a rigorous test for the use of these new methods of vegetation mapping due to high heterogeneity of plant species.

The resulting map should be seen as a base line study of the ecology of the BCCER project area. Just as the MCV continues to evolve, it is the hopes of the project team that the legacy GIS data from this study will be periodically augmented. Further ares of study associated with this map include the use of legacy GIS data to create a spatial model for the vegetation within the study area. Such a study may be the answer to the difficulties encountered during the error assessment phase of the project.

Currently the Big Chico Creek Vegetation Map contains 872 vegetation polygons representing 23 different alliance types. A summary of the alliances identified in the study area is listed in table 2. Along with the number of unique polygons, area, and each alliances dominance as shown by their percentage of the total study area. The alliances with pertaining to greater than ten percent of the total study area are highlighted.

Table 2. Summary of vegetation classes

Cover Class I	No. of Polygons	Hectares	Percent of Total Area
Bare/Rock	7	41.4	0.9
Bay Laurel	1	1.2	0.03
Big Leaf Maple	1	0.5	0.01
Black Oak	5	11.1	0.2
Blue Oak	97	715.1	15.9
Buck Brush	38	78.8	1.7
Canyon Live Oak	6	47.3	1.0
Grassland	220	639.9	14.2
Grey Pine	77	369.8	8.2

Interior Live Oak	2	1.2	0.03
Water bodies	3	2.2	0.05
Canyon/Interior Live Oak, Bay Laurel	50	174.3	3.9
Infrastructure	23	66.7	1.5
Blue/Valley/Canyon Live Oak	120	1035.2	23.0
Blue Oak/Canyon Live Oak	2	8.4	0.2
Ponderosa Pine	19	257.1	5.7
Riparian	5	125.7	2.8
Scrub Oak	124	561.6	12.5
Shadow	19	54.6	1.2
Springs	13	3.7	0.1
Valley Oak	22	110.2	2.4
Vernal Pools	2	96.8	2.1
Wet Meadows	16	104.8	2.3

Conclusion

This project, along with the efforts of Throne (et al. 2004), provide tested modern methodologies for mapping vegetation distributions from orthorectified aerial photographs . Not only can we now map vegetation from remotely sensed imagery, we can do so at a fine grain (MMU = 1 ha.). The production of such fine grained vegetation maps will allow researches and reserve managers to accomplish studies that once were not possible; such as sustainable resource management and conservation; or vegetation dynamics at the regional scale. Constructing such vegetation maps so that they fit into preexisting frame works will allow collection, archival, and dissemination of vegetation datasets.

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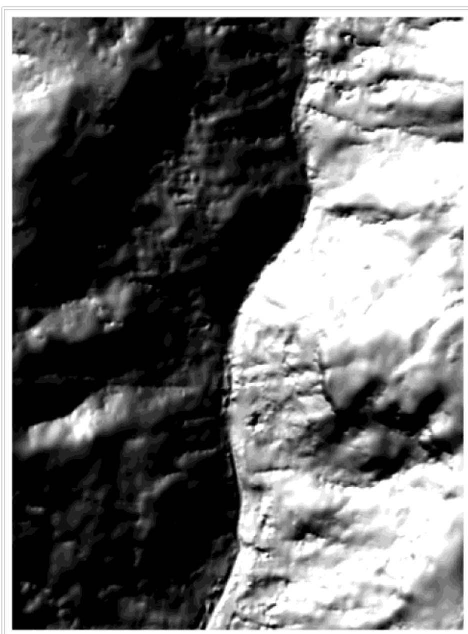

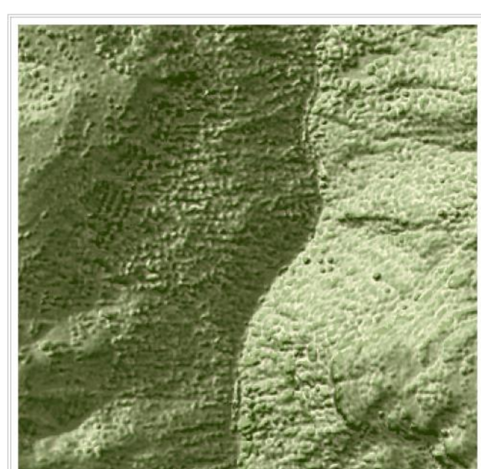

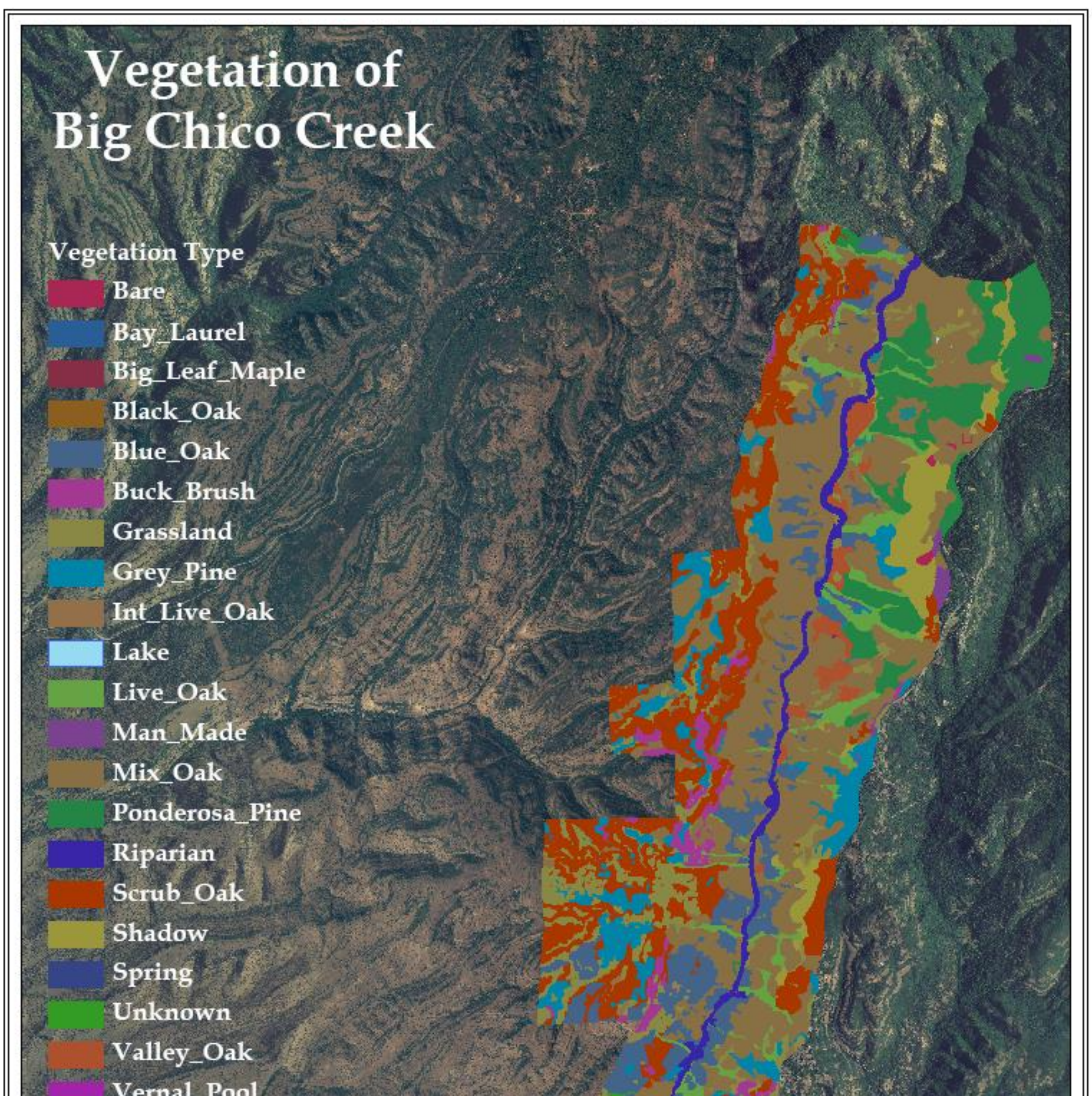
Vegetation of
Big Chico Creek
Vegetation Type
Bare
Bay_Laurel
Big_Leaf_Maple
Black_Oak
Blue_Oak
Buck_Brush
Grassland
Grey_Pine
Int_Live_Oak
Lake
Live_Oak
Man_Made
Mix_Oak
Ponderosa_Pine
Riparian
Scrub_Oak
Shadow
Spring
Unknown
Valley_Oak
Vernal_Pool