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An Assessment of Land Cover Change at the Indio Mountains Research Station

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Dedication

I dedicate this dissertation to Isabella, Matthew, and Johnathon. They are the light of my world and the loves of my life, and the reason I got up every morning to finish this no matter what. They are the best children in the world and have been patient with me, sacrificing the most of everyone I knew so that I could work. They stood by me during my struggle when no one else would, and will now get to celebrate in my success. My life is theirs now, for I am eternally grateful.

AN ASSESSMENT OF LAND COVER CHANGE AT THE INDIO MOUNTAINS RESEARCH STATION

by

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DISSERTATION

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Abstract

Land cover change is a significant contributor to environmental change on a global scale. In the arid regions of the southwest US, shrub encroachment is one of the most important forms of land cover change. Many factors contribute to shrub encroachment, which can impact structure and function. In the Chihuahuan Desert, mountain ecosystems are known as biodiversity hotspots and are especially susceptible to environmental change making them useful indicators of global change. ***The overarching goal of this dissertation was to improve i) understanding of land cover change in a Chihuahuan Desert mountain landscape, and ii) how knowledge of land cover change could be taught to undergraduate students.***

Chapter 1 discusses the importance of land cover change (Section 1.1.1) and shrub encroachment (Section 1.1.2), drivers of change (Section 1.1.3), and what affects shrub encroachment has on ecosystem structure and function (Section 1.1.4). Technological advances that aid the detection of land cover change through time (Section 1.1.5), research challenges in land cover change research on shrubification in the US southwest (Section 1.1.6), and the importance of teaching future scientists to live a more sustainable lifestyle, especially in desert ecosystems susceptible to shrub encroachment and desertification. Key research questions and objectives (Section 1.2.1) are outlined, an overview of the methodologies employed (Section 1.2.2), and a review of the biophysical environment of the IMRS are also given (Section 1.3).

Chapter 2 focuses on the development of a land cover classification for IMRS. Following field-based vegetation sampling, the land cover classification for IMRS was generated using a high spatial resolution satellite image (IKONOS) and supervised classification techniques. This resulted in a land cover map that had good overall, and user and producer accuracies. The land cover map, in combination with other geospatial data extracted using a Geographic Information System (GIS), was used to produce a baseline and conceptual state-and transition model for IMRS land cover using correlation and regression tree analysis. The model shows that the vegetation is distributed along an elevational gradient, and that other factors such as slope, and soil and geology type are also influential.

Chapter 3 focuses on the assessment of land cover change, namely changes in shrub cover, at the IMRS spanning 68 years. The land cover map produced in Chapter 2 was used to select five key sites for change assessment. An automated method for detecting shrub cover was created for GIS, and used to assess changes in shrub cover using aerial photographs spanning 1943 to 2011. The incorporation of kite aerial photography was useful for determining optimal sampling resolution and quantifying uncertainty in the change analysis techniques employed. Results of this analysis show an overall increase in the total number of shrub clumps, but a decline in total and percent cover of all shrubs in the transect, suggesting either fragmentation of shrub clumps or a shift in species composition has occurred over time.

Chapter 4 focuses on the development and evaluation of an undergraduate module-based curriculum that was aimed at developing a holistic understanding of environmental problems and the use of technology in ecological studies related to land cover change and desertification, environmental monitoring, and mitigation in desert ecosystems. To evaluate the effectiveness of the modules, changes in student knowledge and attitude toward ecology and technology, and their sense of efficacy regarding those topics was measured using a series of pre- and post-tests and statistical analyses. Significant increases were observed in almost all categories of evaluation, with marked increases and large effect sizes in knowledge acquisition, and technological and environmental efficacy. It is inferred that the modules effectively enhanced student content knowledge and changed their attitudes towards environmental science and technology.

Chapter 5, the general discussion, reviews the objectives and key questions outlined for the dissertation and discusses these based on the studies outlined above and findings in recent literature. This chapter also addresses priorities for future research based on these discussions.

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Chapter 1: Introduction

1.1 Introduction, Background, and Rationale

1.1.1 Importance of land cover change (LCC)

Land cover change (LCC) is a significant component of global environmental change that affects the structure and function of Earth's ecosystems (MEA, 2005). LCC has had a tremendous impact on the world and the rate of vegetation change is escalating significantly (Jackson et al., 2000; Gonzalez et al., 2010) due to natural effects (such as climate change) and human causes associated with land use (Lambin et al., 2001; MEA, 2005; IPCC, 2007). Forms of LCC include, but are not limited to deforestation of tropical rainforests, clearing of land for agricultural use and urban development, and desertification[1]. The alteration of forests to crop and pasturelands is a prevalent form of vegetation change (Jackson et al., 2000; Achard et al., 2010). In the last three hundred years, approximately 20% of forests and woodlands have vanished (Richards, 1990), about 12,000,000 sq. km. have been cultivated since 1700, and grasslands have decreased by half their former extent (Turner et al., 2000). Additionally, many arid regions of the globe have undergone desertification during the last century (Bond et al., 1994; Dodd, 1994; Archer, 2010). As human populations continue to multiply, the conversion of the Earth's landscape will continue (Jackson et al., 2000). Because of this, land cover change studies in the U.S. have gained importance among agencies such as NSF, USGS, and the U.S. Global Change Research Program.

1.1.2 Land cover change (LCC) in the US southwest deserts

The expansion of woody vegetation in arid and semiarid environments (shrub/woody encroachment) alters biodiversity, is a serious problem world-wide (Archer, 1994; Van Auken, 2000; Reynolds and Stafford-Smith, 2002; MEA, 2005), and is thought to be a major form of LCC contributing to desertification in arid landscapes (D'Odorico et al., 2012). Globally, arid landscapes represent approximately 40% of the Earth's land surface (Reynolds and Stafford-Smith, 2002; Okin et al., 2009) and are home to 2.5 billion people (Reynolds et al., 2007). Locally, shrub encroachment has

1 Land degradation in arid, semiarid and dry sub_humid areas resulting from various factors, including climatic variations and human activities

been documented in many of the deserts, grasslands, and savannas of North America (Barger et al., 2011). Shrub encroachment has been documented in the Mojave Desert (Brooks et al., 2006), and the Sonoran Desert where most of the research has documented shrubification in the southeastern parts of Arizona (Hastings and Turner, 1965; Bahre and Shelton, 1993; Bahre, 1995; Swetnam and Betancourt, 1998; McClaran, 2003; Browning et al., 2008; King et al., 2008; Browning and Archer, 2011). In the northern Chihuahuan Desert, woody plant invasion has also been reported at the USDA-ARS Jornada Experimental Range (JER), which hosts the Jornada Long Term Ecological Research (LTER) site (JRN, Buffington and Herbel, 1965; Goslee et al., 2003; Laliberte et al., 2004; Gibbens et al., 2005), and the Sevilletta Wildlife Refuge (SWR) (Barger et al., 2011). Though many studies have reported shrub encroachment throughout the southwest, the relative contribution of different drivers of shrub encroachment is still poorly understood (Bestelmeyer et al., 2009).

1.1.3 Drivers of shrub encroachment

In the southwest United States, shrub encroachment appears to be converting grasslands into shrublands as a result of overgrazing, fire suppression, increasing atmospheric CO_2 concentrations favoring shrubs over grass plants, drought, extreme events, and climate change (Johnson et al., 2000; Peters, 2000; Peters and Gibbens, 2006; Coetzee et al., 2008; Peters et al., 2012). The complexity of these ecosystems suggests that a combination or even all of these drivers, rather than a single factor, interact with ecosystem processes to stimulate shrub expansion in US southwest desert landscapes (Archer, 1994; Van Auken, 2000; Mielnick et al., 2005; Peters and Havstad, 2006). Below is an overview of the factors contributing to shrub encroachment.

Grazing: livestock and small animals

The introduction and production of domestic livestock, mainly cattle, over the last 150 years is the major altered land use in North American desert grasslands and has been associated with shrub encroachment in the Chihuahuan Desert before the turn of the century (Bahre, 1995; Nash et al., 1999; Barger et al., 2011; Browning et al., 2011). The effects of overgrazing on plant communities are thought to affect the structure and function of semiarid grasslands (Kerley and Whitford, 2000). The period of rapid invasion of shrubs coincided with, for example, peak abundance of cattle at the JER (Peters and

Gibbens, 2006). Even during favorable climatic periods for plant growth, *Bouteloua eriopoda* (black gramma grass) declined under light to moderate livestock grazing (Holecheck et al., 1994). Livestock effects on grassland vegetational change include consumption of above-ground biomass of grass species, seed dispersal, plant and soil trampling, and nutrient redistribution (Peters and Gibbens, 2006). Evidence suggests that thresholds for shrub dominated communites caused by livestock grazing were crossed by the 1930's (Browning and Archer, 2011). In addition to livestock grazing effects on grasslands, native herbivore species, such as kangaroo rats, deer, and ants, also contribute to this process through the selective consumption of aboveground biomass, mostly seeds, dispersal of shrub seeds, and burrowing activities which displaces soil and nutrients (Peters and Gibbens, 2006). It was also documented that granivory by ants can have an important influence on grasslands bringing about changes in vegetation (Kerley and Whitford, 2000).

Fire

Regular fire regimes can support diversity, heterogeneity, and dynamic ecosystem stability in mountain ecosystems, as well as control the evolution and distribution of species (Ravi et al., 2007). Vegetation communities and ecosystems can be strongly affected when fire patterns change (Allen, 2007), such as when fire suppression was used as a land management tool in the southwest US (Browning and Archer, 2011). Shifts to shrub dominated communities from grassland communities decreases fire frequency and intensity further enhancing shrub proliferation and transitions to shrublands (Van Auken, 2000; D'Odorico et al., 2006). A change from grassland to shrubland caused by fire suppression was shown in the desert grasslands in southern Arizona (Bock and Bock, 1997) and at the JER in southern New Mexico (Cornelius, 1989; Browning and Archer, 2011). The transition from grassland to shrubland caused by fire suppression has also been shown to reduce biodiversity in desert mountain landscapes (Ravi et al., 2007).

Increases in atmospheric CO_2 concentrations

Since 1850, the amount of CO_2 in the atmosphere has increased from 275 ppm to more than 390 ppm, with an average annual release of CO_2 estimated of about 5.5 Pg (Petagrams = 5,500,000,000,000,000 grams) (IPCC, 2007). Increases in atmospheric CO_2 have been thought to aid in

the growth and spread of shrubs over grasses (Archer et al., 2001). Though increases in CO_2 concentrations in the atmosphere are thought to benefit all vegetation with sufficient water and nutrients, C3 plants[2] such as many desert shrubs can utilize CO_2 in a more efficient manner than than C4 plants[3] such as many grasses (NAST, 2000). In the Nevada desert FACE (free-air CO_2 enhancement) experiment, elevated levels of CO_2 had a greater affect on carbon assimilation in shrubs such as *Larrea tridentata* (creosote bush) than grasses (Houseman et al., 2003). Also, increases in CO_2 affect regional and continental to global climate patterns by increasing radiative forcing potential that results in atmospheric warming, which affects vegetation (IPCC, 2007; Gonzalez et al., 2010).

Climate Change: Drought and Extreme Events

A characteristic of arid ecosystems is limited water availability due to low annual precipitation (Schlesinger et al., 1990; D'Odorico et al., 2012). Because plant diversity and productivity are strongly affected by soil moisture, precipitation patterns in arid regions structure plant communities (Peters, 2000; Peters et al., 2012). Over the years, the average summer precipitation levels have declined (Gutzler and Robbins, 2010) with trends projecting to become drier (Burke et al., 2006; Seager et al., 2007) especially in the arid regions such as the southwest (Gutzler and Robbins, 2010). This in turn will cause a decline in soil moisture availability during most of the year (Wetherald et al., 2002) effecting herbaceous plants (such as *Bouteloua eriopoda*) susceptible to drought conditions (Peters et al., 2012), further exacberated depending on soil type as well (Browning et al., 2012). Drought conditions in the 1950's which caused vegetation shifts from grasslands to shrublands were documented in the Mojave, Sonoran and Chihuahuan Deserts (Hennessy et al., 1983; Barger et al., 2011). In addition, drought conditions will enhance erosion processes causing changes in the distribution patterns of soil resources between interspaces and shrub canopies (Li et al., 2008).

Accompanying these recent changes in climate is an increase in extreme precipitation events during the summer season in the arid regions of the southwest US (NAST, 2000) despite average

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2 Plants that survive solely on C3 carbon fixation and thrive in areas where sunlight intensity and temperatures are moderate, water is abundant, and CO2 conc. are ~200 ppm or higher

3 Plants that utilize the C4 carbon fixation, an "improvement" over the simpler C3 pathway, and have a competitive advantage over C3 plants under conditions of drought, high temperatures, and limited CO2 and nitrogen

summer precipitation levels declining (Gutzler and Robbins, 2010). The patterns of these extreme climatic events are projected to increase (Seager et al., 2007) in the arid regions such as the southwest. This scenario has given shrubs such as creosote and mesquite an advantage over grasses, thus contributing to increased shrub communities in desert grasslands (Jurena and Archer, 2003; Good and Caylor, 2011). This is because intermittent events of extreme precipitation replenish deeper soil layers with water that deep-rooted plants such as shrubs can access, whereas smaller, more frequent rains tend to increase the growth of the more shallow-rooted grasses (Gibbens and Lenz, 2001).

In addition, recent increases in winter precipitation after 1977 appeared to have favored the establishment of winter active C3 shrubs (e.g., *Larrea tridentata*) over summer active C4 grasses (like *Bouteloua*, Bahre and Shelton, 1993; Brown et al., 1997). This increase in winter precipitation has been brought about by recent changes in global climate as well (IPCC, 2007). The challenge of identifying and assigning mechanisms driving change when multiple interacting causes are present emphasizes the need for creative experimental designs in novel locations such as mountain ecosystems, which are susceptible to change but scarcely studied.

1.1.4 Impacts of shrub encroachment on ecosystem processes, function, and structure

Improved understanding of woody encroachment through continued LCC research in the southwest U.S. is necessary for relating patterns of LCC with possible impacts on ecosystem processes, structure, and function of arid regions (Lambin et al., 2001). A discussion of how shrub encroachment impacts ecosystem processes, function, and structure follows in the sections below.

Ecosystem Processes and Function

Increase in erosion is one ecosystem process that is affected by increases in shrublands, which in turn increases surface runoff of vital soil nutrients (Schlesinger et al., 1999; Ludwig et al., 2000; Okin et al., 2006) and influence the distribution of soil carbon and nutrients (Jackson et al., 2000; Li et al., 2008; Okin et al., 2009). Erosion through water runoff increased 20% when grasslands shift to shrublands (Abrahams et al., 2006) causing a shift in soil nutrient patterns with most accumulation of nutrients under shrubs in the shrublands of the Chihuahuan and Mojave Deserts (Schlesinger et al., 1996). This accumulation of nutrients under shrubs is what is known as “islands of fertility” (Schlesinger et al.,

2006; Okin et al., 2009) and has been documented in North Texas (Archer et al., 2001; Hibbard et al., 2001; Asner et al., 2003; Hughes et al., 2006). With wind erosion, cover by grassland vegetation can protect soil by sheltering, reducing momentum from the wind, and trapping soil particles (Okin et al., 2009). With change in vegetation cover to shrublands, interspaces[4] form among patches of shrubs, and while soil accumulates under shrubs, wind erosion of soil and nutrients in the interspaces increases (Okin et al., 2001). In addition, deposition of transported soil can bury top layers of soil thereby reducing available soil nutrients that are available to plants growing at the surface (Okin et al., 2006).

Albedo[5] and energy balance are also impacted by changes in vegetation (Kurc and Small, 2004; Beltran-Przekurat et al., 2008). With higher albedo, the amount of radiation reflected from the surface increases. A change from grassland to shrub dominated communities can increase surface reflectance and thus albedo (Kurc and Small, 2004). When albedo increases, this can affect regional climate by affecting air temperatures due to more radiation being reflected back into space. This can have implications for global climate change (Beltran-Przekurat et al., 2008). A change from grasslands to shrub dominated communities can alter the energy balance over large areas (Beltran-Przekurat et al., 2008) causing changes in microclimate conditions that bring warmer temperatures which can further enhance shrub encroachment (D'Odorico et al., 2010). Therefore, the dynamics seen at each site can be highly complex and responses to change can be variable, highlighting the need for further research related to desert LCC and its impact on surface energy balance (Peters et al., submitted).

Shrub encroachment has the capacity to affect biogeochemical and hydrologic cycling (nutrient and water balances and fluxes) as well. Measures of CO_2 and evapotranspiration (ET) have shown that grasslands in the Chihuahuan Desert are an annual source of carbon to the atmosphere (Anderson et al., 2011) and that ET rates are higher in the growing season and lower in the winter months (Mielnick et al., 2005). No comparable differences in CO_2 flux between grasslands and shrublands in the Chihuahuan Desert have been found (Anderson et al., 2011), but ET appears to be lower in shrub dominated communities than grassland communities (Dugas et al., 1996). Studies suggest that reduced carbon

4 Spaces between shrubs occupied by little vegetative cover

5 The ratio of reflected radiation to incident radiation of the Earth's surface; is difficult to measure and it is uncertain whether changes in albedo increase or decrease global temperatures

sequestration and storage may occur through reduced foliage and living biomass inferring that shrublands would have reduced carbon sequestration compared to grasslands (Anderson et al., 2011). Soil respiration has increased as well in shrub communities transitioning into grasslands, and Gross Ecosystem Exchange and nitrogen uptake by plants far exceed respiration. Shrub encroachment also affects aboveground net primary production (ANPP) where ANPP was found to be homogenous with higher peaks across grassland landscapes, but patchy in shrub dominated areas during most growing seasons (Huenneke et al., 2002).

Ecosystem Structure

Major changes in animal population dynamics and community composition have coincided with these recent shifts in vegetation and climate, though species diversity is unchanged (Brown et al., 1997). The near extinction of the keystone species[6] *Dipodomys spectabilis* (kangaroo rat) in some locations due to a decline in grassland ecosystems has also caused declines in other species dependent on it as a food source (Hawkins and Nicoletto, 1992). Several species of seed harvesting ants, including *Pogonomyrmex rugosus* and *P. desertorum*, and *Aphaenogaster cockerellii* have declined in numbers along with the horned lizard, *Phrynosoma cornutum* and *modestum*, which specialize on these harvester ants as a food source (Munger, 1984; Chew, 1995). In 2005, Bestelmeyer explored whether desertification reduces biodiversity. In his study on ant species, he found that ant species richness was greater in a mesquite shrubland at the JER than in undisturbed grassland at Sevilleta Wildlife Refuge (SWR) suggesting that mesquite encroachment did not have a negative impact on ant diversity or abundance. He also found turnover in species[7] composition was related to mesquite density and that already existing ant communities either persisted or prospered with increases in shrubs (Bestelmeyer, 2005). In addition, a major turnover in avian communities were linked to shifts from grasslands to shrublands when bird species that specialized on grassland ecosystems disappeared and those that were adapted to shrublands became more abundant. Also, species richness in avian communities was higher in shrublands than grasslands (Pidgeon et al., 2001).

6 a species that has a key role in an ecosystem, affecting many other species, and whose removal leads to a series of extinctions within the ecosystem

7 Species turnover: species populations in a community that go extinct and are replaced by other species

Shrub encroachment can impact biodiversity by changing the vegetation types of the area (Sala et al., 2000; Ravi et al., 2009; Archer, 2010; Eldridge et al., 2011). Changes in vegetation from grassland to shrubland can reduce species diversity (Peters and Gibbens, 2006). A phenomenon exists whereby one species aids in the growth of another species in environments that would otherwise be too extreme for survival and is known as nurse-protégé interactions, or facilitation, and allows for the conservation of species (Valiente-Banuet et al., 2006). In the arid and semiarid regions of the world, this phenomenon is very common and important for survival of some species in these extreme environments (Flores and Jurado, 2003). These relationships have been documented in the northern Chihuahuan Desert at the JER ((De Soyza et al., 1997; Guo, 1998) and Big Bend National Park (Yeaton, 1978; Poulos et al., 2007), and at the SWR (Smith and Ludwig, 1978; Hochstrasser and Peters, 2004). These facilitative relationships may play an important role in preserving biodiversity and can have important implications for the development and maintenance of biodiversity in arid regions and species/community responses to climate change (Guo, 1998; Valiente-Banuet et al., 2006).

1.1.5 Technological advances aiding in the detection of land cover change

A first step in understanding shrub encroachment is to develop a reliable method for measuring LCC over broad spatial and temporal scales so that patterns of change can be related to physical factors. Prior to aerial and satellite remote sensing science, earlier studies on land cover change focused on field surveys and historical accounts (Buffington and Herbal, 1965; York and Dick-Peddie, 1969), and vegetation and land cover mapping were performed using extensive and labor intensive field surveys (Buffington and Herbel, 1965; Poulos, 2009). Even though field surveys produced highly accurate maps, these were limited in spatial coverage, inefficient, and expensive (Poulos, 2009). In 1965, Hasting and Turner used repeat ground photography to determine changes in land cover along the border of the region of the southwest US called La Frontera (Bahre and Hutchinson, 2001). Contemporary photos were compared to historic photos collected at the same exact location along the border. Evidence of land cover change could be seen in the photos, but there was uncertainty in what were causing the observed changes. Since these photos only offered a “snapshot” in space and time, it was impossible to ascertain broad scale patterns of vegetation change (Bahre and Hutchinson, 2001). With the development of GIS

(geographic information systems), historical vegetation maps could be digitized and compared with recent vegetation survey maps to estimate changes in overall percent cover of different land cover types (classes) (Gibbens et al., 2005). In 1991, Bahre became the first published researcher to utilize repeat aerial photography to assess changes in land cover in Arizona. Some arguments against the use of repeat aerial photography were that they could only go as far back at the early 1930's, and that older aerial imagery had less resolution and clarity (Bahre and Shelton, 1993). With development of faster and better computers and image processing software, some of the issues associated with historical photos have been lessened (Lillesand et al., 2004). In addition, with the launching of several satellites and innovation of remote sensing tools though time, high resolution imagery and information derived from satellite platforms have given additional tools to help detect patterns of change. Since this innovation, historical aerial photograph inter-comparison with recent aerial photographs in conjunction with high spatial resolution satellite imagery have become the primary tools in determining broad scale decadal time scale LCC (Lillesand et al., 2004). Aerial photography and satellite imagery interpretation techniques utilized in conjunction with GIS have been used successfully in other semi-arid landscapes for this purpose by a number of researchers, including Schlesinger and Gramenopoulos (1996), Yool et al. (1997), Peters et al. (1997), Brown and Carter (1998), Fransen et al. (1998), Hudak and Wessman (1998), Ansley et al. (2001), Coppedge et al. (2001), Goslee et al. (2003), Asner et al. (2003), Bruelheide et al. (2003), Laliberte et al. (2004), Briggs et al. (2007), and King et al. (2008). With the advancements of these techniques, species that are associated with landscape level change can be determined and land cover types that are increasing and decreasing over time can be assessed.

1.1.6 Research challenges in land cover change and shrubification research in the US southwest deserts

Arid landscapes comprise the largest land area of any biome on Earth (Okin et al., 2009), and support more than a third of the global human population (Reynolds et al., 2007). Importantly, arid landscapes are under increasing pressure from anthropogenic impacts and climate change (IPCC, 2001; MEA, 2005), which are likely to affect the sustainability of these landscapes in the future (DeBuys, 2011). Mountain systems in desert ecosystems contain most of the diversity found in these regions and are recognized as hotspots for plant richness, diversity, and endemism (Weldon, 1967; Warshall, 1994).

The southwest US sky island archipelago is unique and includes southwestern New Mexico, southeastern Arizona, northwestern Chihuahuan and northeastern Sonora (Weldon, 1967; Warshall, 1994). In the southwest US arid regions, the role of topography plays a profound role. The extreme aridity and climate conditions of lower elevations causes lower species diversity and differences in species composition (Whitaker and Niering, 1965; Poulos and Camp, 2005), whereas higher elevations have reasonable conditions compared to lower elevations, and northern exposures have more moderate moisture conditions than southern exposures, which tend to be drier, causing differences in species composition as well (Poulos and Camp, 2005).

Mountain ecosystems within the Chihuahuan Desert are high in biodiversity due to the ideal climate present for plant species caused by elevation gradients (Gitlin et al., 2006). In the face of unprecedented global environmental change, understanding of vegetation distribution patterns of mountain ecosystems within arid and semiarid regions are even more important in order to maintain biodiversity and further understanding of vegetation responses to changes in the environment. To help mitigate change in mountain ecosystems, an integrative modeling approach is necessary to provide insight on how the environment can influence the distribution of vegetation and how any changes in the environment can cause changes in vegetation community types (Beniston, 2003). Studies show the importance of understanding changes in biodiversity in response to environmental changes (Peterson, 2003; Coblentz and Riiters, 2004; Poulos, 2009) yet the use of conceptual models, which have been noted as a critical component of research into change dynamics (Bestelmeyer et al., 2003), has not been developed for Chihuahuan desert mountain ecosystems. One way to model communities is to select associations based on dominant species and classify their distributions to generate land cover maps (Lenihan, 1993; Austin, 1998; Guisan and Theurillat, 2000). With recent advances of DEM's, computer capabilities, remote sensing techniques, and high spatial resolution satellite imagery, land cover maps can be created which can act as a measure of biodiversity (Guisan and Theurillat, 2000). The use of land cover maps as measures of biodiversity has prompted the analysis of topographic and spatial distribution of biodiversity relationships (Coblentz and Riiters, 2004) for development in conceptual state and transition models (Bestelmeyer et al., 2009). Species-environment relationships are important

determinants of vegetation abundance and spatial distribution, and as indicators of environmental change (Poulos and Camp, 2005). Despite the importance of land cover maps and conceptual models and tools aiding in the detection of environmental change as seen in other studies in rangelands (Herrick et al., 2006; Bestelmeyer et al., 2009), few have focused on mountainous terrain.

In addition, shrub encroachment has been well documented in many areas of the southwest (Barger et al., 2011) (Fig. 1.1), but especially at the JER near Las Cruces, approximately 97 km from El Paso and approximately 483 km from the Indio Mountains Research Station (IMRS). Most of the studies at the JER have focused on lowland grasslands where grazing has occurred. Few studies have focused on the mountains of the Chihuahuan Desert. The IMRS is a mountainous habitat with limited grazing for the past 30 or more years. The study gives us a unique opportunity to look into possible factors associated with shrubification, primarily climate change factors that can expand our knowledge base on the occurrence of shrub encroachment in the southwest United States.

Figure 1.1. Sites in the US where land cover change, in particular shrub/woody encroachment, has been documented.

Much of the past remediation at the JER has not been successful, but there have been enough successes to indicate that the system can be reverted (Herrick et al., 2006a). It is recognized that future success depends on the idea that the conditions of today, such as in the soils, climate and fauna, are not the same as they were many years ago when shrub invasion began and that it may be impossible to restore certain plant communities to pre-shrubification conditions (Herrick et al., 2006a), especially if climate and precipitation patterns are favorable for grass re-establishment (Peters et al., 2012). Observed changes in mean annual temperatures have increased about 2°C over the past 100 years in the southwest (IPCC, 2007). While projections for future climate are predicted to be warmer and drier (Gutzler and Robbins, 2010; Seager et al., 2007), some models project future precipitation is to increase up to 30%, mainly in the form of winter precipitation (IPCC, 2007). It is important to be able to predict the state of these desert ecosystems under these climate scenarios. The shifting border between arid and semiarid ecosystems, especially mountain ecosystems, will be one of the most sensitive indicators of global change in the future (Havstad and Schlesinger, 2006; Poulos et al., 2007). Terrestrial monitoring sites need to be designated as barometers of change in places where climatic effects on ecosystems will be apparent and where long-term monitoring can occur (Peters et al., 2011). Research aimed at predicting changes caused by drought events should focus on dominant plant species subject to the greatest drought impacts in locations with poor soil quality, southern exposures, high elevations such as mountain ecosystems, and high levels of competition. Ecosystems at these barometer sites will be the first to react to dry conditions or any other changes in climate and long term studies will allow us to see how ecosystems respond and what the future state would likely be (Gitlin et al., 2006).

1.1.7 Education in land cover change and shrubification research for sustainability in the US southwestern deserts

Higher education should play a critical role in assisting change towards a sustainable present and future in society (Junyent and Geli, 2010; Chapin et. al., 2011). Action for sustainability is needed because human activities are strongly impacting Earth's life support systems to the point of threatening the ecological services important to society (Chapin et. al., 2011). Sustainability is based on the concept of maintaining the long-term integrity of the Earth System while meeting the long-term needs of human well-being in a changing world (National Research Council, 2010; Chapin et. al., 2011). The knowledge

needed to inform sustainability requires an interdisciplinary approach that depends on the observations, skills and creativity of a range of scientists, practitioners, and society (Chapin et. al., 2011). This makes sustainability an emerging and important concept that should be integrated into science curricula (Junyent and Geli, 2010; Chapin et. al. 2011). It is necessary to train students in a range of different disciplines on environmental and sustainability concepts and values in order to improve sustainability viewpoints for future careers and lifestyle choices (Tilbury, 2004; Junyent and Geli, 2010). Incorporating sustainability concepts into STEM (Science, Technology, Engineering, and Mathematics) courses is even more important (Hopkins and James, 2010). This is because STEM students tend to participate in any campus sustainability programs, their careers will likely provide opportunity to add to the advancement of greener lifestyles and technologies, and they will shape broader public and science policy debates in the future (Hopkins and James, 2010).

1.2 Scope of this Dissertation

1.2.1 Key questions and objectives

In response to desertification, Land Cover Change (LCC) is the form of woody plant encroachment that has been linked to dramatic changes in ecosystem structure and function (MEA, 2005; D'Odorico et al., 2012). Most of the shrub encroachment research conducted in the southwest US have focused on desert basins (Barger et al., 2011), but few have focused on mountain ecosystems in desert regions, also known as hotspots for plant richness and endemism because most of the diversity found in these regions is located in mountains (UN, 1992). This makes shrub encroachment in mountain ecosystems important.

Dramatic human and environmental change is altering the world we live in and the sustainability of ecosystem goods and services available to humans (MEA, 2005; Reid et al., 2010). Although there remains a high degree of uncertainty as to how this state change will affect humans and terrestrial ecosystem structure and function, the current generation of students will be among the first societal leaders and decision makers to witness and make critical environmental decisions. This makes desertification an important component of the educational curriculum with the aim of teaching the next generation of scientists to lead more sustainable lifestyles. For the reasons given above, the overarching

goal of this dissertation was to improve i) understanding of land cover change in a Chihuahuan Desert mountain landscape, and ii) how knowledge of land cover change could be taught to undergraduate students. All research will be conducted at the Indio Mountains Research Station (IMRS), an example of a heterogenous Chihuahuan Desert mountain ecosystem. The following objectives and underlying questions will be addressed to meet this goal:

1) What vegetation and other land cover types or classes exist at the IMRS, can they be classified using high spatial resolution satellite imagery, and what environmental factors influence their distribution?

   Objectives:

   a. Determine the vegetation communities and other land cover types (classes) at the IMRS by:

      1. Compiling ground based surveys of vegetation, and where necessary, conducting further vegetation surveys to enhance classification ground truthing.
      2. Completing a supervised land cover classification and accuracy assessment of extant vegetation and other land cover using high spatial resolution satellite imagery.

   b. Determine what environmental factors influence the distribution of vegetation and other land cover classes at the IMRS, and develop a conceptual state and transition model.

2) Has land cover change/shrubification occurred at IMRS over the past half Century?

   Objectives:

   a. Determine where land cover change, namely a change in shrub cover, has occurred by:

      1. Selecting and establishing sampling transects in key sites and collect kite aerial photography for the sites.
      2. Conducting a multi-temporal analysis of aerial photography.

3) Can education modules focused on my research be created, implemented, and effective in student acquisition of knowledge and changes in attitude of the topics in the classroom?

   Objectives:

a. Identify and implement lesson modules based on ecological research of the Chihuahuan Desert into a university level classroom.
b. Test the effectiveness of the lessons in knowledge acquisition and changes in attitude with respect to implementation of lesson knowledge and practices into student personal and professional practices.
c. Determine whether these lessons can be incorporated into biology courses based on the effectiveness of the lessons on student learning and changes in attitude.

1.2.2 Methodological Overview

Research Question 1

Objective a1: Determining the vegetation classes of IMRS. During the summer (June-August) 2008 and 2009, a total of 830 sites where large areas of homogenous communities of vegetation exist were observed within the IMRS. At each site, elevation, slope, aspect, geology type, dominant plant species composition, and estimated percent cover of each dominant species was recorded. The 830 sites were entered into a data matrix for analysis in PCOrd statistical software. A cluster analysis and a non metric multidimensional scale (NMS) were performed on the data matrix by using only the estimated percent cover for each dominant species at each site. The vegetation classes for IMRS were determined by searching for natural breaks in the cluster dendrogram, and class designations were determined from visual interpretations of ground photographs and field visits, and by reviewing the floristic data from field notes.

Objective a2: Mapping vegetation and other land cover classes at IMRS. The appropriate number of land cover classes suitable for mapping were determined utilizing the results from the cluster analysis and ordination (NMS) described above. A high spatial resolution IKONOS satellite image was acquired and processed for remote sensing analysis. After determining the sites to be used as training sites from the results of the NMS, a supervised classification was conducted in ENVI 4.4 software to produce the land cover map for IMRS. Finally, an accuracy assessment was conducted on the IMRS land cover map utilizing a confusion matrix to generate user and producer accuracies for the resulting classification.

Objective b: Assessing the environmental factors influencing the distribution of vegetation at IMRS. Environmental data were acquired through GIS data extraction methods in ArcGIS 10 software. These data were combined with the NMS scores described above to perform correlation analysis, which revealed how the relationships among environmental variables explain the distribution of vegetation classes at the IMRS. Using regression tree analysis of the environmental data in JMP 9 statistical software and the vegetation relationships discovered, a conceptual model was produced for IMRS.

Research Question 2

Objective 1: Selection of key sites for acquiring kite aerial photographs (KAP) and shrub change detection. Utilizing the land cover map of IMRS and GIS spatial analysis, five key sites were chosen for acquisition of kite aerial photographs (KAP) and shrub change analysis using repeat aerial photography. During the fall (Sept-Oct) 2010 and spring (March-May) 2011, the five pre-selected sites were visited, a 200 m x 40 m transect was set up at each of the sites, and the kite was launched and moved across the site transect allowing for two passes where anywhere between 100 and 400 overlapping pictures were acquired.

Objective 2: Analysis of shrub change. Historical aerial photograph inter-comparison with recent aerial photographs is one of the only means possible to determine broad scale decadal time scale LCC. So for this study, aerial photography was used to determine the spatial and temporal patterns of LCC. I followed methods developed by Johnson et al., 2000, Goslee et al., 2003, Laliberte et al., 2004, Gibbens et al., 2005, and Browning et al., 2008. Aerial photographs spanning 1943 to 2011 (2011 KAP images) were acquired and processed for shrub change detection in ArcGIS 9.2 software. An automated method for delineating shrub cover was developed for ArcGIS 9.2 and used in the analysis of shrub change at the five sites within the IMRS.

Research Question 3

Objective a: Development and implementation of education modules. A module-based curriculum that was aimed at developing a holistic understanding of environmental problems, solutions, and the use of technology in ecology was implemented. Four modules were developed with desert ecosystems and desertification as the themes for ecological and technological discussion. The first

module acquainted students with a world-wide and local environmental problem, desertification. The second and third introduced methods for characterizing and modeling ecological processes, and the fourth module presented solutions to the problems described in the first three modules. Each module was taught using power point presentations, documentary movies relating to the topics, lab activities, and demonstrations during an undergraduate ecology lab on the UTEP campus.

Objective b: Testing the effectiveness of the lessons in knowledge acquisition and changes in attitude. To test the effectiveness of each module, a pre-test survey was given prior to the module to assess students' knowledge and attitude on the selected topic. At the conclusion of the module, a post-test survey was given to assess students' knowledge and attitude of the topic. Both surveys were identical. Then, independent 2-sample t-tests in Minitab and SPSS statistical software was conducted to determine if there was a significant difference in the mean overall score of the pre-test and post-test surveys.

Objective c: Determining whether these lessons can be incorporated into the curriculum. Effect size was used to scientifically quantify the effectiveness of the modules. Effect size allows the question 'how well it worked' to be asked, not just 'did it work'.

1.3 Biophysical Environment of Indio Mountains Research Station

1.3.1 Location

The IMRS (30.77688°N, 105.01617°W, elevation 1235 m) is located in the southeast tip of Hudspeth County approximately 42 kilometers southwest of Van Horn in western Texas, within several kilometers of the US border with Mexico (Fig. 1.2). It consists of most of the Indio Mountains and a low southern spur of the Eagle Mountains to the north of the property with elevations ranging from 900 to 1600 meters. The Rio Grande separates these mountains from the Sierra de Pilares of Mexico. The 15,992.4 hectare research station is an example of a Chihuahuan Desert mountain ecosystem and is ideal for conducting land cover change studies.

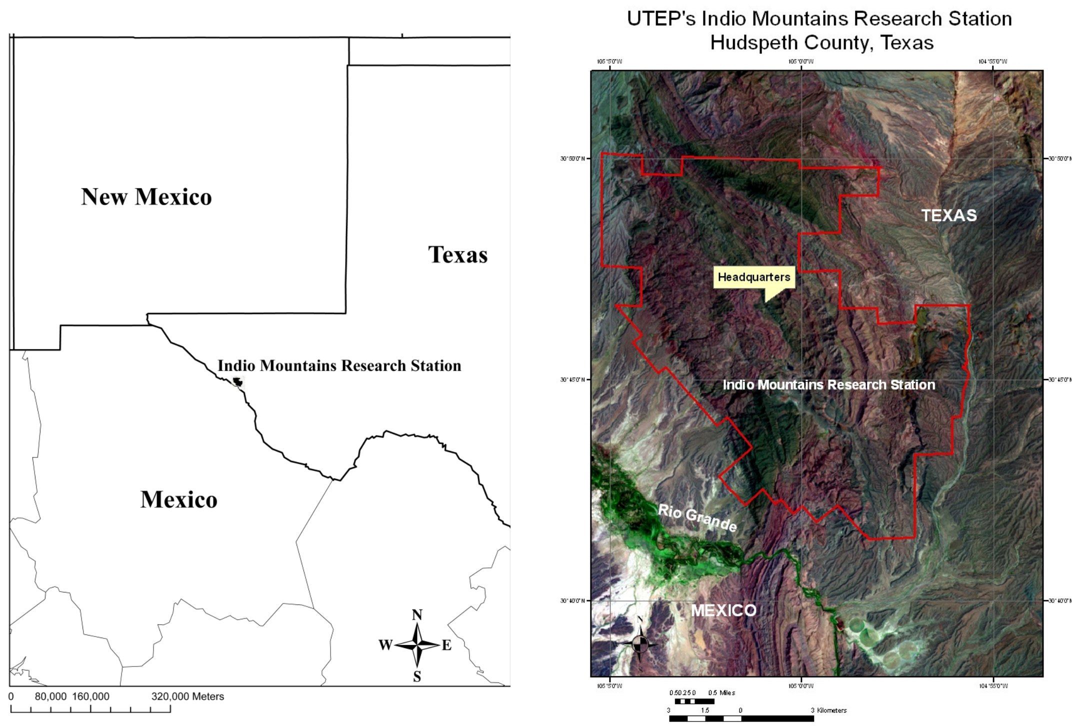


Figure 1.2. Location of the Indio Mountains Research Station in Western Texas, U.S.A.

1.3.2 Landscape Features

The IMRS is found within the Basin and Range Physiographic Province of North America. The terrain is a mixture of mountainous outcrops, bajadas, and arroyos that slope towards the Green River in the northeast and the Rio Grande in the southwest. Block-faulting in the area shaped the topography where tilted beds of Cretaceous limestone can be seen. Volcanic activity has further shaped the terrain. Folding, contraction, and extensional events have made the mountainous terrain what it is today. Perennial water flow occurs along Squaw Creek and originates at Squaw Springs (Worthington et al., 2004).

1.3.3 Geomorphology

A shallow sea known as the Chihuahuan Trough filled the area of the Indio Mountains in the Cretaceous. Sediments deposited gave rise to the 3,261.4 meter section of exposed Cretaceous rocks seen today (Underwood, 1963). Many of the beds have a sand and pebble appearance due to erosion and deposition of sediments from nearby land, while other beds are limestone indicative of marine origins.

1.3.4 Geology

The area was formed by thrust faulting, folding, and strike-slip faulting during the Laramide Orogeny of the Late Cretaceous into the Early Tertiary (Wallace, 1972; Price et al., 1985). Eruptions from nearby calderas deposited ash on the area which formed the tuffs and trachytes during the Oligocene (Price et al., 1985). Flat Top Mountain's rimrock on the IMRS is made up of these trachytes (Wallace, 1972). During the Middle and Late Tertiary, extensional block-faulting gave rise to the present day Indio Mountains (Price et al., 1985; Rohrbaugh, 2001). The "Indio Fault" runs through the property and divides the range into eastern and western blocks (Wallace, 1972).

Geologic surveys of the area indicate IMRS consists of a Cretaceous section, Oligocene volcanic tuffs and trachytes, and Tertiary to recent alluvial sediments. Some of the beds in the Cretaceous are limestone, while others are sandstone and conglomerate. The Cretaceous is divided into eight formations. The oldest is the well described Yucca Formation comprised of conglomerate, sandstone and siltstone mix, and conglomerate and sandstone mix. The Bluff Formation follows which is made up of three layers: light gray oolitic limestone, fossiliferous limestone mixed with quartz sandstone, and fossiliferous micritic limestone. The Cox Sandstone, which caps the central ridge of the Indio Mountains, is quartz sandstone with limestone and conglomerate mix. The last of the formations are the Finlay Sandstone, Benavides Formation, Espy Limestone, Eagle Mountains Sandstone, and the youngest is Buda Limestone (Underwood, 1963).

1.3.5 Soils

No formal studies on soils have been conducted at the IMRS (Worthington, et al., 2004). The soil information provided herein is from soil surveys conducted by the Natural Resources Conservation Service (2011). The soil types found in the IMRS are Culberspeth-Chilicotal complex, Blackgap and Terlingua soils and rock outcrop, Chipotle-Riverwash complex, Pantera-Riverwash complex, Ojinaga-Corazones complex, Castolon Galindo and Lomapelona soils, Chillon extremely gravelly sandy loam, Changas-Corazones complex, and Baviza loamy fine sand (NRCS, 2011).

1.3.6 Climate

The climate of IMRS is that of a Chihuahuan Desert ecosystem and is similar to areas surrounding the property suggesting that climate does not appear to be influenced by rainshadow effects despite the mountainous terrain (De La Cerda Camargo, 2011). A thorough climate analysis was conducted at the IMRS with several HOBO® weather stations located throughout the property. Average temperatures recorded at the Ranch house weather station for 2009-2010 were about 19°C, with a maximum high of about 31°C and minimum low of 7.5°C (Fig. 1.3). Average monthly high temperatures were recorded at about 29°C in July 2009 and June 2010, and average monthly low temperatures at about 7°C in December 2009 and January 2010. Temperature at other sites within the research station showed similar temperature patterns, but sites located towards the southern end tended to be warmer than other sites, and temperature patterns seemed to be influenced by elevation and aspect with lower elevatios being warmer and sites with west aspects having variable temperature ranges (De La Cerda Camargo, 2011).

Average monthly sum precipitation recorded at the ranch house was 23 mm with a total of 264 mm for 2010. Average monthly high sum precipitation was about 80 mm in July 2010, and average montly low sum precipitation was about 0 mm in March and April 2009 and March 2010 (Fig. 1.3). Precipitation patterns for the other sites around IMRS were variable, and wetter sites tended to be towards the northeast side of the property with the Ranch house being the wettest of all sites, and sites at lower elevations and southerly had reduced levels of precipitation (De La Cerda Camargo, 2011).

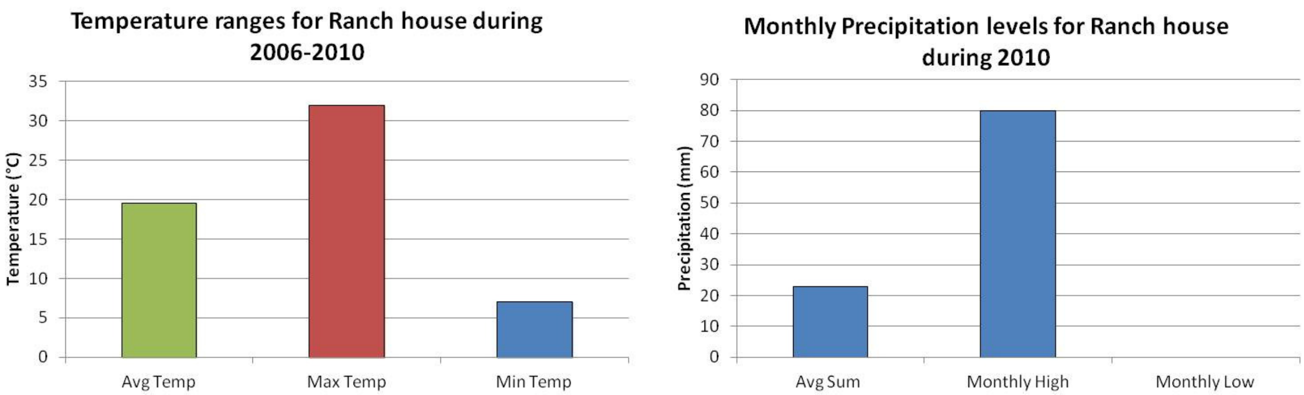


Figure. 1.3. Temperature and precipitation ranges recorded at the Ranch house between 2006 and 2010. Precipitation is shown for 2010 only. Data from De La Cerda Camargo, 2011.

1.3.7 Flora

Floral surveys of the area indicate IMRS is representative of a broad range of Chihuahuan Desert vegetation cover types. The flora is influenced by the Rio Grande corridor with remnants of widespread desert grasslands. Floral inventories show 375 species, though it is expected to be closer to 500 (Worthington et al., 2004).

Vegetation Communities

Though the plant communities of the IMRS have not been mapped, Worthington et al. (2004) described several associations from other classifications. Some classification units that appear to be present following Henrickson and Johnston (1983) are: *Larrea* scrub, mixed desert scrub, canyon scrub, *Lechugilla* scrub, *Prosopis-Atriplex* scrub, and Riparian woodlands. Based on the Texas Natural Heritage Program series (1993), the following plant communities appear to be represented on the area: *Fallugia* series, Creosote-marisols series, Creosote series, Lechugilla-sotol series, Mesquite-saltbush series, and the Viscid acacia series. Lastly, based on the Association for Biodiversity Information International Classification of the Chihuahuan desert region (2001), the following appear to be present: *Larrea tridentata* shrubland alliance, *Atriplex canescens* shrubland alliance, *Fallugia paradoxa* intermittently flooded shrubland alliance, *Acacia neovernicosa* shrubland alliance, *Prosopis glandulosa* shrubland alliance, and *Chilopsis linearis* shrubland alliance (Worthington et al., 2004).

1.3.8 Fauna

Fauna surveys of the area indicate IMRS is representative of a broad range of Chihuahuan Desert types. Invertebrates, both aquatic and land based, are abundant. There are 26 mammal species including mule deer, collared peccary, mountain lion, ringtails, coyotes, gray foxes, various rodents, rabbits, bats, and about 70 bird species. Thirty six reptile species have been documented including lizards and rattlesnakes. Only five amphibian species have been found to date (Worthington et al., 2004).

1.3.9 Anthropogenic History

History

Some of the cultural resources found at IMRS are indicative of time periods from Paleo-American or Paleo-Indian (10,000-6,000 B.C.). In addition, sixty-two Native American sites have been recorded at IMRS (Worthington et al., 2004).

The IMRS has not been grazed by cattle over the last 32 years (since 1980; Jerry Johnson and Wynn Anderson, personal communications), and has limited road access and impact from human development. Remnant earthen cattle tanks are still found and many still collect water during the rainy seasons. At least three abandoned mines and several prospect pits exist. Sporadic exploration of mines occurred in the early 1900's with some copper mining occurring between the late 1940's at the Black Diamond Mine and Rossman prospect, and again in 1950 at the Carpenter Prospect and Purple Sage Mine. The last mining lease expired in 1986 (Worthington et al., 2004).

Research is ongoing at IMRS and focuses primarily on faunal and geological studies, (Worthington et al., 2004). IMRS presents a unique and excellent scientific and educational platform for LCC research in the Chihuahuan Desert due to its location in the northern part of the Chihuahuan Desert, its topography and terrain, and low levels of human disturbance.

1.4 Arrangement of the Dissertation

Chapter 2 focuses on the i) developing and assessing the accuracy of a supervised land cover classification derived from high spatial resolution satellite imagery and plot level species cover and abundance data for a northern Chihuahuan Desert landscape, ii) assessing which environmental variables may be associated with the distribution of these land cover types, and iii) using a conceptual

state and transition modeling approach, develop hypotheses of how environmental change may impact land cover in these landscapes. Chapter 3 assesses the degree of woody encroachment over the last 68 years of the Indio Mountains Research Station (IMRS), an example of a heterogenous Chihuahuan Desert mountain ecosystem by assessing changes in shrub density and cover between multi-temporal aerial photographic time series. In addition, a relatively novel component of this study will explored the potential utility to use Kite Aerial Photography (KAP) in detailed land cover change assessments of arid landscapes. Chapter 4 describes the implementation of a module-based undergraduate curriculum that was aimed at developing a holistic understanding of environmental problems, solutions, and the use of technology in ecology. The activities present in the modules include ecological and environmental discovery in relation to local desert ecosystems and the process of desertification active in the region, remote sensing using satellite imagery, computer modeling, and experimental manipulations that explore how ecosystem restoration can improve sustainability. To evaluate the effectiveness of the modules, we used a series of pre- and post-tests to measure changes in student knowledge, perception of ecology and technology, and their sense of efficacy regarding those topics. Chapters in this dissertation are formatted for publication, and as such, repetition may be evident is some areas.

Chapter 2: Vegetation-environment relationships in a Chihuahuan Desert mountain ecosystem

Abstract: Mountain landscapes are known to be biodiversity hotspots in the northern Chihuahuan Desert and have served as important refugia in periods of past environmental change. Within these landscapes, however, the link between vegetated land cover and the environment remain poorly studied and a conceptual model of likely changes in land cover in response to environmental change are lacking. This study focused on the Indio Mountains Research Station south of Van Horn, Texas to produce a high spatial resolution land cover map and accuracy assessment, establish relationships between land cover and the environment, and develop a conceptual model describing how land cover may be altered in response to environmental change. Data from field surveys of 830 sites where plant community and other environmental data was derived, were analyzed using cluster analysis and non-metric multidimensional scaling to derive a 10 class land cover map using IKONOS imagery and a supervised classification, with an overall accuracy of 78.7% and a Kappa statistic of 0.716 from the confusion matrix used to conduct the accuracy assessment. Land cover was combined with a range of environmental data using ArcGIS 9.2 to determine the land cover-environment relationships that exist, and shows no difference in the land cover-environment relationship between classes. Finally, these land cover-environment relationships and vegetation data from each class were analyzed using correlation and regression tree analyses to derive a baseline conceptual model. The numerical analyses of environmental and geospatial data gave a good baseline model that shows the environmental variables responsible for the distribution of vegetation. Our study suggests that transition between one vegetation class type and another would occur from grassland to a more shrub dominated ecosystem when conditions become warmer and possibly drier.

2.1 Introduction

Mountain systems in desert ecosystems contain most of the diversity found in these regions and are recognized as hotspots for plant richness and endemism. These mountain systems are isolated from one another by physical distance and the desert and grassland ecosystems surrounding them, which act as barriers to species movements. For these reasons they are known as “sky islands” of biodiversity

(Weldon, 1967; Warshall, 1994). The Cordoba Mountains in central Argentina constitute a biogeographical island with 41 endemic plant and animal taxa (Cabido et al., 1998; 2003). The Naukluft Mountains in Namibia, Africa are also considered species-rich with high numbers of endemics (Maggs et al., 1994). The Peninsula of Baja California in Mexico is recognized as a hotspot for plant richness and endemism. There are 3789 flora species, with 20% being endemic. There are 567 endemics found in protected areas and 175 endemics not found in protected areas of this region (Riemann and Ezcurra, 2005). The southwest US ski island archipelago is unique and includes southwestern New Mexico, southeastern Arizona, northwestern Chihuahuan and northeastern Sonora (Weldon, 1967; Warshall, 1994). There are 150 endemic taxa found in New Mexico with most occurring in the southern tip of the Rocky Mountain region. The Guadalupe, White, and Sacramento Mountains harbor the remaining endemics (Dick-Peddie, 1993). The Chiricahua Mountains in the Sierra Madre Sky Island of Arizona are one of the most diverse forest ecosystems in the world (Whittaker and Niering, 1975; Warshall, 1994). The Santa Catalina Mountains in Arizona have rich floral communites and high biodiversity with the richest communities found on the desert slopes (bajadas) of the mountains of the Sonoran Desert (Whittaker and Niering, 1965). The Huachuca Mountains in Arizona is known as a "sky island" that has 994 species of flora and 36 endemic species (Bowers and McLaughlin, 1996). The Pinaleño Mountains have 824 flora species (McLaughlin, 1993).

Mountains are considered a significant element of the global ecosystem because they have been recognized as a reservoir for biodiversity and as a home to endangered species (UN, 1992). Mountains systems in general exhibit high biodiversity due to favorable climatic conditions over elevational gradients, where cooler and moister conditions exist at higher elevations (Whiteman, 2000). In addition, a higher number of endemic species are found at higher elevations because surrounding desert barriers cause them to remain isolated (Beniston, 2003). These factors make mountains hot spots for biodiversity (Diaz et al., 2003). In the southwest US arid regions, the role of topography plays a profound role. The extreme aridity and climatic conditions of lower elevations causes lower species diversity and differences in species composition (Whitaker and Niering, 1965; Poulos and Camp, 2005), whereas higher elevations have reasonable conditions compared to lower elevations (Poulos and Camp, 2005).

Northern exposures have more moderate moisture conditions than southern exposures, which tend to be drier, causing differences in species composition as well (Poulos and Camp, 2005). Further, changes in the topography of mountainous terrain can cause a lack of water creating water stress (Ogle et al., 2000; Nevo, 2001). Different species have site specific adaptations in response to climate affected by topography, and differences in physiological tolerances of plant species to drought affect vegetation distribution patterns across these landscapes (Poulos and Camp, 2005). Mountain ecosystems within the Chihuahuan Desert are high in biodiversity due to the ideal climate present for plant species caused by elevation gradients (Gitlin et al., 2006). In the face of unprecedented global environmental change, understanding of vegetation distribution patterns of mountain ecosystems within arid and semiarid regions are even more important in order to maintain biodiversity and further understanding of vegetational responses to changes in the environment.

Climate change is one of the global environmental changes occurring today. Mountains represent unique areas for the detection of climate change because as climate changes rapidly with height over short horizontal distances, so does vegetation (Whiteman, 2000) as they migrate towards more favorable climatic condition (McArthur, 1972). In addition, high relief and gradients make mountain systems vulnerable to changes in climate (Diaz et al., 2003) making any changes in the native flora species composition and abundance leading indicators of future global change. This is because these mountain systems have a propensity to amplify environmental change (Seastedt et al., 2004). These climate change effects on vegetation shifts has been seen in numerous studies using GAP models in the Western US mountains (Woodward et al., 1995) and the British Columbia mountains (Cumming and Burton, 1996). Climate change also has effects on the mountain water system and resources by causing declines in snow cover and glacier storage (Messerli et al., 2004) which have consequences for the mountains and lowlands that depend on this valuable water resource (Beniston, 2003). Studies done in the French Alps utilizing snow models show shifts of seasonal snow packs and declines of snow cover (Martin and Durand, 1998), which have implications for early seasonal runoff (Dettinger and Cayan, 1995) and triggering of annual plant cycles of mountain flora (Cayan et al., 2001). Other types of environmental change include deforestation, over-grazing by livestock, shifting fire regimes, and cultivation of soils

(Beniston, 2003). Cattle ranching, agriculture, mining, and introduction of exotic and invasive species have been increasing causes of environmental disturbance in the Baja California Peninsula in Mexico, and it is recommended that protected areas and knowledge of the distribution of endemics are needed (Riemann and Ezcurra, 2005). Live-stock grazing and anthropogenic fires caused erosional and woodland degradation in the Cordoba Mountains of Argentina (Renison et al., 2002; Cingolani et al., 2003). Changes in fire regimes through the removal of fires has caused changes in forest stand structure and increased fuel loads (Swetnam and Baisan, 1996; Fule et al., 2004). This has brought the extreme intensity fires as a hazard, instead of the low intensity surface fires that were prominent (USDA forest service and USDI, 2000). In Big Bend National Park in Texas and the Maderas del Carmen in Coahuila, Mexico predictive modeling was used to map fire prone areas and to correlate environmental factors to fire hazards (Poulos, 2009). White and Vankat (1993) looked at vegetation distributions in response to the environment and changes in land management practices (fire regimes) in Grand Canyon National Park, Arizona. They used vegetation classifications of field data with detrended correspondence analysis and regression and analysis of variance to determine relationships between vegetation and topographic features (White and Vankat, 1993). Coblentz and Riiters (2004) looked at the effects of topography on the distribution of vegetation in the southwest US arid regions using a quantitative biodiversity model to predict biodiversity based on topographic features. Beatley (1974) looked at vegetation communities' response to precipitation changes in the Mojave Desert using flow diagrams. Peterson (2003) used ecological niche modeling to look at changes in bird species diversity and distribution in montane ecosystems versus flatlands within the Chihuahuan desert. The flatlands were more susceptible to climate change predictions. These studies show the importance of understanding changes in biodiversity in response to environmental changes, yet the use of conceptual models, which have been noted as a critical component of research into change dynamics, is not seen in any of these studies.

To help mitigate change in mountain ecosystems, an integrative modeling approach is necessary which requires 1) knowledge about present environmental and ecological conditions, and 2) knowledge about future states through information and modeling (Miller et al., 2007). The development of a conceptual model, derived from an ecological concept about a specific environment, aids in the

understanding of complex change dynamics (Riebsane et al., 2000), and can provide insight on how the environment can influence the distribution of vegetation and how any changes in the environment can cause changes in vegetation community types (Beniston, 2003). To derive conceptual models of a particular site, critical conceptual models components are needed and include: 1) species (vegetation) distribution patterns, and 2) direct and indirect predictors that predict the distribution of biotic entities on the basis of environmental parameters (Guisan and Zimmermann, 2000). The most sophisticated projections of vegetation cover come from simulations of biological patterns of vegetation change with abiotic factors such as soils (Riebsame et al., 2000) and topography, which is the most readily measurable and accurately known of all parameters used to describe the Earth (Coblentz and Riiters, 2004). Also, even though modeling species instead of communities comes closer to what is realistic in nature (Franklin, 1995), an alternative to modeling communities is to select associations based on dominant species and classify their distributions to generate land cover maps (Lenihan, 1993; Austin, 1998; Guisan and Theurillat, 2000). With recent advances of DEM's, computer capabilities, remote sensing techniques, and high spatial resolution satellite imagery, land cover maps can be created which can act as a measure of biodiversity. This has prompted the analysis of topographic and spatial distribution of biodiversity relationships (Coblentz and Riiters, 2004). Species-environment relationships are important determinants of vegetation abundance and spatial distribution (Poulos and Camp, 2005). In the Chisos Mountains of Big Bend, tree species abundance and distribution patterns were correlated with elevation and potential soil moisture gradients, while aspect and heat load did not predict species abundance and distribution. In addition, drought tolerant species were found at lower elevations while mesophytic species dominated the higher, wetter elevations (Poulos and Camp, 2005). This study used NMS for correlation of environmental factors to vegetation, and cluster analysis and species indicator analysis were used to determine vegetetation class. No conceptual model was used in this study. The utilization of concept models in southwest US mountain ecosystem research have focused on ecohydrological patterns in pinyon-juniper woodlands (Ludwig et al., 2005) and erosion processes in pinyon-juniper woodlands (Davenport et al., 1998). A good example of a conceptual model developed for probabilistic modeling to predict changes in vegetation communities caused by

environmental changes is seen in Johnson et al. (2011) at Niwot Ridge, Colorado. In the Chihuahuan desert, conceptual models in the form of state and transition models have focused on rangeland ecosystems at lower elevations for management of rangeland sustainability (Stringham et al., 2003; Bestelmeyer et al., 2003, 2009; Herrick et al., 2006; Peters and Havstad, 2006).

Mountains cover 25% of the earth's land surface (Diaz et al., 2003) and are important sources of water, energy, minerals, forest and agricultural products, and areas of recreation and tourism (UN, 1992). Mountain runoff provide for 50% of the globe's rivers (Viviroli et al., 2003), and climate change can impact the hydrological cycle through declines in snow cover, glacier storage (Messerli et al., 2004), and through changes in vegetation community structure and composition (Wondzell et al., 1996; Ludwig et al., 2005), which have consequences for the mountains and lowlands that depend on this water resource (Beniston 2003). This is especially important in arid and semiarid regions of the world where mountain runoff is 50-90% of its water source. Because of the increasing scarcity of water in these regions and the implications it has on irrigation and food production (Messerli et al., 2004), this makes sustainability of mountain water resources important. Even then, the Earth is in an era of rapid environmental change never seen in the history of the world (Miller et al., 2007). In the face of this change, an understanding of factors affecting biodiversity is necessary (Coblentz and Riiters, 2004). Despite the confidence in global changes, predicting directions of change at local and regional scales is still a challenge (Miller et al., 2007), making conceptual frameworks of great importance. In addition, the effects of climate change and human impacts on biodiversity have focused on Chihuahuan desert flatlands, and not in montane areas that dominate the region (Peterson, 2003). Lastly, conceptual models in the form of state and transition models in the Chihuahuan desert have focused on rangeland ecosystems at lower elevations for management of rangeland sustainability (Stringham et al., 2003; Bestelmeyer et al., 2003, 2009; Herrick et al., 2006; Peters and Havstad, 2006), ecohydrological patterns in pinyon-juniper woodlands (Ludwig et al., 2005), and erosion processes in pinyon-juniper woodlands (Davenport et al., 1998). Despite studies focusing on vegetation-environmental relationships in a Chihuahuan desert mountain ecosystem (Poulos and Camp, 2005), the development of a conceptual model describing the area was not done. An important challenge in the future in understanding climate

changes' effect on biodiversity is that of arriving at a generalizable and predictive understanding of those effects.

The primary objectives of this study are to i) develop and assess the accuracy of a supervised land cover classification derived from high spatial resolution satellite imagery and plot level species cover and abundance data for a northern Chihuahuan Desert landscape, ii) assess which environmental variables may be associated with the distribution of these land cover types, and iii) using a conceptual modeling approach, develop hypotheses of how environmental change may impact land cover in these landscapes. The study will focus on the Indio Mountains Research Station owned and managed by the University of Texas at El Paso. This study also serves to develop fundamental baseline data useful to the gamut of other research, monitoring, and educational activities ongoing at IMRS.

2.2 Methods

A work flow of the methods used in this study is presented in Figure 2.1.

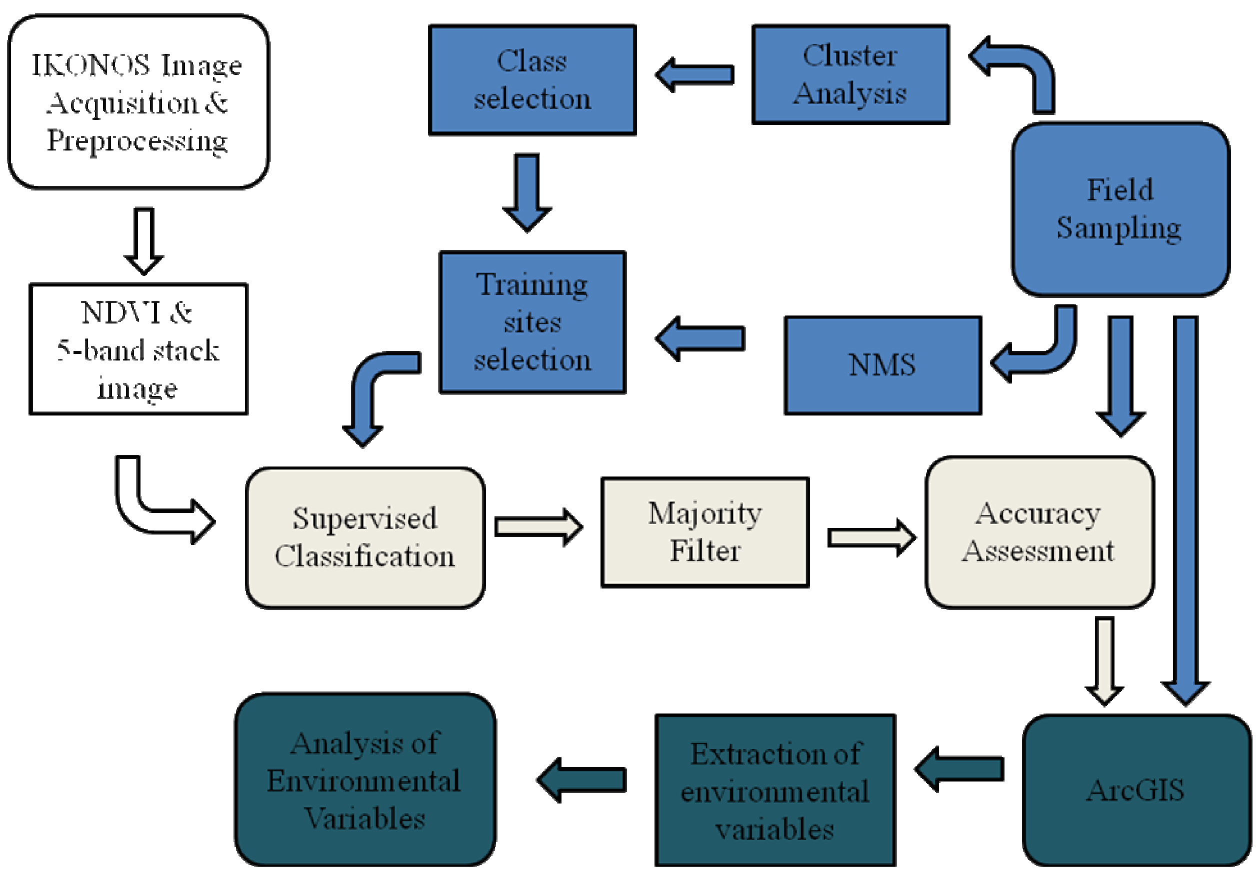


Figure 2.1. Flowchart of the methodology used in this chapter.

2.2.1 Field data collection and analysis

In June-August 2008 and 2009, a total of 830 sites within IMRS were sampled. Sites were non-randomly located within less than 500m and more than 5m of minor roadways spanning IMRS where relatively homogenous stands of vegetation were observed (Fig. 2.2). At each site, a site photograph was captured and GPS, location, elevation, slope, and aspect were recorded. The geology of parent material near each site was assigned categorical values (Table 2.1) which were derived from geology maps for the Indio Mountains Research Station area (Stoeser et al., 2005; Underwood, 1963). Soil type was assigned categorical values (Table 1) which corresponded to soil types derived from soil survey maps of the area (Table 1) (Natural Resources Conservation Service, 2011). The cover of dominant plant species was also recorded using a variation of Daubenmire's scale (1-5%, 5-20%, 21-40%, 41-60%, 61-80%, 81-100%).

Vegetation classes were determined from the plant species cover – site matrix using cluster analysis performed in the software PCOrd version 5 using a Euclidean distance measure and Ward's linkage method (McCune and Grace, 2002). A non metric multidimensional scaling ordination was then executed on the same data matrix using PCOrd in autopilot mode and a Euclidean distance measure. The ordination was used to affirm the results of the cluster analysis and identify suitable training sites for supervised image classification. Vegetation classes were named based on the dominant species found in each plant association as in Beatley (1974) and Plumb (1991). Wetland species is defined as any aquatic annual or small perennial plant species confined to locations within the tanks found in IMRS, and are dependent on the unique ecosystem provided by the tanks (acting as a wetland) thus these species are not found anywhere else.

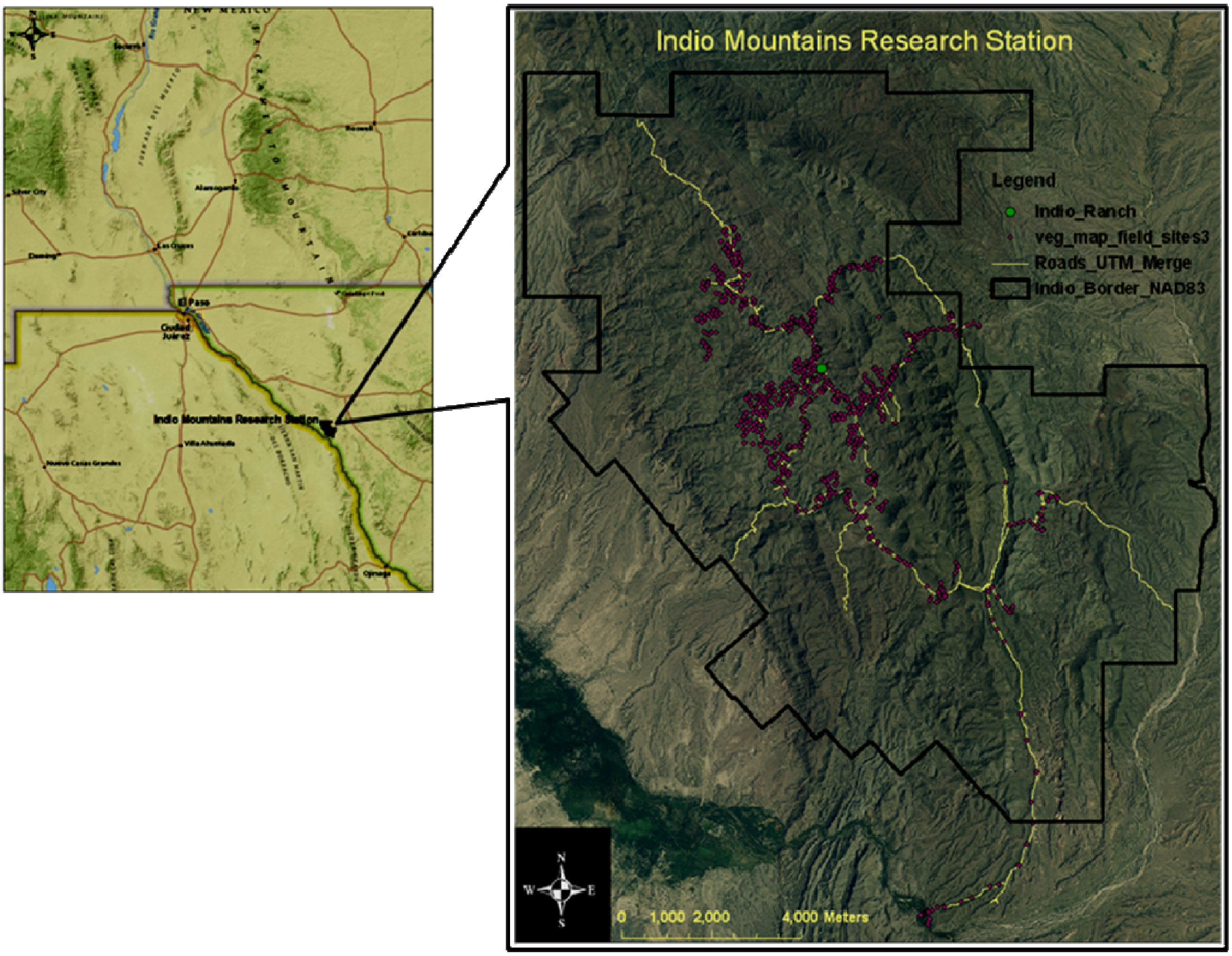


Figure 2.2. Location of the Indio Mountains Research Station, near Van Horn, Texas, U.S.A. All sites sampled are denoted by the purple point on the map.

Table 2.1. Categorical value assignments to the geology and soil types found at IMRS.

Code	Soil type	Geology type
1	Culberspeth-Chilicotal complex	sedimentary
2	Blackgap and Terlingua soils and rock outcrop	conglomerate
3	Chipotle-Riverwash complex	sandstone
4	Pantera-Riverwash complex	limestone
5	Blackgap and Terlingua soils and rock outcrop	igneous/volcanic
6	Ojinaga-Corazones complex	sandstone/limestone mix
7	Castolon, Galindo, and Lomapelona soils	conglomerate, sandstone, siltstone, and limestone mix
8	Chillon extremely gravelly sandy loam	alluvium
9	Ojinaga-Corazones complex	shale, sandstone, and limestone
10	Changas-Corazones complex	---
11	Baviza loamy fine sand	---

2.2.2 Image acquisition and classification

Following review of publicly available high spatial resolution imagery for the IMRS area of interest, a cloud-free IKONOS image acquired on October 29, 2007 (acquisition time 17:57 GMT, 11:57 a.m. local mountain time, and 26° off nadir view angle. The four band multispectral (4m) and panchromatic (1m) images were provided by the GeoEye Foundation orthorectified and spectrally corrected for atmospheric disturbances. It has an RMS error of 12 m. A Normalized Difference Vegetation Index (NDVI) layer was created using the red and near-infrared bands in ENVI version 4.4 with the following equation: NDVI = (NIR – RED)/(NIR + RED) (Burgan and Hartford, 1993). The four multispectral bands and NDVI layer were then stacked to create a 5-band image for supervised classification.

Following identification of the 6-class vegetation classification derived from cluster analysis and ordination, additional classes for bare ground, water, riparian vegetation and shadow were identified on the image following ground truthing to create a total of 10 land cover classes for the image area. For each vegetated land cover class, with the exception of riparian vegetation, training sites for the supervised classification were chosen as the five sites nearest to the mean ordination axis score for a given land cover class. These five sites were used as the training sites for supervised classification mapping since the sites are considered the best representatives of each class because they are the closest to the mean score. For the riparian and other land cover types, training sites were selected within known areas of each class in the image. The supervised classification was executed using a maximum likelihood algorithm on the 5-band IKONOS image in ENVI 4.4. A majority filter was applied to the resulting map to reduce granularity using a 3 by 3 meter kernel.

2.2.3 Accuracy Assessment

The remaining 795 field sites not used in the training of the supervised classification were used to assess the accuracy of the land cover map, since land cover at each site was previously classified according to the cluster analysis and verified with site photographs. The map class for each site was extracted from the supervised classification raster graphic using ArcGIS 9.2 and a confusion matrix was developed following protocols for land cover accuracy assessment laid out by Congalton (1991). Errors were evaluated and adjusted for georeferencing error, misclassification of sites in the cluster analysis, and vegetation class diversity within the area creating 5m buffer zones around each site's gps location, and assessing the classes that fell within the buffer area. The class was then classified according to the dominating class within the buffer zone. The error of commission, or producers accuracy, indicates the probability of a given map class being that map class when it is visited on the ground. The error of omission, or consumer's accuracy, indicates the probability that the land cover for a given location has been accurately mapped (Congalton and Green, 2008). Kappa statistics are typically used to test for conformity between matrices in a contingency table and account for chance agreement. Kappas below 0.4 are generally regarded as poor, 0.4 to 0.7 fair to good, and above 0.7 good to excellent (Fleiss, 1981).

2.2.4 Association between land cover and the environment

To determine likely drivers of land cover change using natural environmental gradients, the relationship between a range of environmental variables and land cover types was explored. Environmental variables included NDVI, geology, soil type, elevation, slope, aspect, latitude and longitude, annual solar radiation, and plant species composition. A GIS layer was made for each parameter where spatial joins could be used to combine the information for each pixel in the land cover map with the information of the GIS layer for each environmental parameter. NDVI raster values were extracted using ArcGIS 10 from the NDVI band computed in ENVI (4.4). Geology was extracted using the Texas geologic survey map (Stoeser, 2005) and reclassified according to Underwood (1963). Soil type was determined using the soil survey map of Texas (USDA Natural Resources Conservation Service, 2011). Elevation, slope, and aspect raster values were calculated using a Digital Elevation Model (DEM) (produced by the US Geologic survey and available online at http://www.eros.usgs.gov) of the area and extracted using ArcGIS 10. Solar radiation was computed for the 2010 year using the solar radiation tool, which calculates the insolation across the entire landscape using the DEM, and extracted in ArcGIS 10. Random numbers were generated in Excel and combined with all of the environmental values generated above and imported into a database where the random numbers generated previously selected 10,000 random records from the 10,000,000 total for analysis.

2.2.5 Development of a conceptual model

The mean axis scores for each class from the NMS were then combined with environmental and biological parameters computed for each of the sites to develop a conceptual model for IMRS. Mean estimated cover for each species in each class was calculated from the field data and a correlation analysis was conducted on the mean estimated cover to find the associations among the vegetation classes. The scatterplot derived from the NMS determined the location of the vegetation classes in relation to one another in ordination space, and Pearson's r-squared values derived from the correlation analysis were used to determine the strength of the relationships between the vegetation classes. Then, we used regression tree analysis in JMP version 9 on the environmental variables and species data to partition the vegetation classes in terms of the biological and environmental variables that will act as

predictors, or indicators, for each axis of the conceptual model. Regression tree analysis is a nonparametric method, robust to the type of continuous and categorical data used in this study, and appropriate for species composition data (McCune and Grace, 2002). The regression tree analysis split the vegetation classes to find the single best predictors for each axis until a stabilized cumulative r^2 was reached, whereby adding more splits did not add much to the cumulative r^2 value. The results gave us an overall assessment of which variables were indicators for changes between the vegetation classes.

2.3 Results

2.3.1 Vegetation classification

Cluster analysis identified a total of eight vegetation classes after 50% of information remaining. The NMS ordination run on the data showed some of the classes, groups 1 and 4, and 6 and 7, overlapped in ordination space (Fig. 2.3). The results of the NMS identified six vegetation classes overall.

The non metric multidimensional scaling recommended a two-dimensional solution that yielded a final stress and instability of 16.70 and 0.0019 after 200 iterations (Fig. 2.3). The ordination represented 89.7% of the cumulative variance with axis 1 and 2 explaining 66.6% and 23% of the variation respectively. The NMS shows axis 1 and 2 are each correlated with two environmental variables (r^2 = 0.32 and 0.05, respectively), denoted by the red arrows. It appears that axis 1 is negatively correlated with elevation and slope (r^2 = 0.22 and 0.1, respectively). Axis 2 seems to be correlated with soil type and geology (r^2 = 0.03 and 0.01, respectively).

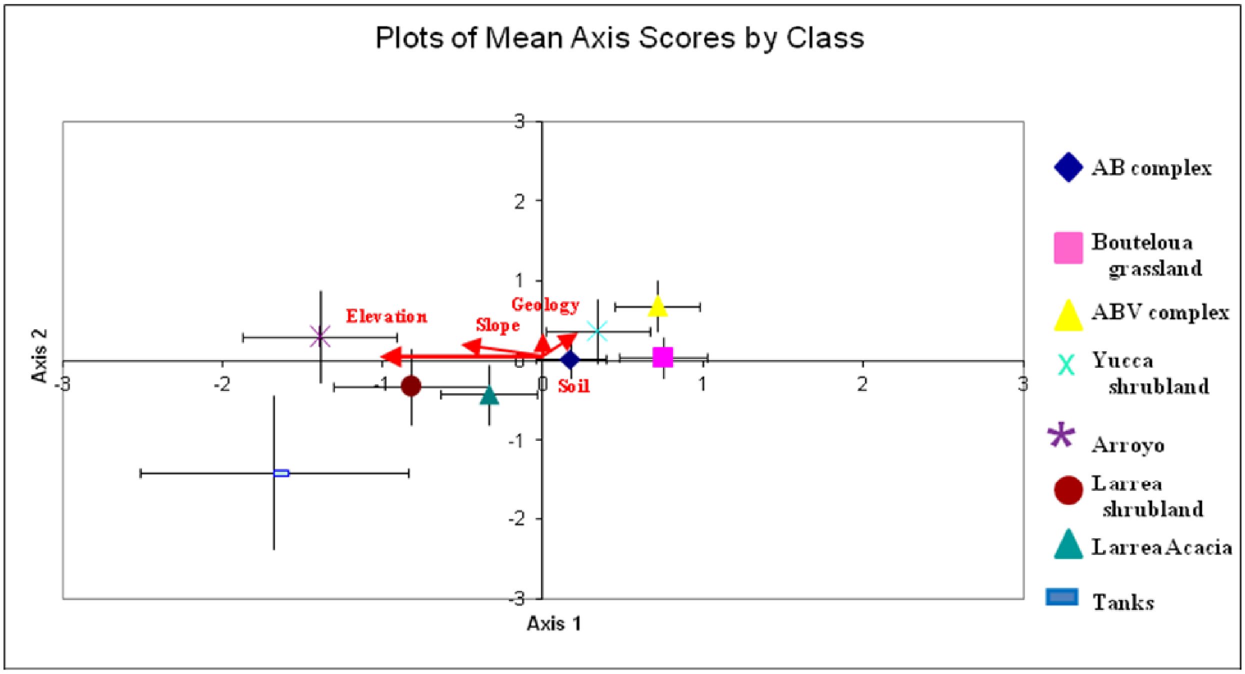


Figure 2.3. Plots of mean NMS axis scores for each class derived from the cluster analysis. Error bars denote standard deviations. Red arrows show the axis that each environmental factor correlates to.

The six classes derived from the cluster analysis and ordination are described below (see Fig. 2.4 for pictures). Following are the names of each class, given based on the dominant species for the class, and a description of the vegetation, geology, and soil types found in each class with further descriptions in Table 2.2.

Table 2.2. Table of class descriptions.

Map Class (Area in hectares/%)	Land cover class	Class Description	Dominant Species
1 5023, 21.6%	*Agave Bouteloua* complex	*Agave* and *Bouteloua* coverage: moderate to dense (>50% coverage) Other species: *Yucca*, *Larrea*, *Dasylirion*, *Fouquieria*, *Opuntia*, and *Acacia* with sparse to moderate coverage	*Agave lechugilla, Bouteloua eriopoda,*
2 487, 2.1%	*Bouteloua* grassland	*Bouteloua* coverage: dense (>50%) Other species: *Agave lechugilla*, *Yucca*, *Fouquieria*, *Dasylirion*, various shrubs and cacti with sparse and occasional coverage	*Bouteloua eriopoda*
3 4200, 18.1%	*Agave Bouteloua Viguiera* complex	*Agave*, *Bouteloua*, and *Viguiera* coverage: moderate to dense Other species: *Tiquila*, *Opuntia*, *Ephedra*, *Leucophyllum*, *Dasylirion*, *Yucca*, *Fouquieria*, *Acacia*, *Parthenium*, cholla cactus, *Condalia*, *Ziziphus*, other cacti and sub shrubs with moderate to moderate dense coverage *Larrea* and *Prosopis* are occasional	*Agave lechugilla, Bouteloua eriopoda, Viguiera stenaloba*
4 5802, 25.0%	*Larrea Acacia* complex	*Larrea* and *Acacia* coverage: moderate to dense coverage Other species: *Opuntia*, *Yucca*, *Fouquieria*, *Viguiera*, *Bouteloua*, *Agave*, *Dasyochloa*, *Condalia*, *Ziziphus*, and *Parthenium* with sparse to moderate coverage.	*Larrea tridentata, Acacia greggi, Acacia constricta, Opuntia sp.*
5 With riparian	Arroyo	Arroyo 1: *Chilopsis*, *Baccharis*, and *Prosopis* coverage: dense Arroyo 2: *Acacia*, *Fallugia*, *Prosopis*, *Atriplex* coverage: dense Other species: *Larrea*, *Forestiera*, *Rhus spp.*, *Quercus*, *Celtis*, *Populus*, *Juniperus,* and *Tacoma* with moderate dense coverage	*Acacia greggi, Prosopis glandulosa, Atriplex sp., Fallugia paradoxa*
6 With riparian	Tanks	Riparian grasses and annuals: sparse to dense coverage; some tanks have no vegetative cover with bare ground exposed.	Riparian grasses and plants
7 1573, 6.8%	Shadow	Areas in the image that were blocked of incoming light and cast a shadow on the area	none
8 4485, 19.3%	Bare Ground	Areas completely devoid of vegetation cover, usually consisting of roads and arroyos	none
9 38, 0.2%	River	River	none
10 1631, 7.0%	River Riparian	*Populus* and *Chilopsis* coverage: moderate dense to dense Other species: *Tamarix* and *Prosopis* with moderate to moderate dense coverage; riparian grasses with dense coverage along the banks	*Populus fremontii, Chilopsis linearis, Tamarix sp., Prosopis glandulosa*

***Agave Bouteloua* Complex** (Fig. 2.4A). *Agave lechugilla* and *Bouteloua eriopoda* cover dominates this class. Other common species include *Larrea tridentata*, *Dasylirion*, and sometimes *Acacia* spp. There is less diversity and abundance of vegetation overall than the *Agave Bouteloua Viguiera* complex, except for the abundance of *Bouteloua eriopoda*. The geology is dominated by the sandstone-limestone mix (76%) and the dominate soil type is the Blackgap and Terlingua soils and rock outcrop complex making up 63% of the occurrences.

***Bouteloua* Grassland.** Class 2 is the *Bouteloua* grassland class (Fig. 2.4B). This class is similar in vegetation make-up to the *Agave Bouteloua* complex. *Agave lechugilla* is present sometimes and *Bouteloua eriopoda* coverage is dense (always more than 50% coverage) and clearly dominates the class. Other species are present but coverage is sparse or occasional. There is less diversity of vegetation than classes 1 and 4, but associated species include *Yucca*, *Fouquieria splendens*, *Dasylirion*, and various shrubs and cacti. The dominant geology type for this class is the conglomerate-sandstone-siltstone-limestone (50%) and soil type is the Blackgap and Terlingua soils and rock outcrop complex (92%).

***Agave Bouteloua Viguiera* Complex.** Class 3 is the *Agave Bouteloua Viguiera* complex (Fig. 2.4C). This class has dense coverage overall and is the most diverse of all the classes. It has moderate dense to dense coverage of *Bouteloua eriopoda*, *Agave lechugilla*, and *Viguiera stenaloba*. It has moderate to moderate dense coverage of *Tiquila greggi*, *Opuntia spp*., *Ephedra*, *Leucophyllum*, other cacti, and various other sub shrubs. Other species present include *Dasylirion*, *Yucca*, *Fouquieria splendens*, *Acacia spp.*, *Parthenium incanum*, cholla cactus and other shrubs such as *Condalia ericoides* and *Ziziphus obtusifolia*. *Salaginella lepidophylla* is present in some sites. *Larrea tridentata* and *Prosopis glandulosa* are occasional. The dominant geology type for this class is the conglomerate-siltstone-sandstone-limestone mix (79%) and soil type is the Blackgap and Terlingua soils and rock outcrop complex (97%).

Arroyo. Class 5 is the Riparian arroyo class (Fig. 2.4E). Thick stands of vegetation are found along the banks of arroyo zones and extend 20 meters from the banks on either side. The mid-arroyo zones are normally bare ground due to the force of water that comes from flashfloods during heavy thunderstorms. Along the banks and extending 20 meters on both sides vegetation include two arroyo subclasses:

Acacia spp., *Fallugia paradoxa*, *Prosopis glandulosa*, *Atriplex canescens* and *Chilopsis linearis* with *Baccharis* and *Prosopis glandulosa*. Some arroyos also contain *Forestiera angustifolia*, *Rhus microphylla*, *Quercus pungens*, *Xerophyllum*, *Rhus virens*, *Celtis reticulata*, *Populus freemontii*, *Juniperus pinchotii*, and flowers such as *Tacoma stans*. These shrubs are unique to the arroyo zones and may not be found anywhere else. Extending 20 meters from the banks, these plants may dominate the area. Shrubs with these tendencies include *Larrea tridentata*, *Acacia* spp., and *Prosopis glandulosa*. Plants characteristic of the class in the area will also be denser in these zones creating a dense mixture of vegetation classes. The dominant geology type is the conglomerate-siltstone-sandstone-limestone mix (36%) and the soil type is the Blackgap and Terlingua soils and rock outcrop complex (90%).

***Larrea Acacia* Complex.** Classes 6 and 7 comprise the *Larrea Acacia* complex (Fig. 2.4D). The dominant species in this class is *Larrea tridentata* and varies in coverage from moderate to dense. This class has moderately dense to dense coverage of *Acacia* spp. and is second dominant. In some sites, the dominant species is *Acacia* spp. with *Larrea tridentata* as second dominant. *Dasyochloa pulchella* is common in these sites. *Bouteloua eriopoda* and *Agave lechugilla* are abundant occasionally. Other species associated with this complex are various cacti species including *Opuntia* spp., *Condalia ericoides*, *Ziziphus obtusifolia*, *Viguiera stenaloba*, *Parthenium incanum*, *Yucca*, and *Fouquieria splendens*. The dominant geology type for this class is the conglomerate-siltstone-sandstone-limestone mix (51%) and the soil type is the Blackgap and Terlingua soils and rock crop complex (80%).

Tanks. Class 8 is the Tanks class (Fig. 2.4F). Tanks are spread throughout various locations within the Indio Ranch property. They are large areas of land where water collects. The center of the tanks can range from bare ground with occasional riparian species to dense coverage of riparian grasses and other riparian species. Surrounding the tanks are thickets of *Prosopis glandulosa*, *Acacia* spp., and *Larrea tridentata*. The dominant geology type is the sandstone (38%) and the soil type is the Blackgap and Terlingua soils and rock outcrop complex (92%).

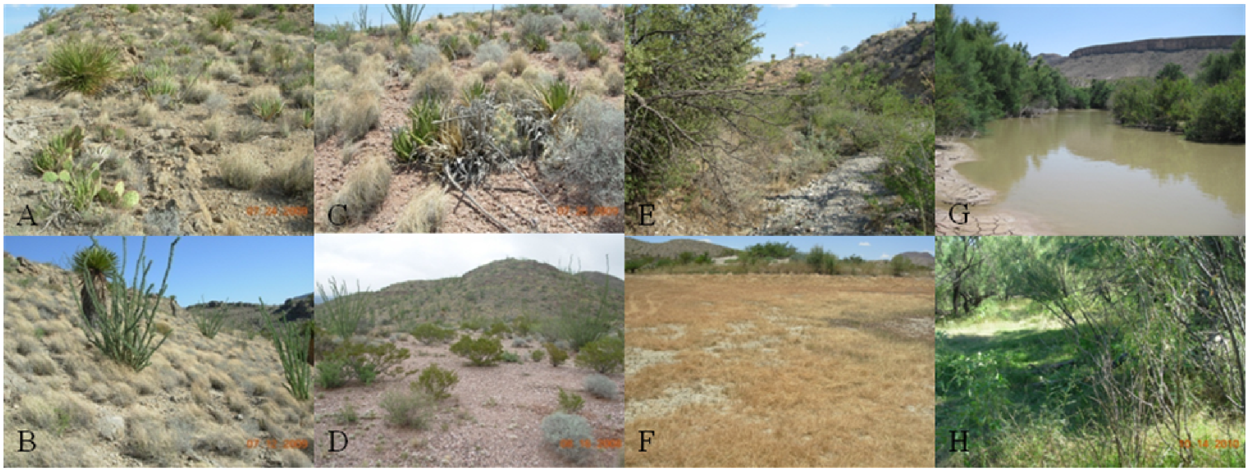


Figure 2.4. Images of vegetation classes shown. *Agave Bouteloua* complex (A), *Bouteloua* grassland (B), *Agave Bouteloua Viguiera* complex (C), *Larrea-Acacia* shrubland complex (D), Arroyos (E), Tanks (F), River (G), and River riparian (H).

2.3.2 Land cover classification and accuracy assessment

The land cover map of the Indio Mountains Research Station derived using supervised classification is given in Figure 2.5. The map aligns well with landscape features and appears to delineate relatively fine scale micro-topographic features including roads, tanks, and corrals. Areal extent of each land cover class is given in Figure 2.6. Class 4, the *Larrea Acacia* complex, covered the greatest area (24.97%) followed by the *Agave Boutleoua* complex (21.62%), the bare ground class (19.30%), and the *Agave Boutleoua Viguiera* complex (18.08%). The riparian, shadow, and *Boutleoua* grassland classes covered less than 10% of the mapped area of interest.

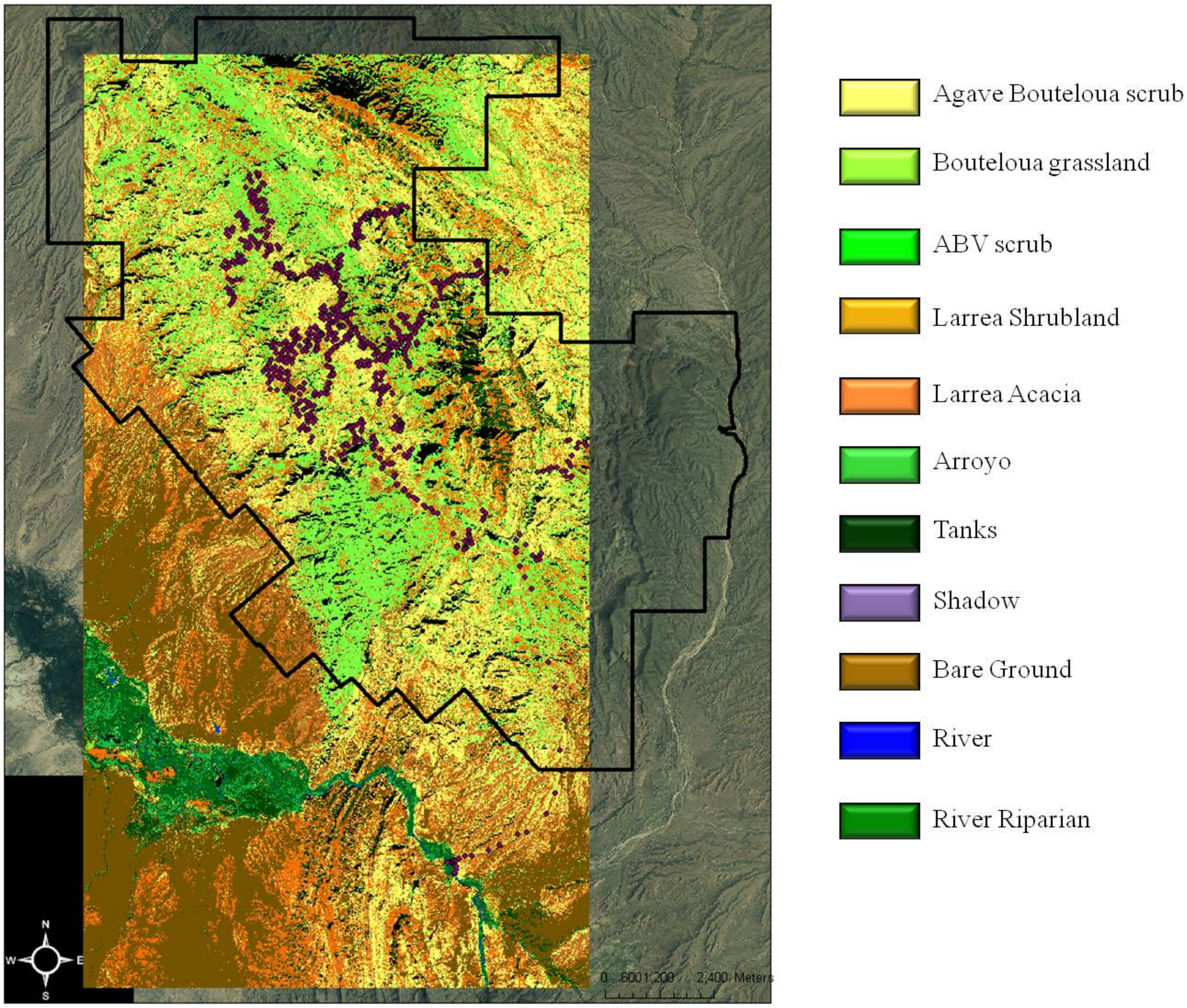


Figure 2.5. Land cover map of the IMRS and surrounding area using IKONOS satellite imagery.

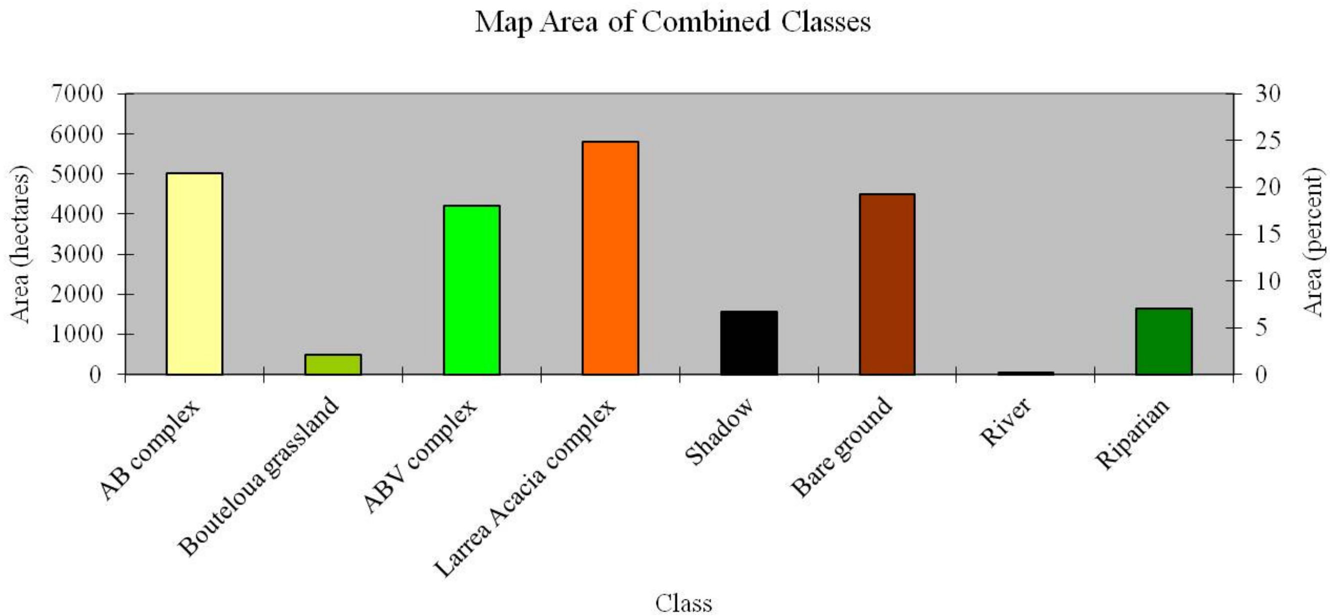


Figure 2.6. Bar graph representing the amount of land occupied by each land cover class. The *Larrea-Acacia* complex occupies the most land at nearly 6,000 hectares.

Results from the accuracy assessment are shown in Table 2.3. The overall accuracy (79%) and Kappa statistic (0.72) were good (*sensu* Fleiss, 1981) indicating that the land cover map adequately described the range and extent of the mapped land cover classes in the study area. The error of commission, or user accuracy, was 86% and the error of omission, or producer accuracy, was 80%. The user accuracy for the river, river riparian, and arroyo classes were 100%, while the *Agave Bouteloua* complex and shadow class were 75%. The producer accuracy for the shadow, bare ground, and river classes were 100%, while the *Bouteloua* grassland class was 52%, with all other classes fell between these ranges (Table 2.3).

For some accuracy assessment points, error appeared to be related to poor image orthorectification. Other sources of error include misclassification of sites caused by similar pixel values between classes. For example, the shaded areas of the image were mapped as riparian and river classes in some cases, and vice versa. In addition, low accuracies for the *Agave Bouteloua* and *Agave Boutleoua Viguiera* classes were related to misclassification of the classes to primarily the *Bouteloua* grassland. This could be due to the variation in the cover of *Bouteloua eriopoda.*

Table 2.3. Confusion matrix for the land cover classes. User and producer accuracy, along with overall accuracy, Khat, and Kappa statistics are shown.

	IKONOS Classes										
Ground Classes	Shaded	Bare ground	River	River riparian	Agave Bout. Comp.	Bouteloua grassland	ABV comp.	Larrea Acacia complex	Tanks	Arroyos	User Accuracy
Shaded	12				4						0.75
Bare ground		36		2	4				1		0.84
River			1								1.00
River riparian				5							1.00
AB complex				1	223	11	11	45		1	0.76
Bouteloua grassland					1	24		3			0.86
ABV complex					32	7	149	10		2	0.75
Larrea Acacia complex					14	4	10	155	1	2	0.83
Tanks					1			1	12	1	0.80
Arroyo										9	1.00
Producer Accuracy	1	1	1	0.63	0.80	0.52	0.88	0.72	0.86	0.60	

OverallAccuracy%	
0.79	
A	626
B	158686
Khat	1.05
Kappa	0.72

2.3.3 Relationship of vegetation distribution to the environment

The mean and standard deviation for NDVI, solar radiation, elevation, slope and aspect for each land cover class are given in Figure 2.7. The mean NDVI (Fig. 2.7A) for the *Agave Bouteloua*, *Agave Bouteloua Viguiera*, and *Larrea Acacia* complexes and the bare ground and river classes were about the same and lower than the arroyo, tanks, shadow, and river riparian classes. The highest mean NDVI was the river riparian class and the lowest was the bare ground class. The mean solar radiation (Fig. 2.7B) for each land cover class was approximately equal across all classes, except the shadow class which had the lowest mean and the tanks class which had the highest mean. The mean elevation (Fig. 2.7C) was also approximately equal across all land cover classes except the tanks and shadow classes which had higher mean elevations, and the bare ground class which had the lowest mean elevation. The mean slope (Fig. 2.7D) was approximately equal for all classes, except the tanks and shadow classes, which had

slightly higher mean slope values, and the river riparian, which had the lowest mean slope. The mean aspect (Fig. 2.7E) for each land cover class was also approximately equal, except the *Bouteloua* grassland class which had the lowest mean aspect. The shadow class had the highest mean aspect.

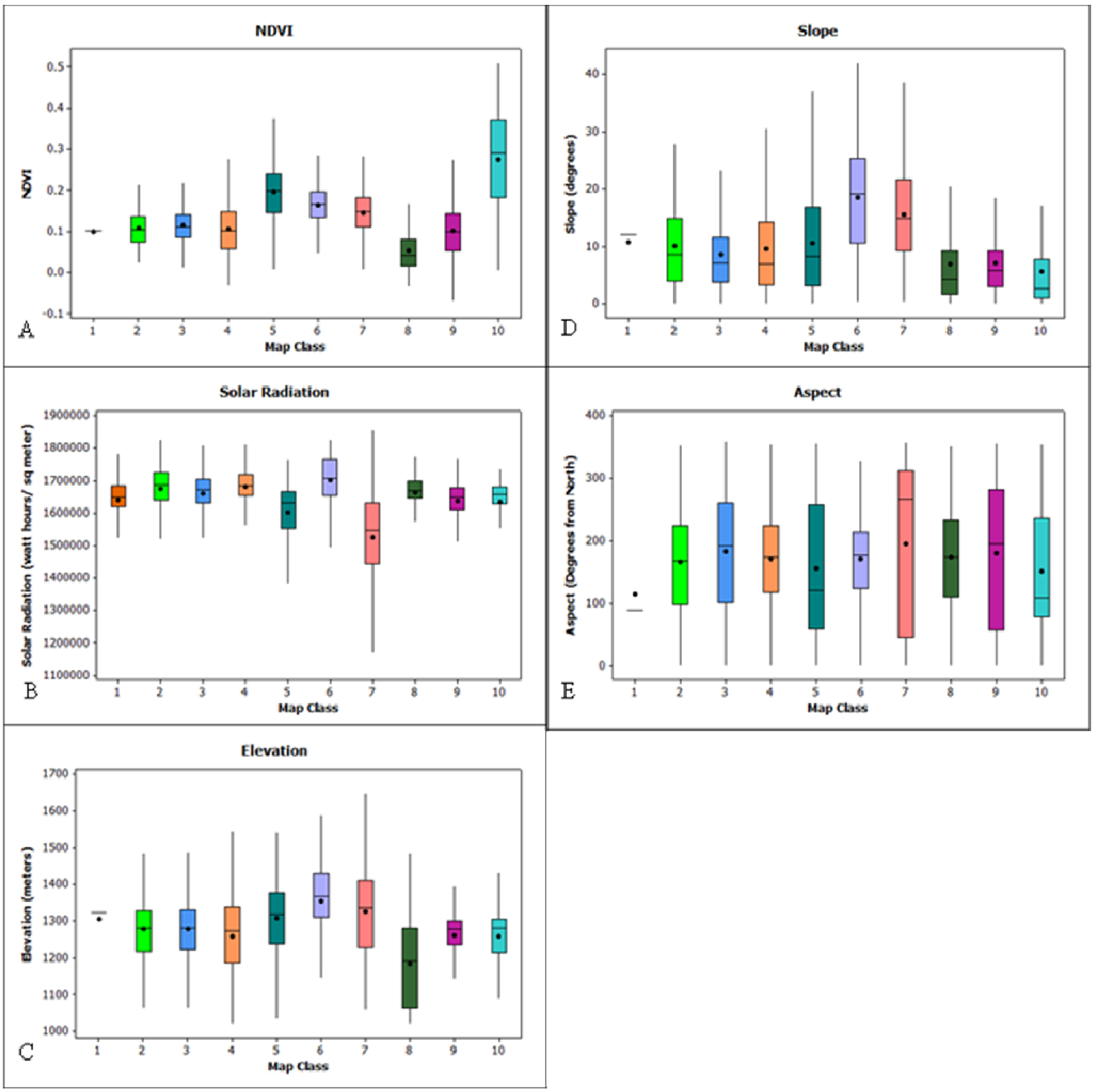
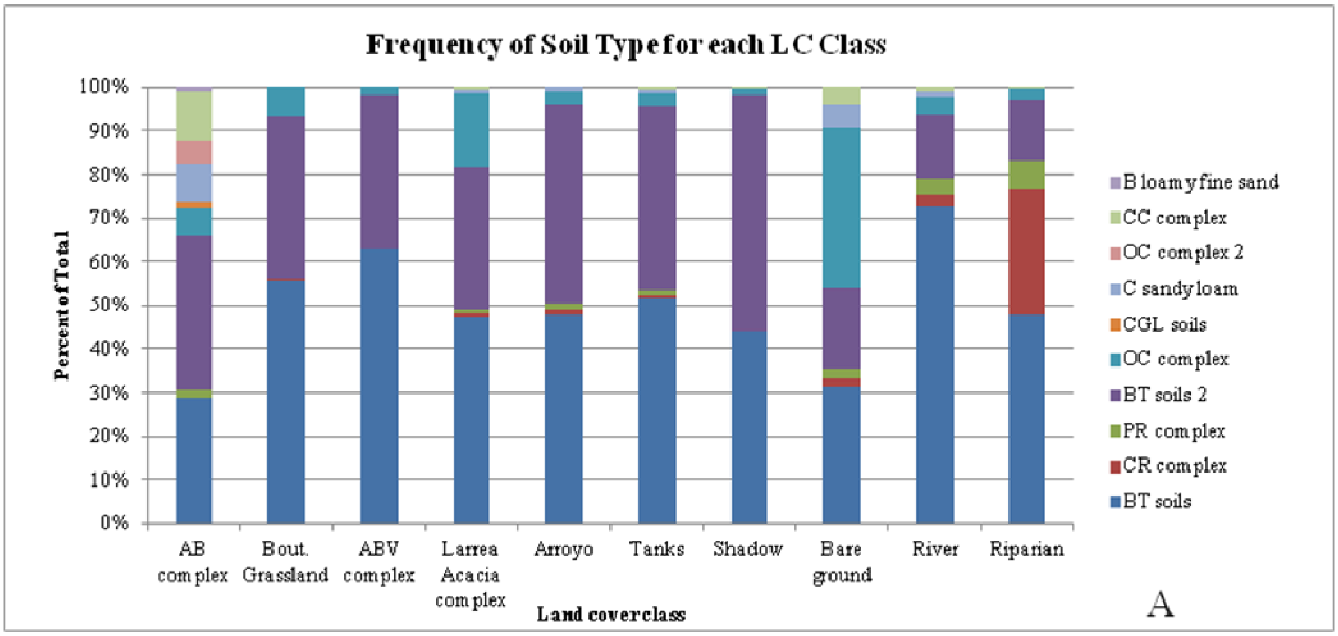


Figure 2.7. Mean and standard deviations shown as box and whisker plots of NDVI (A), solar radiation (B), elevation (C), slope (D), and aspect (E) for each land cover class. Solid circles (•) represent the mean of the dataset.

The frequency of soil class types and geology class types is shown in Figure 2.8. All land cover classes had high frequencies of Blackgap and Terlingua soils and rock outcrop (Fig. 2.8A), with the river class having the highest and the bare ground class having the lowest. The Blackgap and Terlingua soils and rock outcrop is characterized with 5 to 35 percent slopes (BT soils 1) and with 35 to 65 percent slopes (BT soils 2), both as undifferentiated groups. The lowest occurring soil types were the Baviza loamy fine sand and the Castolon-Galindo-Lomapelona soils complex. The bare ground class had a high frequency of the Ojinaga-Corazones complex, as compared to the other land cover classes. In addition, the river riparian class also had a high frequency of the Chipotle-Riverwash complex as compared to the other land cover classes. The *Agave Bouteloua* complex, had a higher frequency of limestone and sandstone mixed geology as compared to the other land cover classes (Fig. 2.8B). The *Agave Bouteloua Viguiera* complex and shadow class had the highest frequencies of conglomerate, sandstone, limestone, and siltstone mixed geology (also known as the Yucca Formation) as compared to the other land cover classes, and was the most frequently occurring geology type found in all classes. The tanks class had a high frequency of sandstone as compared to the other land cover classes. In addition, the bare ground class had a higher frequency of the conglomerate as compared to the other land cover classes. Lastly, the river and river riparian classes had a higher occurrence of shale, sandstone, and limestone mixed geology than do the other land cover classes.



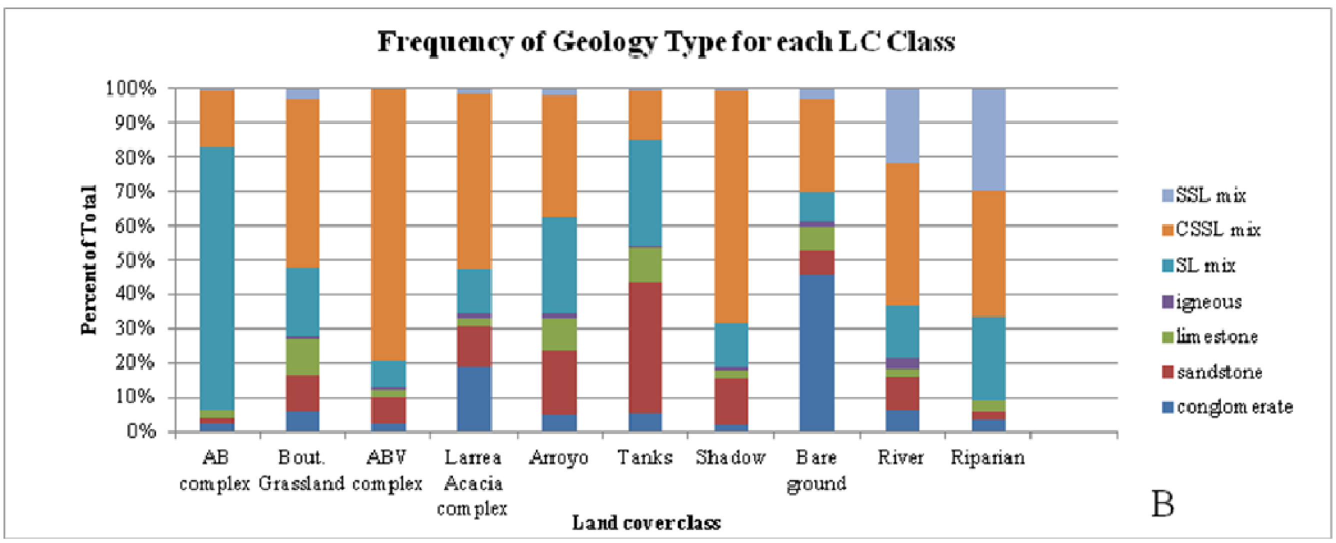


Figure 2.8. Frequency of soil class type (A) and geology class type (B) for each land cover class.

2.3.4 Conceptual model for IMRS

The conceptual model for land cover at IMRS is shown in Figure 2.9 and depicts the relationships between vegetation classes in ordination space, and the biological and environmental factors that affected the distribution of vegetation between classes, and for both axis 1 and 2. The *Agave Bouteloua* and *Agave Boutleoua Viguiera* complexes, and *Bouteloua* grassland class had high r^2 values between the classes (r^2 = 0.98) from the correlation analysis. The results from the regression tree analysis showed that the environmental and biological indicators between the *Agave Bouteloua* complex

and the *Bouteloua* grassland were aspect and *Bouteloua eriopoda* coverage, respectively with lower values in the *Agave Bouteloua* complex. The environmental and biological indicators between the *Agave Boutleoua* and the *Agave Boutleoua Viguiera* complexes were slope and *Viguiera stenaloba* coverage, respectively. The environmental and biological indicators between the *Agave Boutleoua Viguiera* complex and *Bouteloua* grassland class were geology type and *Acacia* spp. coverage, respectively. The relationship between the *Agave Boutleoua* and the *Larrea-Acacia* complexes had an $r^2 = 0.71$ from the correlation analysis. The regression tree showed that the environmental and biological indicators between the classes were aspect and *Bouteloua eriopoda* coverage. The *Larrea-Acacia* complex and arroyo classes had a small relationship ($r^2 = 0.57$) from the correlation analysis. The regression tree showed the environmental and biological indicators between the classes were solar radiation and other cacti species presence in the *Larrea-Acacia* complex. The relationship existing between bare ground and tanks classes had an $r^2 = 0.77$ from the correlation analysis, and the regression tree showed elevation and wetland species coverage to be the environmental and biological indicators, respectively. The relationship between the tanks and river riparian classes had an $r^2 = 0.63$ from the correlation analysis, and the regression tree showed slope and *Tamarix spp.* coverage to be the environmental and biological indicators, respectively. A small relationship between the bare ground class and *Larrea-Acacia* complex ($r^2 = 0.33$) existed, based on the correlation analysis. The regression tree showed slope and *Larrea tridentata* coverage to be the environmental and biological indicators between these classes. Based on the regression tree analysis, the overarching environmental and biological indicators existing for NMS axis 1 were elevation and *Bouteloua eriopoda* coverage, respectively. Other environmental indicators associated with NMS axis 1 were latitude, slope, and geology with a cumulative $r^2 = 0.37$. The other biological indicators included *Agave lechugilla* and wetland species associated with the river riparian and tank classes, with a cumulative $r^2 = 0.83$. The overarching environmental and biological indicators existing for NMS axis 2 were latitude and *Acacia* spp. coverage, respectively. Other environmental indicators associated with NMS axis 2 were elevation and slope ($r^2 = 0.20$). Other biological indicators associated with NMS axis 2 were *Tamarix* spp., *Bouteloua eriopoda*, and *Viguiera stenaloba* coverage ($r^2 = 0.55$).

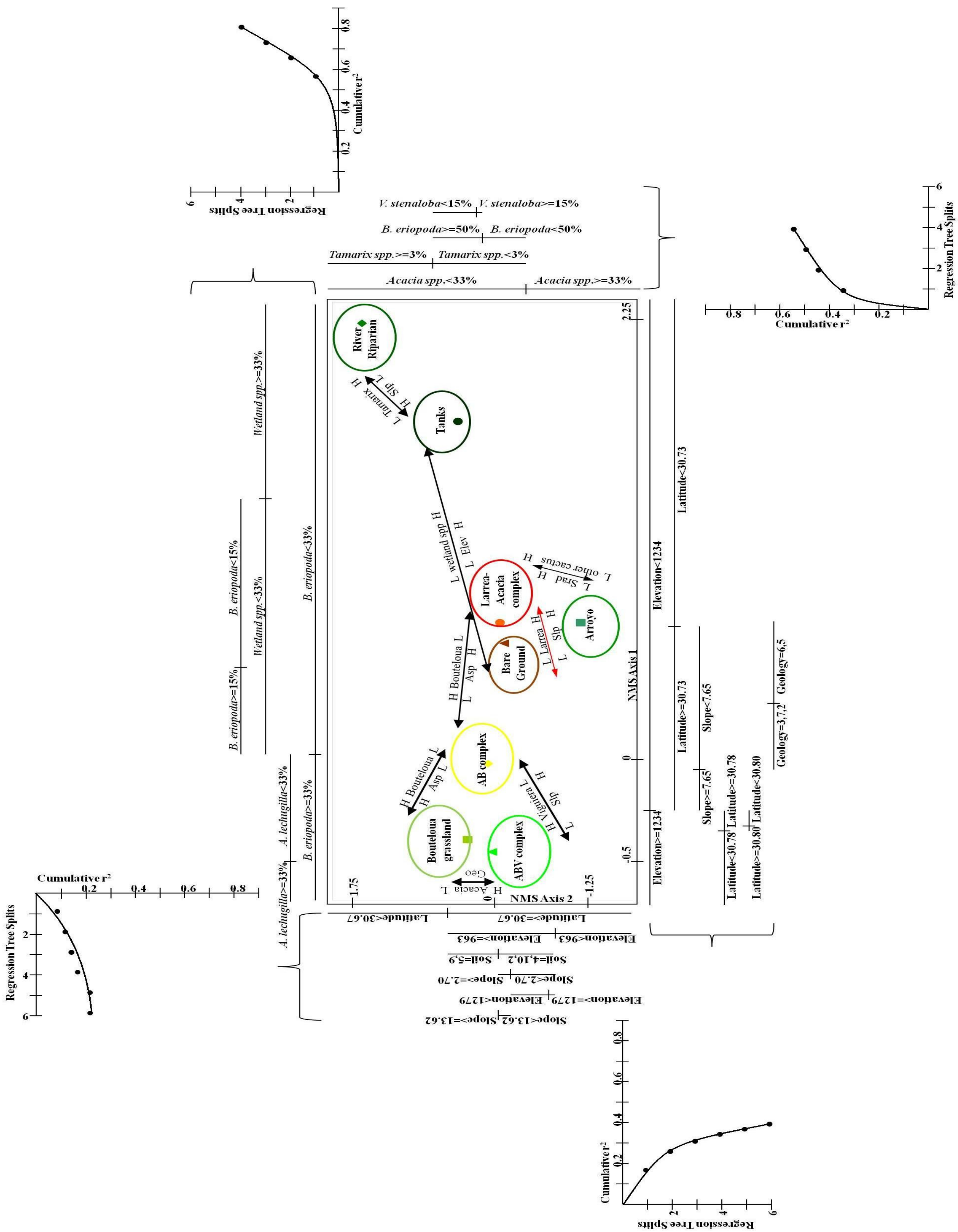


Figure 2.9. Conceptual model for the IMRS. High and low values are indicated by H and L, respectively. Cumulative r^2 plots illustrate the r^2 values leveling off indicating the best number of regression tree splits has been met. Caveat: This model does not consider change to new system states, such as changes that occur due to introduction of an invasive species.

2.4 Discussion

The primary objectives of this paper were to i) develop and assess the accuracy of a supervised land cover classification derived from high spatial resolution satellite imagery and plot level species cover and abundance data for a northern Chihuahuan Desert landscape, ii) assess which environmental variables may be associated with the distribution of these land cover types, and iii) using a conceptual modeling approach, develop hypotheses of how environmental change may impact land cover in these landscapes.

2.4.1 Land cover classes and classification map

The classification and ordination results show that there were six vegetation classes for the Indio Mountains Research Station, a Chihuahuan Desert mountain ecosystem. These six classes were combined with four derived classes that produced a 10-class land cover map with good accuracy using high spatial resolution satellite imagery and supervised classification.

The six vegetation classes derived from cluster analysis and ordination were similar to other vegetation types described for the Chihuahuan Desert in Big Bend National Park in Texas (Plumb, 1991), in the rangelands of the JRN (Gibbens et al., 2005), the bajadas of the Guadalupe Mountains (Dick-Peddie, 1993), and the International Classification for the Chihuahuan Desert (Reid, 2000).

The land cover map produced from the supervised classification on high spatial resolution satellite imagery (IKONOS) had good accuracy, aligned well with landscape features, and appeared to delineate relatively fine scale micro-topographic features including roads, tanks, and corrals. Supervised classifications of mountainous terrain in arid regions have been used successfully in other studies. (Cingolani et al., 2004; Wehrden et al., 2006). Cingolani et al. (2004) used a maximum likelihood classification to produce a land cover map of the Cordoba Mountains in Argentina with 78% accuracy, and Wehrden et al. (2006) also used a maximum likelihood classification to produce a land cover map of the Gobi Gurvan Sayhan National Park of Southern Mogolia with 78-88% accuracy in the mountainous ranges. The accuracy of our map (79%) falls within the ranges of these studies, and demonstrates the validity of the classification map produced for the Indio Mountains Research Station. The complexity of the mountainous terrain and heterogeniety of vegetation types were cited in both studies as challenges in

classification utilizing satellite iamgery of mountain ecosystems. The *Boutleoua* grassland had the lowest producer accuracy (52%), with many of the sites being misclassified as either *Agave Bouteloua* complex or *Agave Boutleoua Viguiera* complex. This could be attributed to the variations of grass cover within the *Bouteloua* dominant classes which cause the misclassification of these three particular classes. Also, the river riparian has a producer accuracy of 63%, probably due to misclassification caused by the highly dense vegetation within the classes of the river riparian, tanks, and arroyos classes. Much of the classes share similar vegetation composition, such as *Prosopis gladulosa*, and share some differences, such as *Tamarix*. Nagler et al. (2005), documented difficulty in distinguishing between such vegetation types in arid riparian zones of the lower Colorado River. Another type of misclassification is seen in the greater pixel value variation within land cover classes giving way to misclassifications and a decrease in proper classification of the land cover classes. For example, the river and shadow classes share similar pixel value ranges causing misclassification of river sites as shadow class and vice versa. Similar complications were seen with high resolution imagery such as IKONOS and Quickbird in other classification studies (Laliberte et al., 2004; Yan et al., 2006). It may be worth utilizing an object oriented classification approach to refine the land cover map in the future because it utilizes shape and texture characteristics of objects, not just spectral information, providing more highly accurate maps of heterogenous landscapes (Laliberte et al., 2004).

2.4.2 Conceptual model of vegetation-environment relationships

The framework for a conceptual model of the Indio Mountains Research Station, an example of a Chihuahuan Desert mountain ecosystem was built in this study. It is hypothesis driven and it lays the foundation for future ecological research as the model is a baseline to be refined. The correlations of species composition and abundance, along with the results of the regression tree analysis, showed a clear picture of the relationships among vegetation communities and the environmental factors that determined their distribution. The distribution of vegetation classes was affected by several inter-related environmental factors including slope, position with respect to latitude, and soil and geology type, and was distributed along an elevational gradient: Riparian → Tanks → *Larrea Acacia* complex → Arroyos

→ Bare ground → *Agave Boutleoua* complex → *Bouteloua* grassland → *Agave Bouteloua Viguiera* complex (lowest to highest) (Fig. 2.9).

The conceptual model showed elevation, position with respect to latitude, and slope played a significant role in the distribution of vegetation (cumulative $r^2 = 0.35$) and appeared to account for much of the heterogeneity present in the IMRS landscape. The *Larrea-Acacia* complex, arroyo and riparian classes are located primarily at lower elevations on bajadas and on the flood plain near the river, while the *Agave Bouteloua* and *Agave-Bouteloua-Viguiera* complexes were associated with higher elevations and steeper slopes. The *Bouteloua* grassland was most common at the higher elevations. This was also seen in similar studies in a semiarid mountain ecosystem in Naukluft Mountains, Africa (Burke, 2001) and in the arid mountains of Kirthar National Park in Pakistan (Enright et al., 2004) where vegetation was primarily distributed along an elevational gradient. In the southwest US arid regions, elevation was shown to be one of the primary factors influencing the distribution of vegetation in the Chiricahua Mountains (Poulos et al., 2007) and the Santa Catalina Mountains (Whittaker and Niering, 1965) in Arizona. In the Chihuahuan Desert, elevation was one of the primary environmental factors affecting vegetation distribution in the Chisos Mountains of Big Bend National Park, Texas (Poulos and Camp, 2005).

The results of the regression tree analysis and the conceptual model showed that geology and soil had very little influence on the distribution of the vegetation classes (except for the *Bouteloua* grassland class) at the research site. Similar finding are seen in other studies (Enright et al., 2004; Poulos et al., 2007). This is contrary to what we observed on the ground during field surveys. On several occasions, sudden shifts in vegetation were observed to occur with changes in geology and soil types. These observations suggest that the geology and soil maps utilized for comparison with the supervised classification were of insufficient detail to define relationships at the spatial resolution of the land cover map derived in this study.

2.4.3 Conceptual model as indicator of vegetation change in response to climate change

The resulting conceptual model derived from the results above allowed us to hypothesize that climate could be the driver of vegetation change, and transition between one vegetation class type and

another would occur from a grassland to a more shrub dominated ecosystem if conditions become warmer and possibly drier. This is because mountain ecosystems within the Chihuahuan Desert are high in biodiversity due to the ideal climate present for plant species at higher elevations, and that dramatic changes in land cover with changes in elevation also suggest that subtle changes in climate can affect the occurrence and distribution of vegetation in these landscapes (Poulos and Camp, 2005; Gitlin et al., 2006). In addition, climate studies conducted at IMRS have shown that lower elevation sites tended to be warmer than higher elevation sites (De La Cerda Camargo, 2011). Our conceptual model therefore suggests that climate change, represented by the elevational gradients present, will influence the distribution of vegetation classes at the Indio Mountains Research Station, causing a shift from a *Bouteloua* grassland or highly diverse *Bouteloua Agave Viguiera* class (shown at higher end of elevation gradient) to the shrub dominated *Larrea Acacia* class (seen at lower end of elevational gradient). This will occur with warming trends allowing the *Larrea Acacia* class to migrate up in elevation by out-competing the other classes not as able to cope with the warming temperatures. The climate of the southwest is projected (predicted) to be more arid (drier) (Seager et al., 2007; Gutzler and Robbins, 2010), which could have huge implications on arid mountain ecosystem dynamics and biodiversity as well as on the sustainability of the southwest, especially for humanity (DeBuys, 2011).

There are limitations to the conceptual model derived for the Indio Mountains Research Station. First, even if there is a shift in vegetation communities brought about by climate, other factors will determine whether the current diversity is maintained or transitions to an alternative state (Herrick et al., 2006; Peters and Havstad, 2006; Bestelmeyer et al., 2009). Assessing all the factors of soil composition and stability, climate, and biotic integrity in a site for a given state is known as the ecological potential of that site and should be included when assessing changes in vegetation communities (Herrick et al., 2006). Second, disturbance dynamics were observed to play a role in the distribution of vegetation from the field surveys conducted, but not included in this analysis. In addition, preliminary observations in multitemporal aerial photography time series show land cover change to be occurring around arroyos, tanks, and other areas of high disturbance or human activity (Escamilla, unpublished data) and warrants further investigation and inclusion into the conceptual model. Last, our conceptual model did not

incorporate water availability as a factor, though the model hints that it was a factor. It is evident by the arrangement of land cover classes in the model it appeared to go from drier to wetter conditions, the river riparian being the wettest class. It was further shown in the model in the biological indicators for Axis 1. Wetland spp. was the third important biological factor. There were a variety of environmental factors to choose from, and I only looked at the factors given in the model. It would be worth looking into how water plays a role in the model as a future analysis and refinement of the model given. This is because water availability has been shown in other studies to be one of the primary environmental factors influencing the distribution of vegetation communities. Poulos et al. (2007) shows soil moisture was the other variable, along with elevation, to affect distribution of vegetation in the Chiricahua Mountains of Arizona. Also Poulos and Camp (2005) saw that potential soil moisture was the other environmental variable, along with elevation, to influence the distribution of vegetation at the Chisos Mountains in Big Bend. Since water is a limiting factor in arid ecosystems, it is definitely worth adding water availability to the model. Despite these limitations, and as long as they are understood, the conceptual model developed here can be applied to a variety of sites and conditions within Chihuahuan desert mountain ecosystems and provide insight on how the environment can influence the distribution of vegetation and how changes in the environment can cause changes in vegetation community types.

2.5 Conclusion

The Indio Mountains Research Station is a heterogenous Chihuahuan Desert mountain ecosystem where the link between vegetated land cover and the environment remains poorly studied and a conceptual model of likely changes in land cover in response to environmental change are lacking. Based on our study we have three main conclusions. First, from the results of the cluster and NMS analyses on field data, six vegetation classes were described for IMRS. Second, the six vegetation classes were combined to four other derived land cover classes to create a 10-class land cover map with good accuracy using IKONOS satellite imagery and supervised classification. Lastly, the land cover map and analyses of environmental data utilizing GIS tools allowed us to create the framework for a conceptual model for IMRS. The model shows that the biggest environmental indicators are elevation and slope, location with respect to latitude, geology and soil composition. With this information from

the conceptual model, we hypothesize that changes in climate will cause a change in vegetation communities, as the vegetataion communites at the study site are distributed along an elevational gradient. This could have implications for the current state of vegetation communities here, and in other mountain ecosystems that are known as biodiversity hotspots within the arid southwest US, since the climate is predicted to become warmer and drier (Seager et al., 2007; Gutzler and Robbins, 2010).

Chapter 3: Land cover change at Indio Mountains Research Station, Texas

Abstract: Arid and semiarid regions, accounting for 40% of the world's land surface and home to 2.5 billion people, have been undergoing desertification due to both natural effects and human drivers. It is a global problem documented at locations in the southwest region of the United States as shrub encroachment, which has altered the provision of ecosystem goods and services with important social, economic, and ecological implications. Documenting desertification at the landscape scale is important to understanding its manifestation, mechanisms, and implications on ecosystem structure and function at a scale relevant to other biota, and repeat aerial photography has become the preferred tool used in numerous studies. Though this research has been well documented in the Chihuahuan desert, few have utilized this process in the mountain ecosystems of this region, considered some of the biodiversity hotspots of the world. This study is among the first to examine shrub encroachment in a Chihuahuan Desert mountain landscape and uses repeat aerial photographs in combination with Kite Aerial Photography to assess changes in shrub cover and density for the Indio Mountains Research Station South of Van Horn, Texas. The results for this study show that though the total number of shrub clumps has increased at all sites, the total and percent cover has declined, and has declined at the site with the highest disturbance history (ranch house), but increased at the site with no disturbance (mesquite ridge). In addition, mixed results have been shown between the two semi-disturbed sites (triple tank shows declines in percent cover while rattlesnake tank shows increases). It is evident that no single factor can be identified as responsible for changes seen at the IMRS. The results of this study demonstrate that complex interactions are occurring at the study site, a Chihuahuan desert mountain ecosystem that should be seen as an indicator of global change.

3.1 Introduction

Arid landscapes comprise the largest land area of any biome on Earth (Okin et al. 2009), and support more than a third of the global human population (Reynolds et al., 2007). Importantly, arid landscapes are under increasing pressure from anthropogenic impacts and climate change (MEA 2005; IPCC, 2001), which are likely to affect the sustainability of these landscapes in the future (DeBuys,

2011). Much of the expansion in desert landscapes has occurred through desertification, a process that describes a form of degradation in drylands (UNEP, 1994; Eswaran et al., 2001). Globally, desertification has resulted from overgrazing, fire suppression, erosion, increases in atmospheric CO_2 concentration and climate change (Johnson et al., 2000; Peters, 2000; IPCC, 2001). The complex interplay between many of these factors suggests that no single variable causes desertification (Archer, 1994; Van Auken, 2000; Mielnick et al., 2005), and that desertification is attributable to a range of these factors controlling and acting on multiple spatiotemporal scales in association with altered human land use to affect ecosystem structure and function (Herrick et al., 2006b; Peters and Havstad, 2006).

In response to desertification, Land Cover Change (LCC) is the form of woody plant encroachment that has been linked to dramatic changes in ecosystem structure and function (MEA 2005; D'Odorico et al., 2012). These include declining species diversity (Gibbens et al., 1992), altered patterns of primary productivity (Huenneke et al., 2001) and biogeochemical cycling (Schlesinger et al., 1990; 2000) and soil composition and processes (Okin et al., 2009). Increased dominance of shrubs also has the capacity to alter land-atmosphere carbon (Scott et al., 2006), energy (Archer and Smeins, 1991; He et al., 2010) and hydrologic balance (Gutschick and Snyder, 2006), suggesting that regional LCC has the potential to alter regional climatic patterns to warmer conditions (Beltran-Przekurat et al., 2008). Importantly, several studies have shown that desertification and woody plant encroachment appears to have altered the biophysical environment of affected landscapes to a new ecosystem state that appears to be relatively stable and seemingly irreversible (Goslee et al., 2003; D'Odorico et al., 2012).

Typically LCC and shrub encroachment is assessed in arid landscapes by comparing historical aerial photography with recent aerial photographs or high spatial resolution satellite imagery (Asner et al., 2003; Okin and Roberts, 2004; Okin, 2007; Browning et al., 2009) and using a range of geospatial analyses (Kepner et al., 2000; Poulos, 2009; Browning and Archer, 2011).

To date, however, few studies appear to have explored the use of Kite Aerial Photography (KAP) in acquiring aerial photography for monitoring shrub encroachment in desert landscapes. Kite aerial photography (KAP) has emerged in scientific research in recent years because KAP provides a versatile, convenient, effective, and low-cost way to acquire high-resolution, large scale imagery for detailed site

investigations (Aber et al., 1999, 2002a; Wundram and Loffler, 2007). The use of KAP has been used for various scientific investigations by a number of researchers including Aber et al. (1999, 2002b, 2005), Marzolff et al. (2003), and Fraser et al. (1999), and has been used in mountainous landscapes to derive vegetation and landform data (Wundram and Loffler, 2007). It bridges an important gap between ground and aerial surveys (Fraser et al., 1999) because the clarity and detail in the sub-meter images allows for plant identification (Wundram and Loffler, 2007). This ability to derive high quality vegetation data allows for interpretation of plant canopy structure and plant species identification, especially in a heterogenous Chihuahuan desert mountain ecosystem, which could help eliminate exhaustive and time consuming ground-based vegetation surveys at specific sites of interest.

This study assesses the degree of woody encroachment over the last 68 years of the Indio Mountains Research Station (IMRS), an example of a heterogenous Chihuahuan Desert mountain ecosystem. This was accomplished by assessing changes in shrub density and cover between multi-temporal aerial photographic time series. Although the overarching approach is similar to that used to examine shrub encroachment on other arid landscapes (Browning et al., 2008), a relatively novel component of this study will explore the potential utility to use Kite Aerial Photography (KAP) in detailed land cover change assessments of arid landscapes. It is intended that the final results of this study will be used as a baseline for future assessment of land cover change at IMRS.

3.2 Methods

3.2.1 Historical image acquisition and preprocessing

Aerial photographs of the IMRS were acquired for 1943, 1982, and 2004 from P2 Energy Solutions. The 2004 aerial imagery was provided in TIFF format as a black and white Digital Orthophoto Quarter Quadrangles (DOQQ) that were georeferenced to a USGS 30-meter digital elevation model (DEM) and mosaiced by the provider. The 1982 aerial imagery (taken in January and September of 1982) were provided as grayscale contact prints. These contact prints were scanned at 2400 dpi in true color and saved in TIFF format. The negatives of the 1943 aerial imagery (taken in January of 1943) were scanned at 1270 dpi by the provider, and sent as black and white images in TIFF format. Both the 1982 and 1943 digital images were cropped and georeferenced to the 2004 aerial image. During

georeferencing, a minimum number of control points were used, and added until the RMS error reached below 0.5. The final pixel sizes of the images were 1.19m^2, 0.6m^2, and 1m^2 for the 1943, 1982, and 2004 images, respectively.

3.2.2 Selection of sites for collection of kite aerial photographs for change assessment

In order to determine the sites for shrub change analysis, criteria for sites suitable for both shrub change analysis and acquisition of kite aerial photographs (KAP) were defined. The criteria for site selection were that sites: 1) needed to include at least 3 vegetation types, 2) needed to be 20m to 100m away from roads and arroyos but still relatively easy to access, and 3) needed to cover semi-flat to flat terrain. The sites were selected prior to field sampling by importing the land cover map created for the IMRS (Chapter 2), a roads and arroyo shapefile and a digital elevation model (DEM into ArcMap 10. Buffers were created around roads and arroyos and these areas were excluded from the selection process. Using the DEM, the query builder in the select tool was used to limit areas that occurred on relatively flat terrain (no slope or aspect). A spatial join was then implemented to merge these areas with specific classes in the classification map. A total of 33 randomly selected sites were found that fit the criteria. All 33 sites were scouted during a reconnaissance visit to the IMRS where 13 of these sites in 7 general locations were found to best meet the above criteria. A total of five sites were chosen from these for their capacity to represent the range of land cover types at IMRS and for their suitability for KAP. These sites are known hereafter as the ranch house site (disturbed), the mesquite ridge site (undisturbed), the acacia flat site (undisturbed), rattlesnake tank site (semi-disturbed), and the triple tank site (semi-disturbed) (Fig. 3.1).

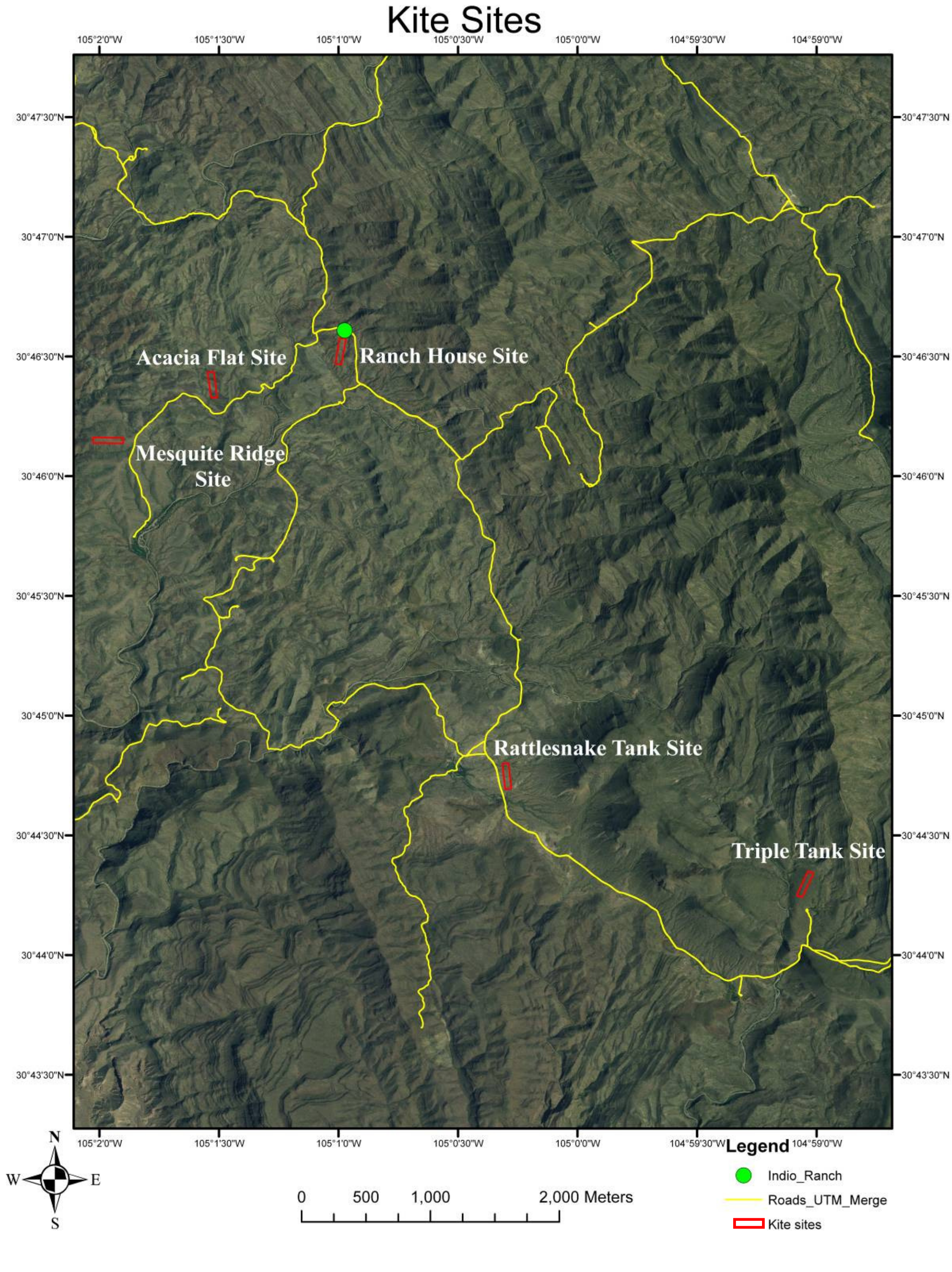


Figure 3.1. Location of sites where kite aerial photographs were taken. KAP sites are shown to scale.

3.2.3 Collection and preprocessing of kite aerial photograph (KAP) system

High spatial resolution digital aerial photographs were acquired with a Kite Aerial Photography system (KAP) similar to that described by Wundram and Loffler (2007). This included a large (3 meters wide) kite with tail, and a motorized camera rig that was attached to a Picavet suspension system on the main kite line approximately 10 meters from the kite. The suspension system worked utilizing a system of pulleys that self level the cradle and dampen vibrations and sudden, erratic movements from the kite. The motorized camera cradle included several servos and a wireless receiver that allowed for the servos to be controlled from the ground, namely tilting of the camera 0-90 degrees vertically and 360 degrees horizontally. The remote control also triggered the shutter on the camera. A Panasonic Lumix DMC-TS2 14 megapixel HD point and shoot digital camera was mounted on the camera cradle and was used to acquire the aerial photographs.

The KAP images were acquired during fall (Sept-Oct) 2010 and spring (March-May) 2011. A 40m x 200m transect was marked with rebar and flags approximately every 10 m along the center of the length of the transect. Large white paper plates were placed at the 0m and 200m marks, and next to the flags ensuring the plates would be visible to the kite. GPS coordinates were taken at each of the paper plates using a Nomad with SX Blue (for differential GPS) as ground control points (GCP) for georeferencing of the kite imagery. Multiple view ground photographs were taken at each of the GCP point to get an overview of vegetation on the ground. When optimal wind conditions prevailed (7—15 knots), the KAP was launched to approximately 100 meters above ground level and used to acquire the aerial photography with the camera set to burst-shooting mode (3 photographs are taken in rapid succession). To ensure adequate photographic coverage of each site, two complete passes of the site were executed, which resulted in between 100 and 400 overlapping pictures being acquired for each site. One person flew the kite, while the second person controlled the motorized camera rig and aided guidance of the KAP system over the each study area.

The kite aerial photographs were screened in the lab and the best 6 to 10 photographs were chosen for each site using the following criteria: 1) images covered the length of the transects, 2) images substantially overlapped one another, 3) images were shot at a vertical angle, and 4) images were free of distortions such as blurriness. Each individual photograph was imported into ArcGIS 9.2 where they

were positioned using the DGPS locations of the GCPs, and georeferenced to a pan-sharpened IKONOS satellite image. During georeferencing, a minimum number of control points were used, and added until the RMS error reached below 0.5. All georefernced images of a site were imported into ArcGIS 10 where they were color balanced and mosaiced. An example photomosaic is given in Figure 3.2 for the Ranch House site.

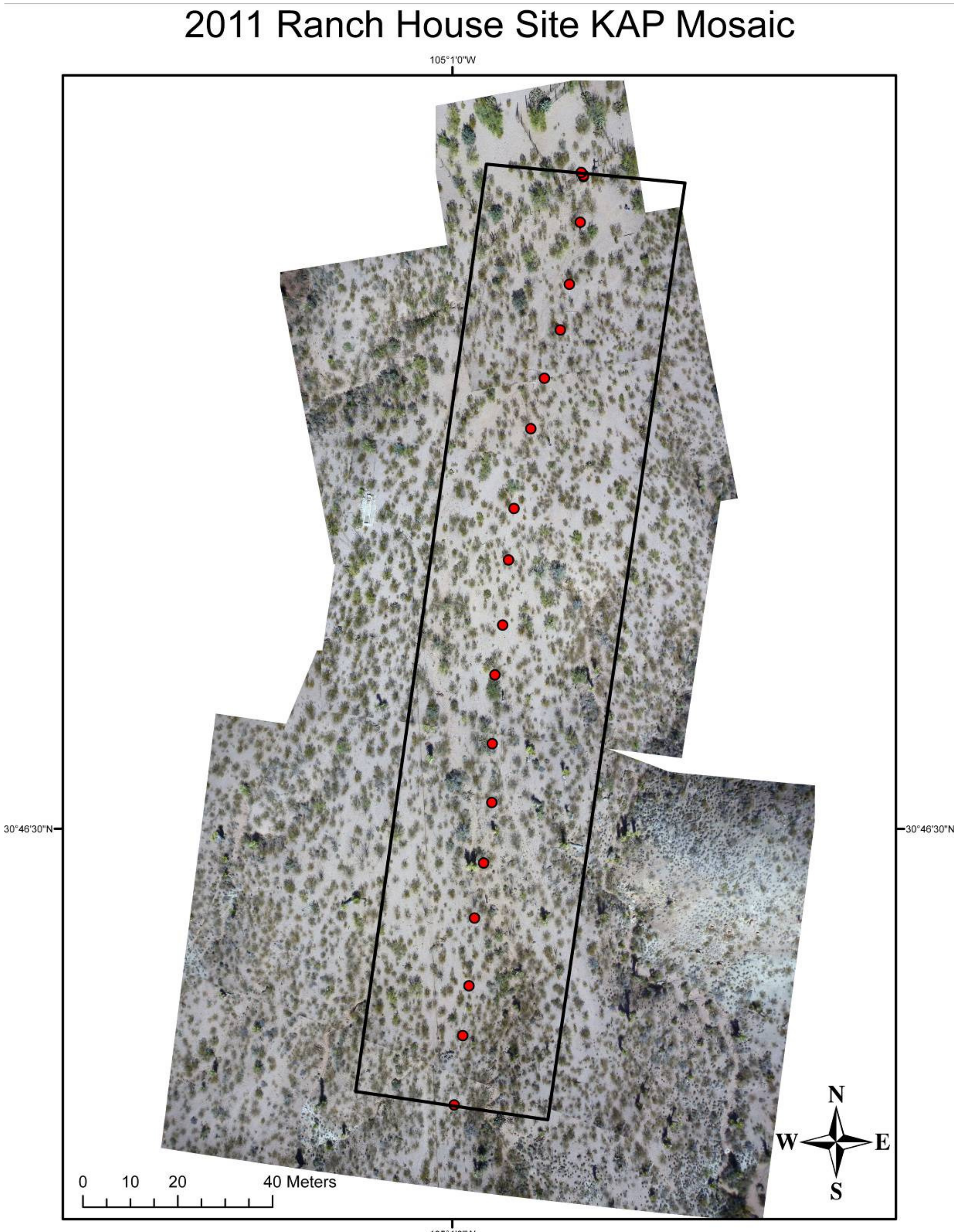


Figure 3.2. Photomosaic of kite aerial photographs taken at the ranch house site in IMRS. GCP's are shown as red dots, and the transect is outlined in black.

3.2.4 Image processing and validation

The kite photomosaics were in RGB color format and had a much higher resolution (approximately 0.02 m^2) than the black and white historic 1943 aerial imagery (approximately 1.19 m^2). The kite photomosaics for the ranch house site were imported into ArcGIS 9.2 and resampled using cubic convolution into several resolutions (grid cell values/pixel size): 0.09 cm^2, 1 cm^2, 6.25 cm^2, 0.50 m^2, 1.00 m^2, 2.00 m^2, and 4.00 m^2. These color images were part of the first analysis in verifying shrub detection. Each of the kite images at the different resolutions were transformed from RGB color composite to black and white stretch image. This second set of black and white images comprised the second analysis in verifying shrub detection.

Shrubs in the original kite photomosaics image for the ranch house site were hand digitized into six shrub size classes (0-0.1 m, 0.1-0.25 m, 0.25-0.50 m, 0.50-1.0 m, 1.0-2.0 m, and shrub diameter ≥ 2.0 m) based on the diameter of the shrubs. The total numbers of shrubs in each size class were counted at each resolution for both the color composites and the black and white resampled images. For the color composites, shrubs were not counted if the green color was not visible or if the shrubs were indistinguishable from other shrubs (part of a clump). Shrubs were not counted if the latter was true for the black and white images. For each size class, the total number of visible shrubs was divided by the total number of shrubs hand digitized to give me the percent visible.

The black and white 1943, 1982, and 2004 time series images were compiled into ArcGIS 9.2 with the 2011 kite photomosaics. All time series images were resampled to the resolution (cell size) of the 1943 image since it had the coarsest resolution, and the kite photomosaics were transformed from RGB color composite to black and white. The time series images were clipped to the extent of each of the five sites. The time series images were histogram matched and displayed with a color ramp in cubic convolution format. This created a smooth, color classified image of shrubs cover. These classified time series images were then exported as TIFFs with a 0.05 m^2 cell size (Fig. 3.5).

In order to accurately delineate shrub cover in each time series, the optimal color ramp value from a surface analysis of the time series classified images was needed. Using the shrub polygons hand digitized from the original kite photomosaics of the ranchouse site, five points were randomly selected around each shrub polygon to determine the color ramp value for each of the five points in all size

classes. Distribution plots and descriptive statistics of the color ramp values were calculated in JMP statistical software for 1) all shrubs, 2) the mean of all shrubs in each size class, 3) for all shrubs 1m or larger, and 4) for all shrubs larger than 2m. The latter two were added to the analysis because of shrub detection limits. These data were used to determine the optimal color ramp value to be extracted from a surface analysis model and converted to a shapefile.

These polyline shapefiles of delineated shrub cover were converted to polygons, and Hawth's tools were used to calculate total perimeter and area for each polygon (clump) in the image. Areas of missing data in the 2011 images were excluded from analysis in the other time series images. The Bowen Burgess ratio for each clump was calculated as: $S = P/2(\sqrt{\pi A})$, where S is the patch shape, P is the patch perimeter, and A is the patch area. An increasing S value is indicative of a patch with an irregular, non-circular shape. The mean Bowen Burgess ratio, total perimeter, total and percent cover and the total number of clumps (polygons) were calculated for each year for each site. Lastly, after combining all sites together, the mean Bowen Burgess ratio, total perimeter, total and percent cover, and the total number of shrub clumps was calculated for each year. To calculate overall change in the total number of shrub clumps and percent cover at each site, the number of total clumps and percent cover in 1943 was subtracted from these values in 2011.

3.3 Results

3.3.1 Validation of shrub detection capacity in multi-resolution imagery

To assess how the resolution and the color of imagery affected detection of shrub canopies, the pixel resolution of KAP photomosaics were resampled at 0.09 cm^2, 1 cm^2, 6.25 cm^2, 0.50 m^2, 1.00 m^2, 2.00 m^2, and 4.00 m^2 and the extent of shrub canopies were manually digitized on each image. As image pixel size became coarser, the size of detectable shrubs decreased, but this was most significant in the black and white imagery (Fig 3.3). For the 0.09 cm^2 photomosaics, 100% of the shrubs in all size classes can be seen in the color images (Fig. 3.3A), and 100% of the shrubs in the 0.1-0.25 size class only and approximately 92% of the shrubs in the other size classes can be seen in the black and white images (Fig. 3.3B). At the 6.25 cm^2 resolution size, the 0.1-0.25 shrub size class is no longer visible in the color imagery, but 10% is still visible in the black and white imagery. At the 0.50 m^2 resolution, the

only shrub size classes visible are the 0.5-1.0 m, 1.0-2.0 m, and shrubs ≥ 2.0 m with 13%, 76%, and 92% respectively for the color image, and 22%, 59%, and 82% respectively for the black and white imagery. At the 1.0 m^2 resolution, the visible shrub size classes are the 1.0-2.0 m and shrubs ≥ 2.0 m with 11% and 71% respectively for the color imagery, and 5% and 61% respectively for the black and white imagery. At the 2.0 m^2 resolution, the only visible shrub size class is the shrubs ≥ 2.0 m with 23% for the color images, and 20% for the black and white images. It is of great importance to note the results of the 1.0 m^2 and 2.0 m^2 resolution sizes, as I will be working with a resolution (1943 image is 1.19 m^2) between this range.

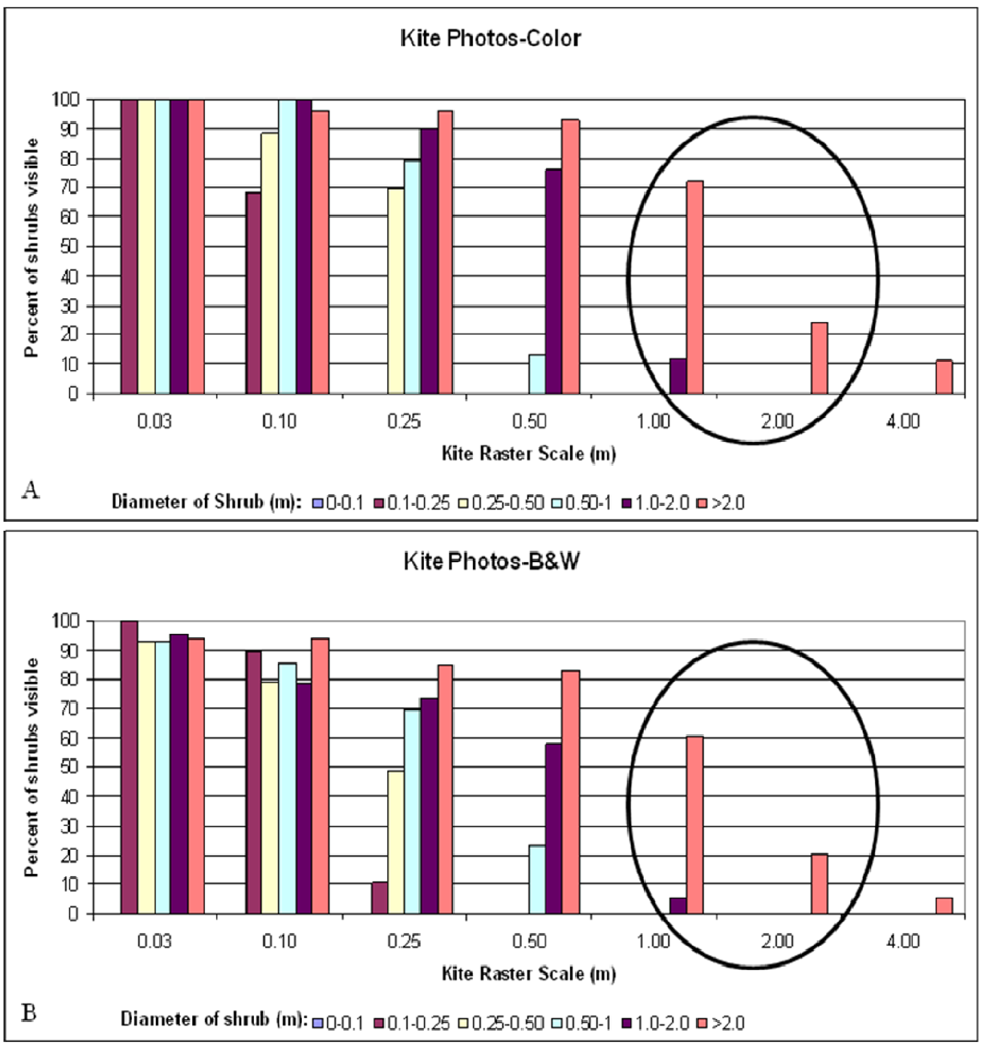


Figure 3.3. The analysis results of the shrub data for the ranch house site for color (A) and black and white (B) kite photomosaics. It shows the percent of visible shrubs at each resolution. The area circled in black is the range where the resolution of the 1943 historic aerial imagery falls.

3.3.2 Automation of shrub canopy edge detection

In order to accurately delineate shrub canopy cover in each time series image, all time series images for the ranch house site were resampled to the coarsest resolution (the 1943 image), histogram matched, and displayed with a color ramp in cubic convolution format that created a smooth, color classified image of shrub cover. Then, five points were randomly placed around the manually digitized shrubs where the color ramp values were extracted and analyzed. When all five points from all shrubs in all size classes (N = 1505) were included the distribution plot showed a mean color ramp value (± SD) of 162.5 ± 28.5 (Fig. 3.4B). The second analysis included the average of the five points around each shrub (N = 301). The distribution plot showed a mean color ramp value (± SD) of 162.5 ± 23.4 (Fig. 3.4A). The third analysis included all five points of each shrub in the shrubs ≥ 2.0 m shrub size class only (N = 275). The distribution plot had a mean color ramp value (± SD) of 133.4 ± 33 (Fig. 3.4C). The last analysis included all five points of each shrub in the 1.0-2.0 m size class and the shrubs ≥ 2.0 m size class (N = 825). The distribution plot showed a mean color ramp value (±SD) of 149.3 ± 28.8 (Fig. 3.4D). Based on this analysis and detection limits of the historic photographs, the color ramp value selected to be the most accurate at delineating shrub cover is 140.

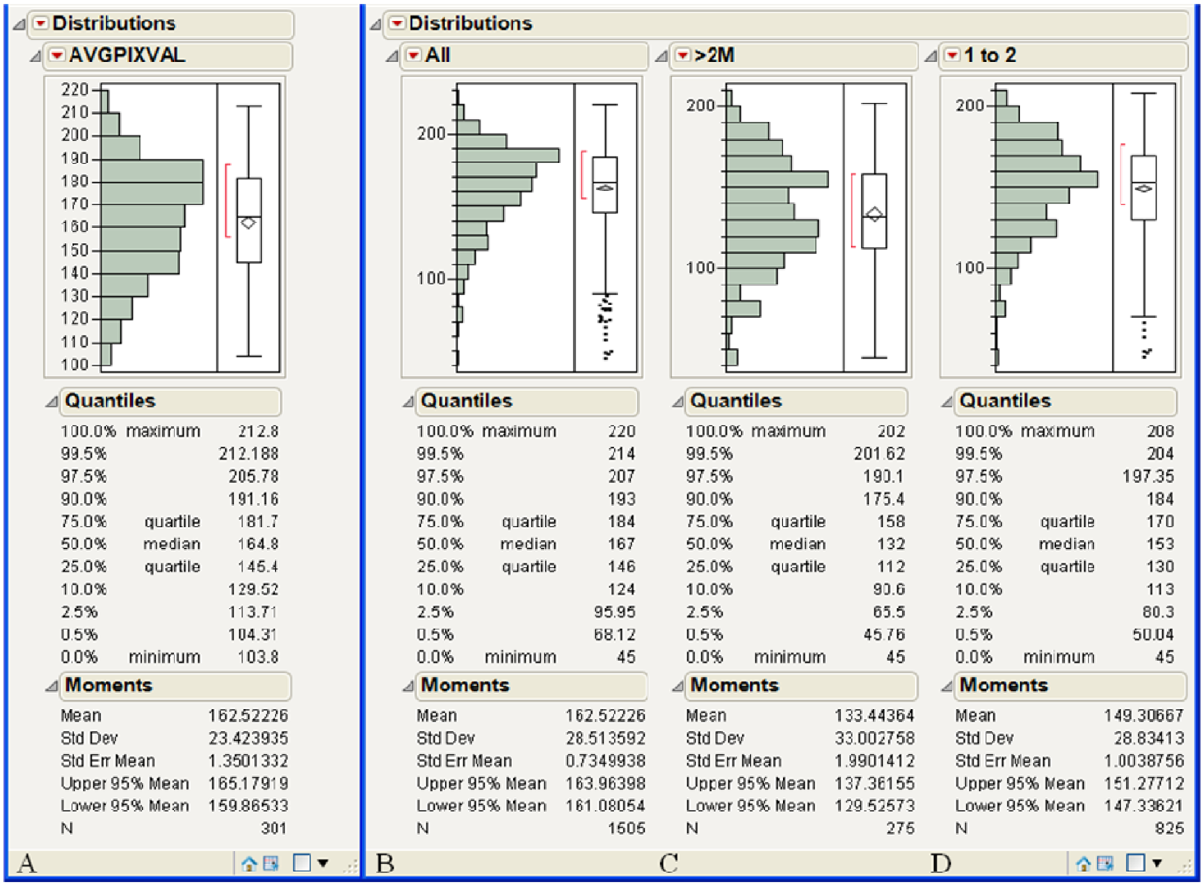


Figure. 3.4. Analysis of pixel values at various class sizes.

3.3.3 Multi-temporal detection of shrub cover change

The analysis of changes in shrub cover spanning 69 years used color classified images to determine changes in shrub cover between 1943, 1982, 2004, and 2011 at five different locations within the IMRS. The color ramp classified images show shrub cover (reds to yellows) relative to non-shrub cover (blues to purples) for these years (Figs. 3.5, 3.7, 3.9, 3.11, and 3.13). A summary of overall results are shown in Table 3.1. When all sites are combined, the total number of shrub clumps and total perimeter increases from 232 to 1,413 and 7,809m to 18,978m respectively between 1943 and 2011. However, the total and percent cover declines from 18,539m^2 to 13,527m^2 and 45.3% to 33.1% respectively between 1943 and 2011.

Table 3.1. A summary of results for the shrub change analysis showing total number of shrub clumps, cover, perimeter, and percent cover, and statistics for the mean/individual shrub (± SD) Bowen Burgess ratio for each year at each site.

Site	Year	Total				Bowen Burgess Ratio	
		No. of Clumps	Cover	Perimeter	Percent Cover	Mean/Indv. Shrub	± Stdev
Ranchouse	1943	49	3309.66	2231.21	40.1%	1.68	0.88
	1982	22	3735.03	1515.89	45.3%	1.48	0.90
	2004	109	2482.86	2203.60	30.1%	1.34	0.46
	2011	277	1996.17	3124.10	24.2%	1.31	0.40
Mesquite	1943	119	1935.89	2096.45	23.0%	1.53	0.44
	1982	21	1212.54	835.77	14.4%	1.60	0.44
	2004	63	1226.42	1279.22	14.6%	1.48	0.34
	2011	165	3343.44	3420.53	39.7%	1.41	0.65
Acacia	1943	4	7490.66	853.12	91.9%	1.63	0.42
	1982	5	6754.31	678.52	82.8%	1.46	0.24
	2004	9	6052.43	1210.73	74.2%	1.70	0.93
	2011	193	2211.18	2786.91	27.1%	1.42	0.52
Rattlesnake	1943	28	524.98	530.37	6.5%	1.55	0.37
	1982	9	875.17	405.77	10.9%	1.59	0.32
	2004	67	1516.36	1406.30	18.8%	1.49	0.59
	2011	347	3408.15	4888.05	42.3%	1.36	0.53
Triple	1943	32	5277.48	2098.14	65.8%	1.60	1.00
	1982	30	2859.65	1181.58	35.6%	1.37	0.40
	2004	79	2972.41	2742.20	37.1%	1.68	0.87
	2011	431	2568.45	4758.43	32.0%	1.32	0.49
All	1943	232	18538.68	7809.30	45.3%	1.58	0.65
	1982	87	15436.71	4617.53	37.7%	1.48	0.56
	2004	327	14250.49	8842.05	34.8%	1.49	0.62
	2011	1413	13527.39	18978.02	33.1%	1.35	0.51

The total number of shrub clumps increased from 49 to 277, 119 to 165, 4 to 193, 28 to 347, and 32 to 431, for the ranch house, mesquite ridge, acacia flat, rattlesnake tank, and triple tank sites respectively between 1943 and 2011 (Figs. 3.6, 3.8, 310, 3.12, and 3.14 A). The total and percent cover increased from 1,935 m^2 to 3,343 m^2 and 23% to 40%, and from 525 m^2 to 3,408 m^2 and 6.5% to 42.3% for the mesquite ridge and rattlesnake tank sites respectively, but declined from 3,310 m^2 to 1,996 m^2 and 40% to 24%, 7,491 m^2 to 2,211 m^2 and 92% to 27%, and 5,277 m^2 to 2,568 m^2 and 66% to 32% for the ranch house, acacia flat, and triple tank sites respectively (Figs. 3.6, 3.8, 310, 3.12, and 3.14 B). The

total perimeter increases from 2,231m to 2,124m, 2,097m to 3,421m, 853m to 2,787m, 530m to 4,888m, and 2,098m to 4,758m for the ranch house, mesquite ridge, acacia flat, rattlesnake tank, and triple tank sites respectively (Figs. 3.6, 3.8, 310, 3.12, and 3.14 C). The mean/individual shrub Bowen Burgess ratio is shown in Table 3.1 and in Figures 3.6, 3.8, 310, 3.12, and 3.14 D. The overall trend for each site shows a decrease in the mean Bowen Burgess ratio.

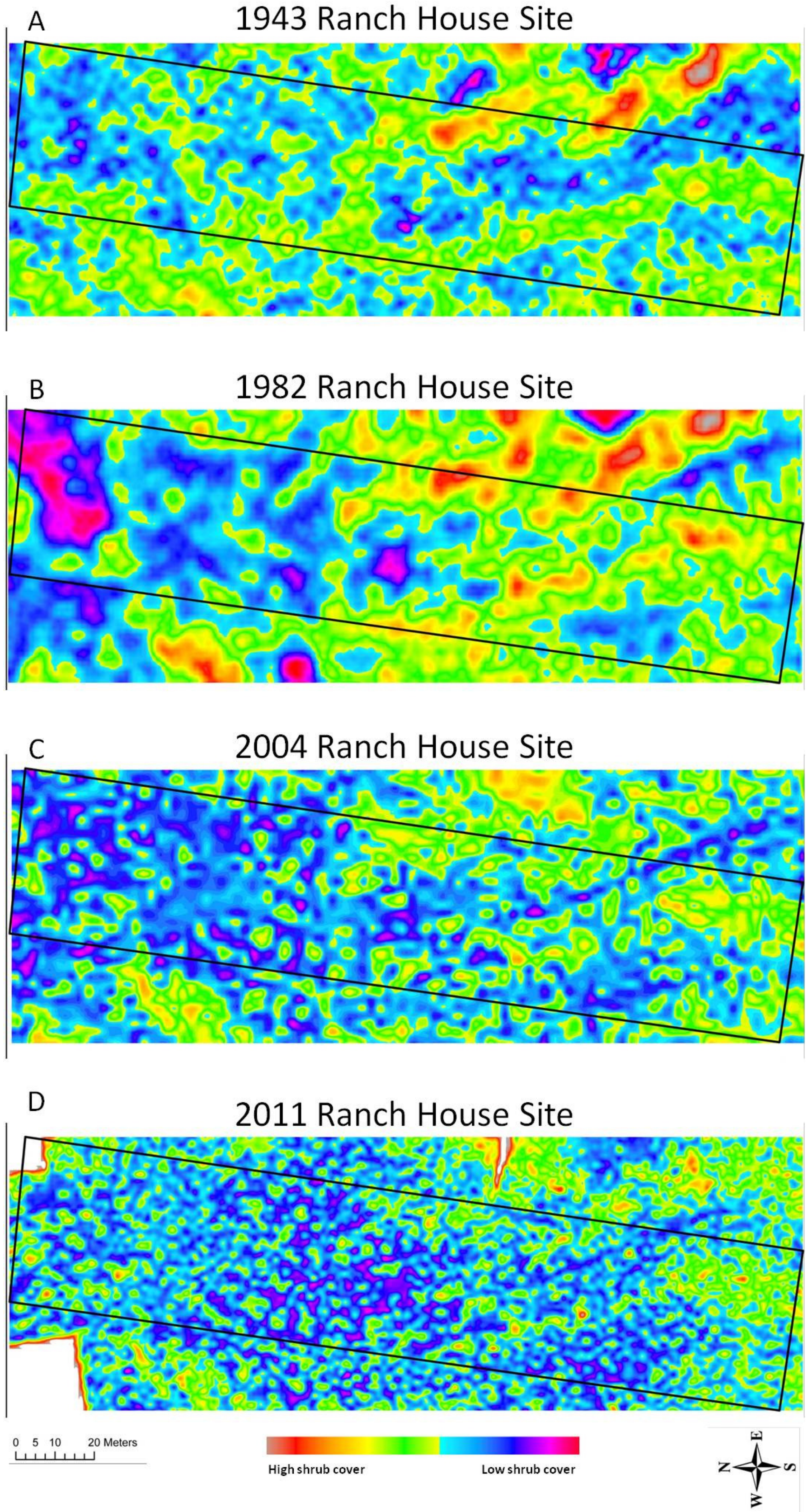


Figure 3.5. Color ramp stretch of aerial imagery for ranch house site. The transect is outlined in black.

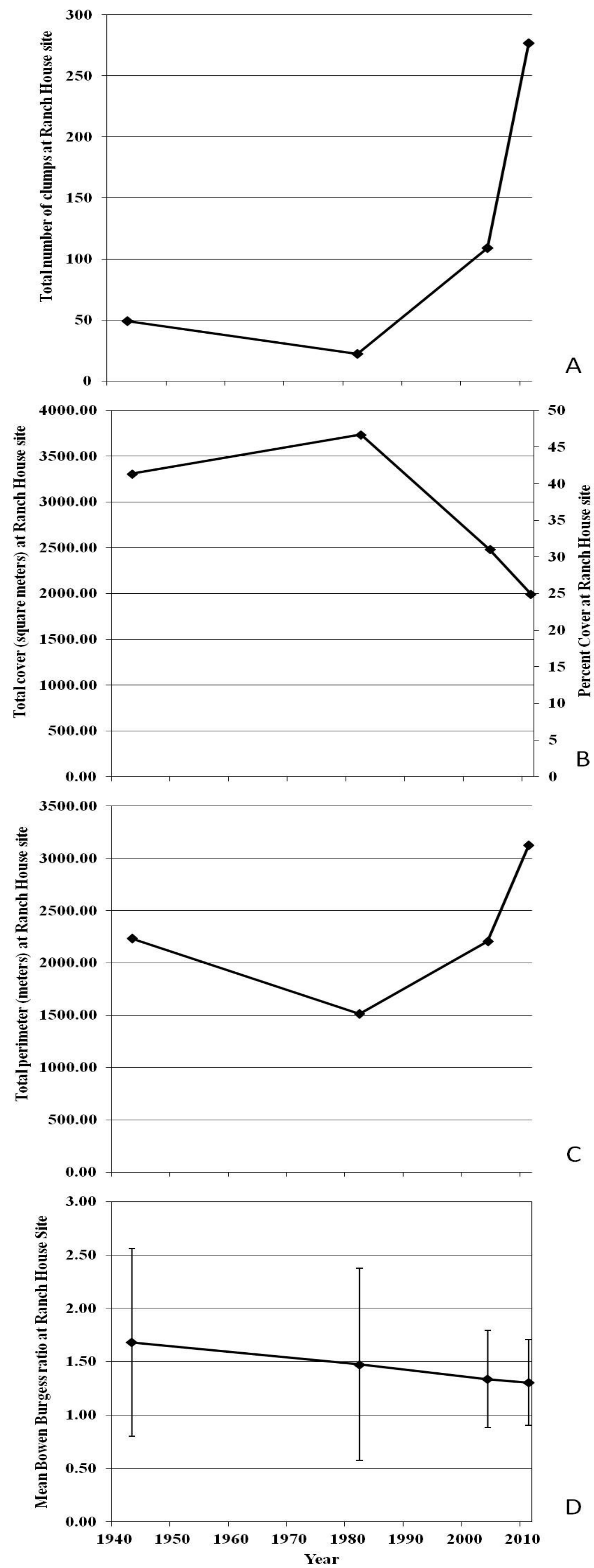


Figure 3.6. Analysis of shrub cover at the ranch house site in the IMRS, showing total number of shrub clumps (A), total and percent cover (B), total perimeter (C), and mean/individual shrub Bowen Burgess ratio (D) for all shrub clumps at the site. Error bars denote standard deviation of the Bowen Burgess ratio.

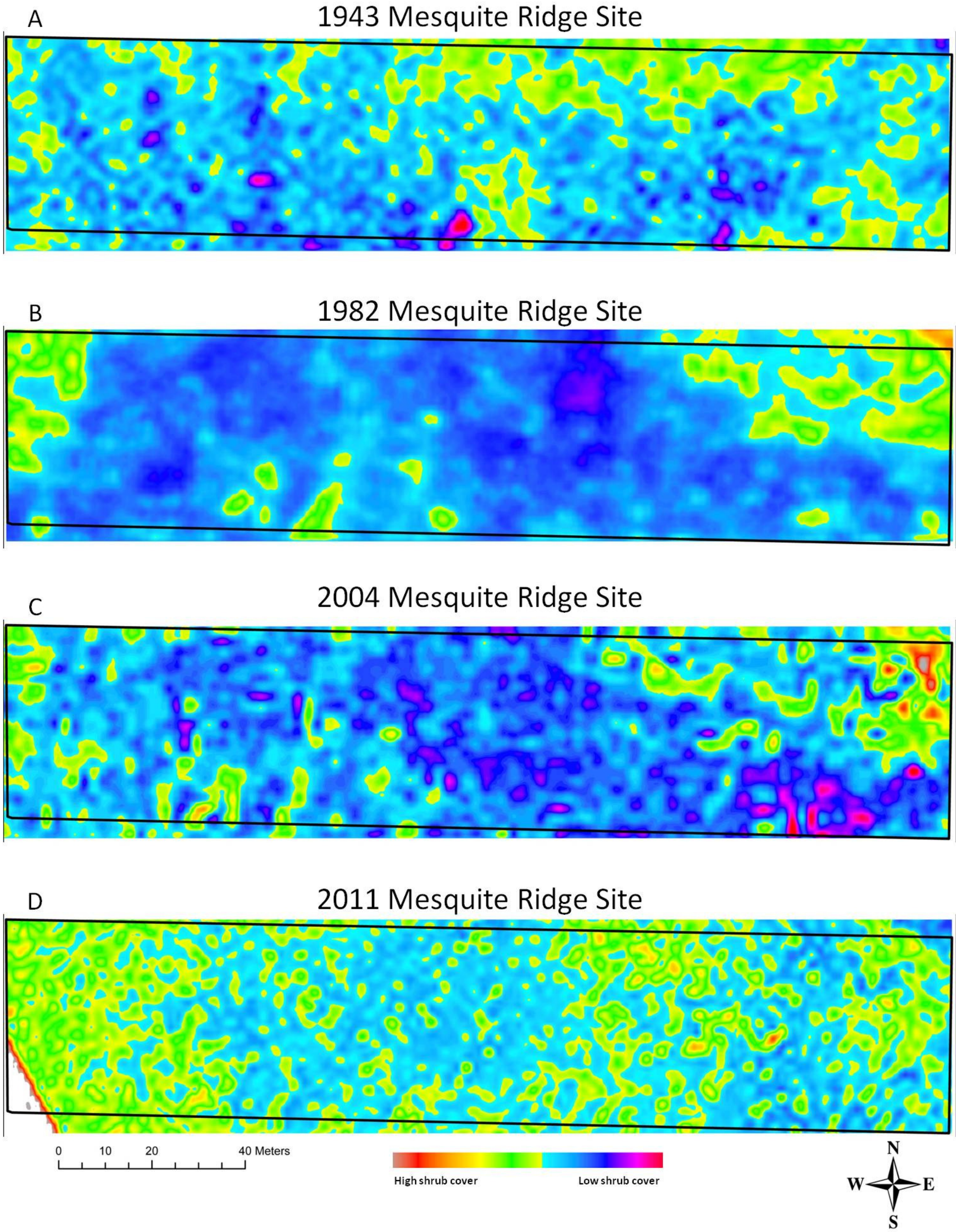


Figure 3.7. Color ramp stretch of aerial imagery for mesquite ridge site. The transect is outlined in black.

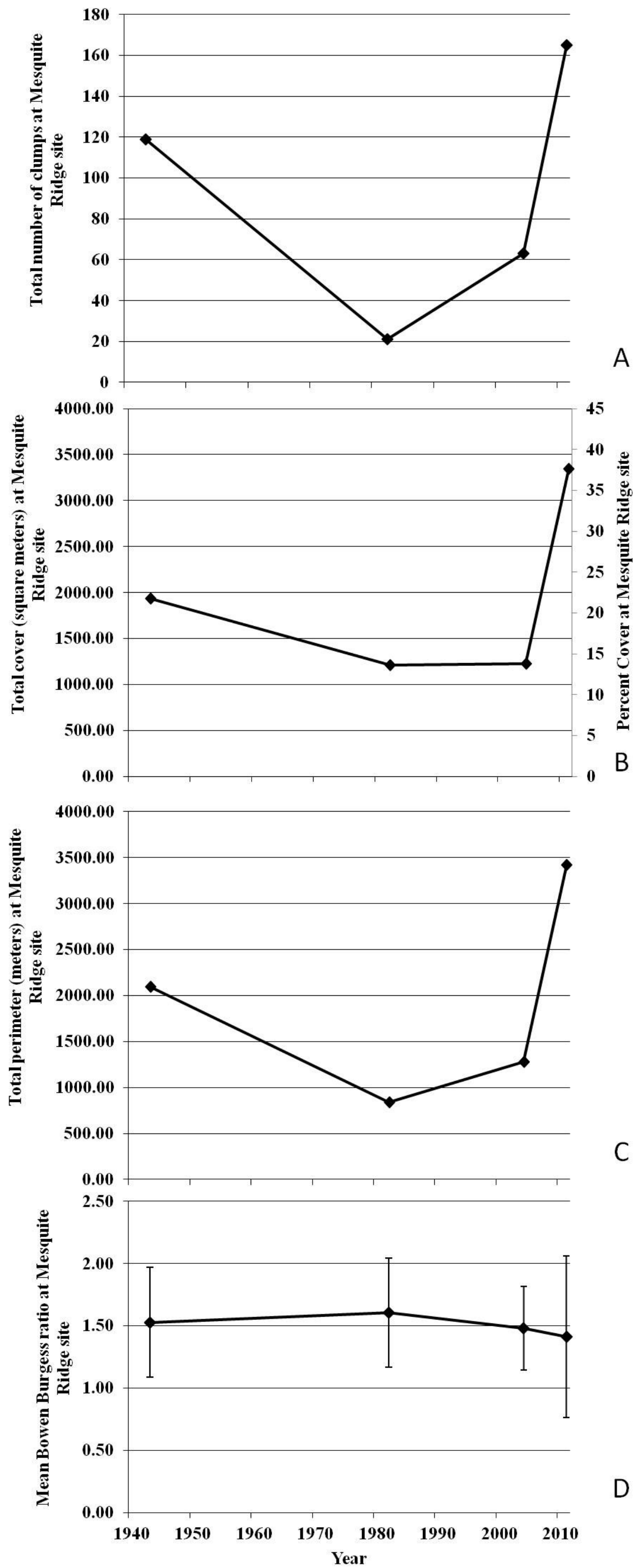


Figure 3.8. Analysis of shrub cover at the mesquite ridge site in IMRS, showing total number of shrub clumps (A), total and percent cover (B), total perimeter (C), and the mean/indivual shrub Bowen Burgess ratio (D) for all shrub clumps at the site. Error bars denote standard deviation of Bowen Burgess ratio.

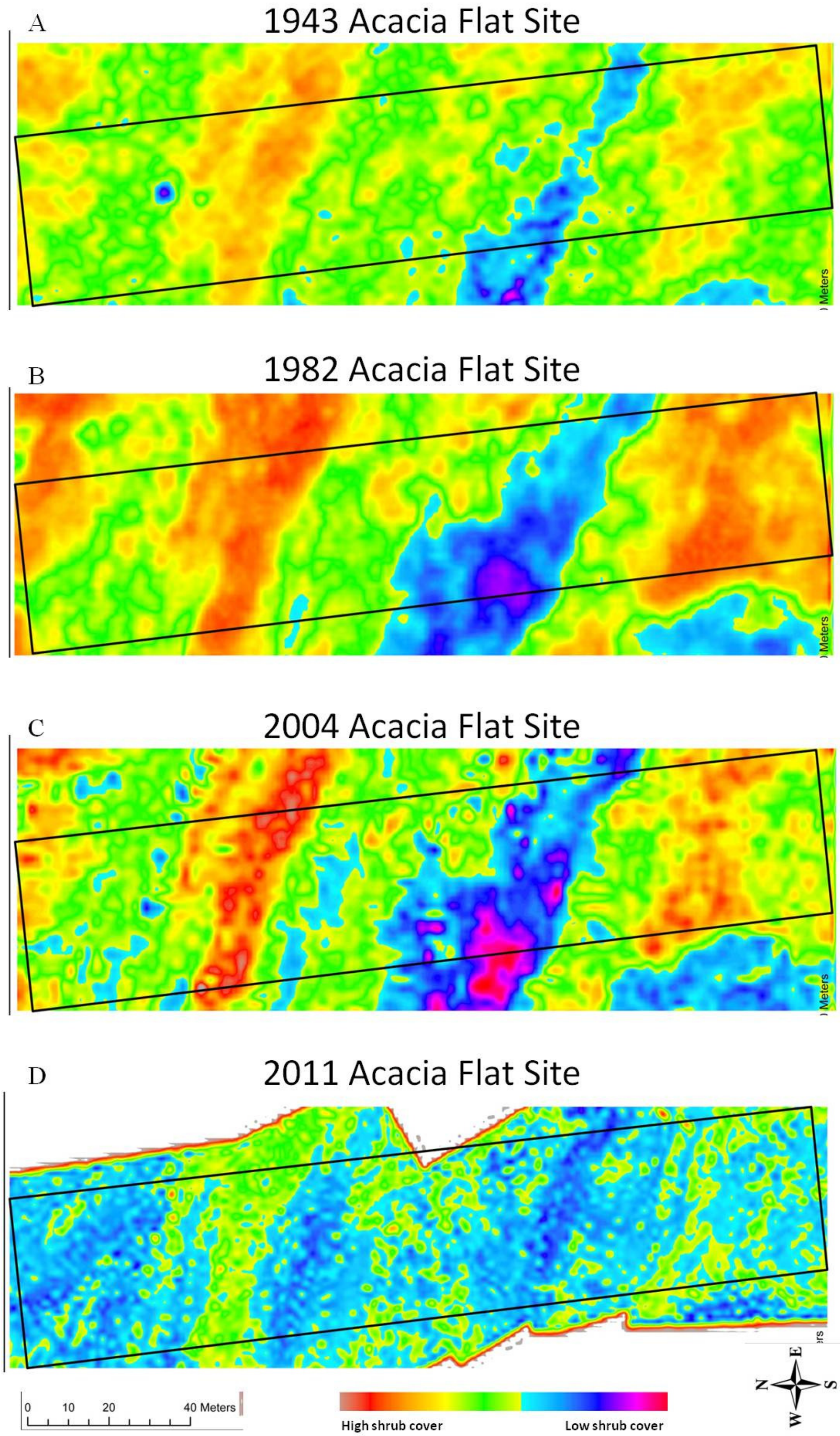


Figure 3.9. Color ramp stretch of aerial imagery for acacia flat site. The transect is outlined in black.

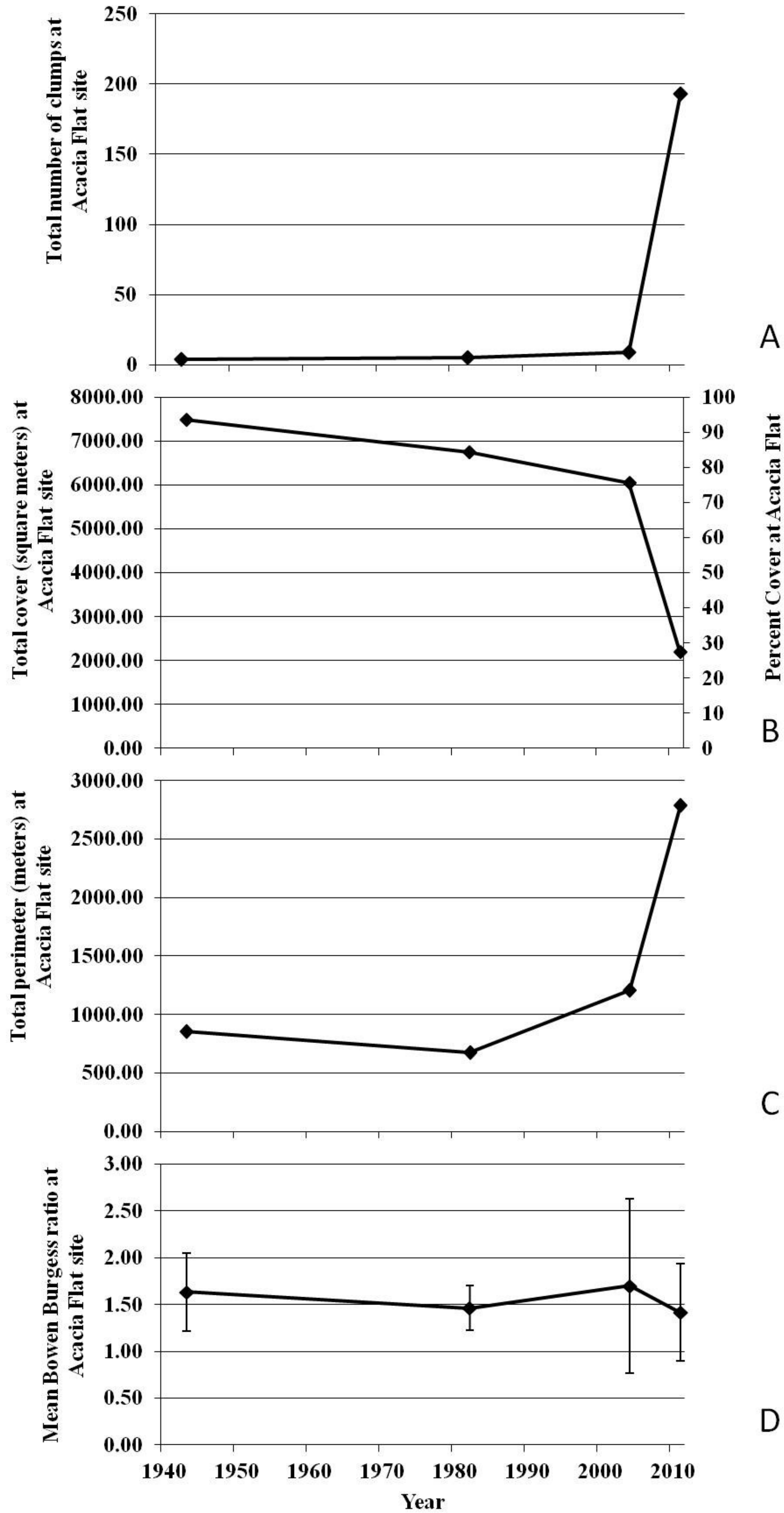


Figure 3.10. Analysis of shrub cover at the acacia flat site in IMRS, showing total number of shrub clumps (A), total and percent cover (B), total perimeter (C), and the mean/individual shrub Bowen Burgess ratio (D) for all shrub clumps at the site. Error bars denote standard deviation of Bowen Burgess ratio.

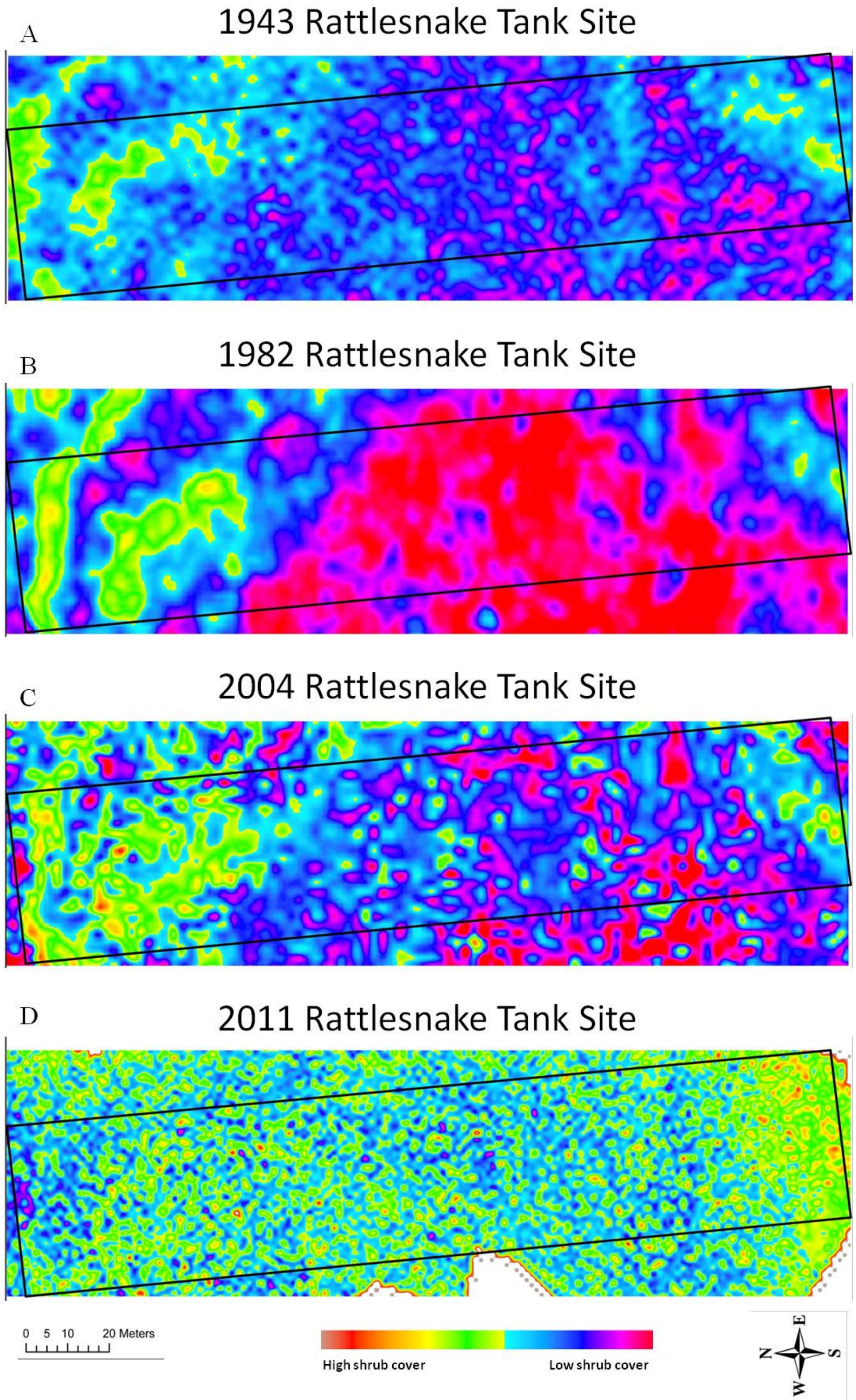


Figure 3.11. Color ramp stretch of aerial imagery for rattlesnake tank site. The transect is outlined in black.

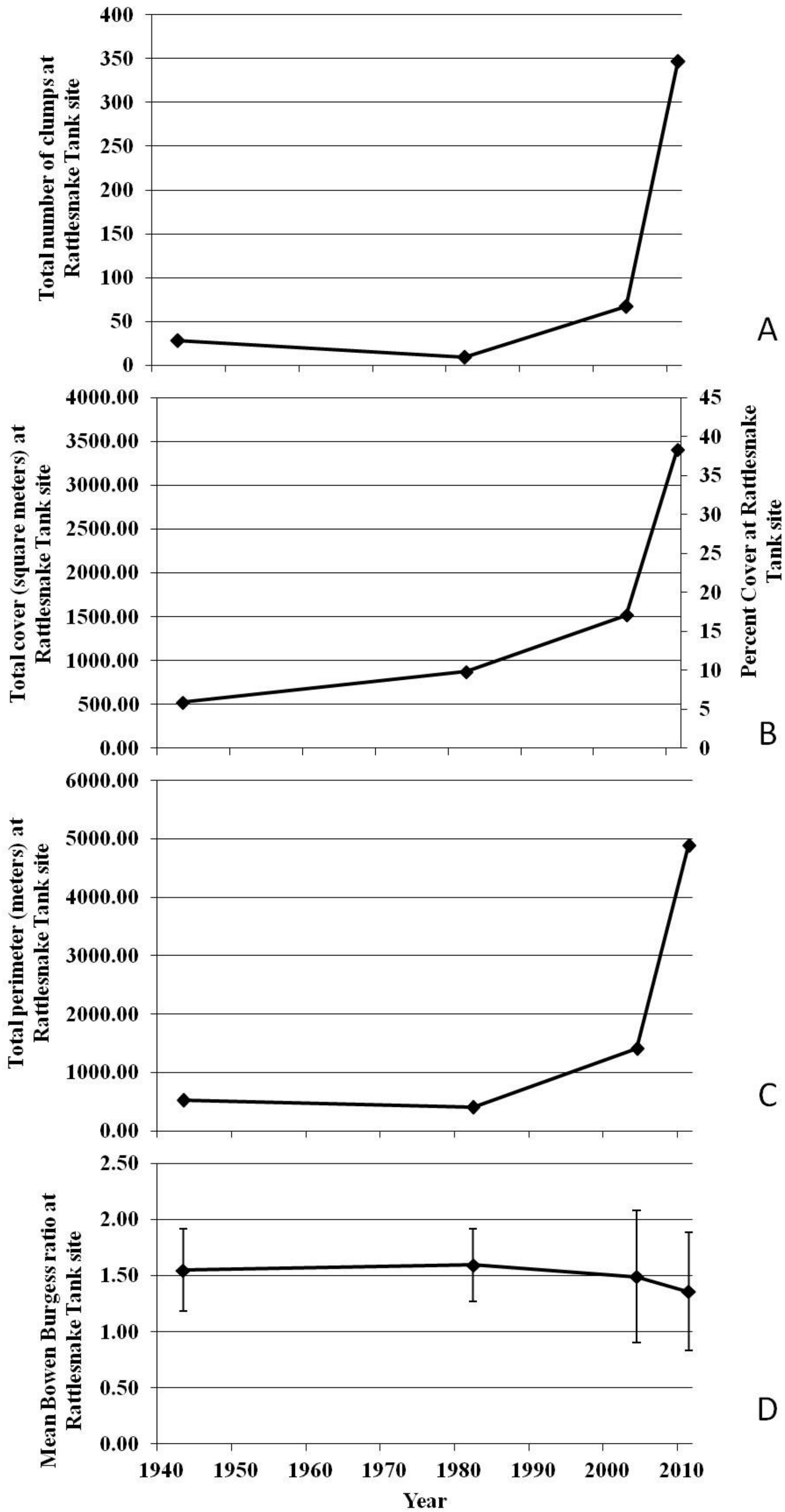


Figure 3.12. Analysis of shrub cover at the rattlesnake tank site in IMRS, showing total number of shrub clumps (A), total and percent cover (B), total perimeter (C), and the mean/individual shrub Bowen Burgess ratio (D) for all shrub clumps at the site. Error bars denote standard deviation of Bowen Burgess ratio.

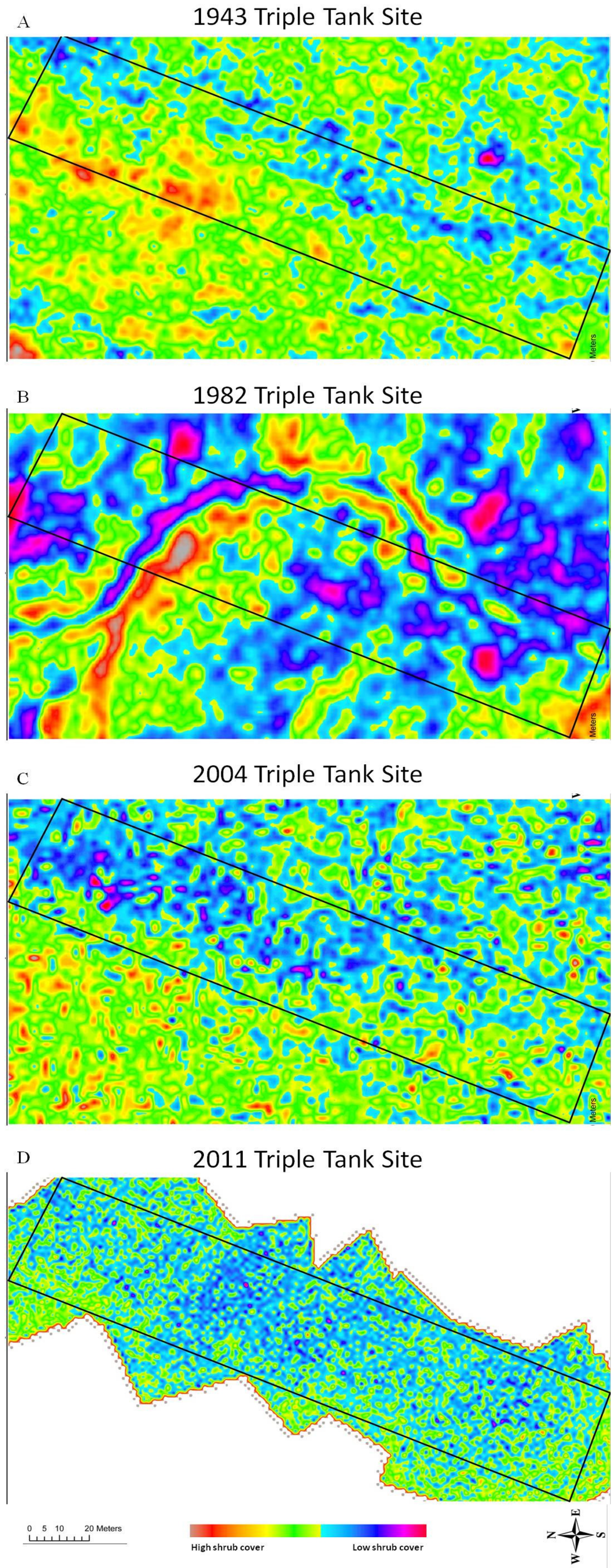


Figure 3.13. Color ramp stretch of aerial imagery for triple tank site in IMRS. The transect is outlined in black.

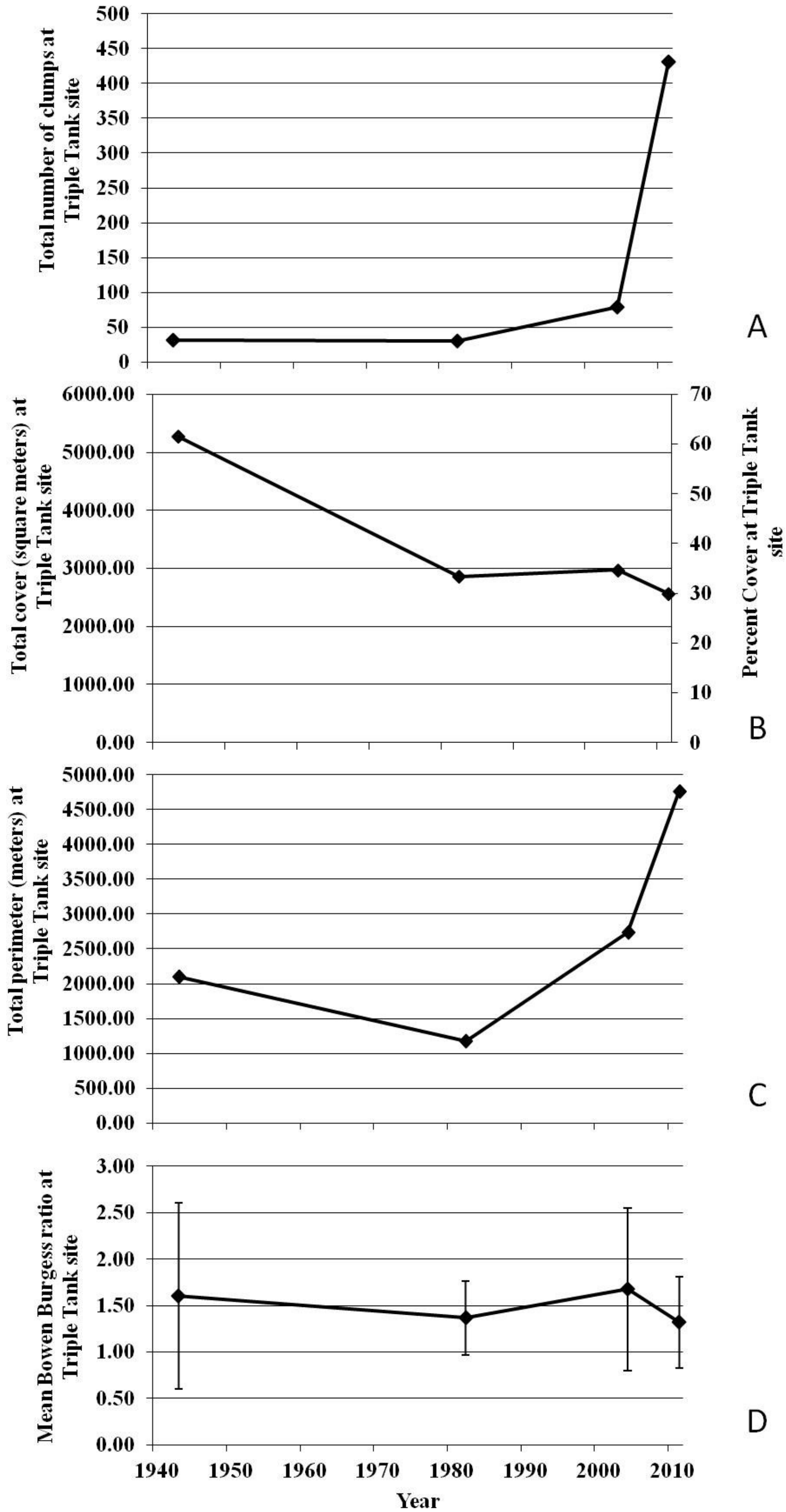


Figure 3.14. Analysis of shrub cover at the triple tank site in IMRS, showing total number of shrub clumps (A), total and percent cover (B), total perimeter (C), and the mean/individual shrub Bowen Burgess ratio (D) for all shrub clumps at the site. Error bars denote standard deviation of Bowen Burgess ratio.

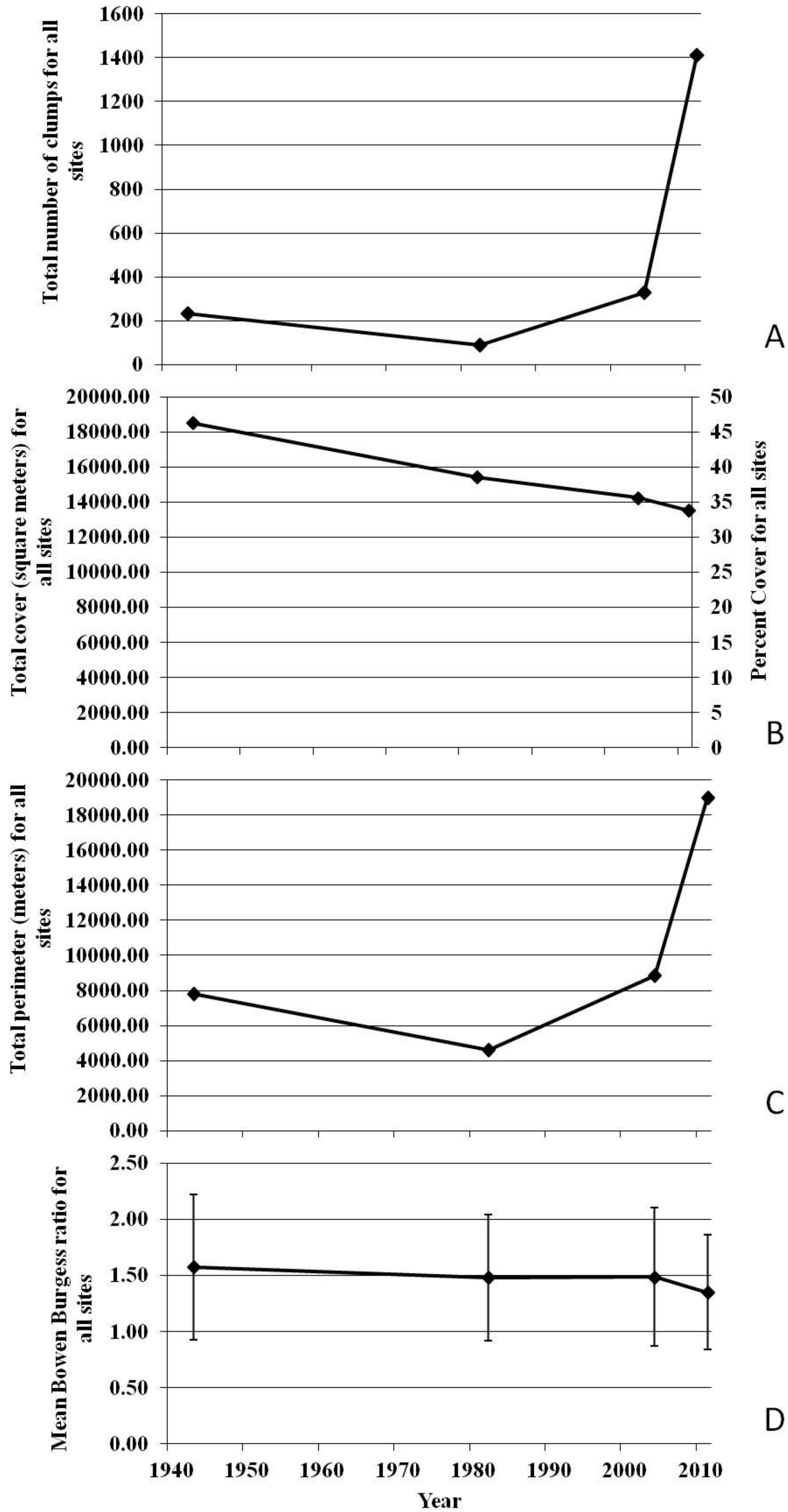


Figure 3.15. Analysis of shrub cover for all sites combined in IMRS, showing total number of shrub clumps (A), total and percent cover (B), total perimeter (C), and the mean/individual shrub Bowen Burgess ratio (D) for all shrub clumps at all sites. Error bard denote standard deviation of Bowen Burgess ratio.

Overall there is an increase in the number of shrub clumps at all sites (Table 3.2). Meanwhile, there is an increase in the total cover and percent cover at some sites, while total cover and percent cover declines at other sites (Table 3.2). When combining all sites, the total cover and percent cover decline slowly. This could be due to fact that even though the number of shrub clumps increases, which is indicative of the growth of shrubs to larger sizes, the total and percent cover by shrubs declines because the shrub and shrub clumps are becoming more fragmented (as seen in Kepner et al., 2000). The Bowen Burgess ratio suggests that not much change occurred through time for all sites. However, at the onset of the study period, the ratio increases indicating the combining of shrubs into clumps giving them irregular shapes. With the eventual decline in the ratio I hypothesize that this would be attributed to the rounding of clumps. Another thought might be that this would indicate a change in species composition from mesquite, which has irregular canopy shapes, to *Larrea tridentata*, which has round canopy shapes.

Table 3.2. Overall change in the total number of shrub clumps and % cover of each site between 1943 and 2011. Negative values indicate loss of cover.

Site	Overall Change	
	Total Clumps	% Cover
Ranch house	228	-15.9
Mesquite ridge	46	16.7
Acacia flat	189	-64.8
Rattlesnake tank	319	35.8
Triple tank	399	-33.8
All	1181	-12.3

3.4 Discussion

The objective of this study was to assess change in shrub count and cover using aerial photographs spanning the last 68 years at the IMRS, an example of a heterogeneous Chihuahuan Desert mountain ecosystem. Based on the results from this analysis, there was an overall increase in the total

number of shrub clumps at all sites between 1943 and 2011 with a small decline between 1943 and 1982. The mesquite ridge and rattlesnake tank sites experienced an overall increase in the total cover and percent cover of shrub clumps between 1943 and 2011, but much of the increase did not occur until after 2004. The ranch house, acacia flat, and triple tank sites underwent an overall decline in total shrub cover and percent cover between 1943 and 2011. When all sites were combined, the total number of shrub clumps increased substantially from 232 to 1413 clumps between 1943 and 2011 with a net change of 1181 clumps. A small drop in shrub clumps (232 to 87) between 1943 and 1982 was noted. When all sites were combined, the overall total cover and percent cover declined slightly from 18,539 m^2 (65%) to 13,527 m^2 (51%) between 1943 and 2011 with a net change in percent cover of -12.3%. This could indicate an increase in shrubs and an increase in overall growth of the shrubs, with shrubs becoming more fragmented (decrease in total and percent cover) over the last 68 years at the sites, as seen in another study located in the Sonoran Desert (Kepner et al., 2000). The sites that showed the largest gains in shrub clumps were triple tank, rattlesnake tank and ranch house sites with changes in total number of clumps being 399, 319, and 228 respectively between 1943 and 2011. These results were expected since these sites are considered to be semi-disturbed and disturbed. Both the mesquite ridge and rattlesnake tank sites had a gain in percent cover with changes in percent cover being 16.7% and 35.8%, while the ranch house, acacia flat, and triple tank sites experienced losses as seen in the change in percent cover (-15.9%, -64.8%, and -33.8 respectively). The rattlesnake tank site had the largest gain in percent cover while the acacia flat site had the greatest loss, and the triple tank site experienced the greatest increase in the total number of clumps. These results are somewhat unexpected. We hypothesized that the ranch house site would have exhibited the greatest change as it experienced the most extensive historical disturbance of all the sites in this study, but appears to be recovering. In addition, shrub cover seemed to change abruptly between 2004 and 2011, which could be attributed to the automated methodology employed in the delineation of shrub cover.

There were several challenges encountered in this study. First, even though the automated method employed in this study seemed to have sufficiently delineated shrub cover, it is important to emphasize that the imagery had limitations in the detection of shrubs. The shrubs delineated only

accounted for anywhere between 20% and 60% of shrubs greater than 2.0 m in size, only about 10% of shrubs 1.0-2.0 m in circumference (Fig. 3), and shrubs smaller than 1.0 m were not detectable due to the coarseness of the 1943 image. So, the overall total number of clumps and total and percent cover by shrubs at the study sites was likely an underestimate of the actual number. It became even more difficult to detect shrubs in older imagery. Browning et al. (2008) had similar challenges automating detection methods for documenting shrub cover in a 1936 aerial image, which showed many shrubs as one large entity, but also found that the extraction of information in historic imagery was the same as more recent imagery (Browning et al., 2009).

Second, delineation of individual shrub canopies was difficult as the automated method in this study had tendencies toward delineating multiple overlapping shrubs as individuals. Others have found this as well and believe it is impossible to distinguish a delineated shrub as a single large shrub, many overlapping shrubs of the same or different species, and caution species-specific interpretations for historic aerial photography (Kepner et al., 2000; Fensham and Fairfax, 2007; Browning et al., 2009). It was initially thought that increasing spatial resolution would solve detection limitations and other issues of automated shrub delineation. However, Browning et al. (2009) found that spatial resolution (0.6 m versus 1.0 m) did not influence detection and, in fact, overall accuracy of shrub cover estimates was higher in the 1.0 m image probably due to the appearance of larger shrub canopies as photo scale coarsened allowing for higher detection accuracy (Fensham and Fairfax, 2007; Browning et al., 2009). This was seen in shadow influences on shrubs which also made shrubs appear larger.

Third, acquiring all imagery of the same season was a problem from the onset of the study. The 1943 and 1982 imagery were from winter seasons when most vegetation cover was dormant except for *Larrea tridentata*, the 2011 kite photomosaics were from the fall season (ranch house, acacia flat, and mesquite ridge sites) and spring season (rattlesnake and triple tank sites), and the acquisition time for the 2004 image was unknown. Seasonal patterns of vegetation can be a huge factor causing underestimates of shrub cover, depending on the woody species of interest and time of year. Lastly, the color of surface soils at some sites limited the accuracy of the automated detection method employed. The Acacia flat site, for example, is mostly bare with sparse coverage of *Larrea tridentata* and *Acacia* spp. The surface

is the important factor being of a very deep red-brown color and widespread. The automated method in this study did not accurately delineate shrub cover at the site because most of site was classified as shrub cover, and ground surveys state otherwise.

If work were to continue from this study, these challenges need to be addressed. First, the addition of more sites spread throughout the property and in various community types will be needed for a more accurate assessment of shrub encroachment. I would caution use and encourage refinement of the automated method used in this study for various reasons. First, geologic and soil characteristics from areas of bare ground, and areas of shadow were highly influential in the outcome of the results. These could be overcome by avoiding collection of aerial photography in these areas. Second, seasonal patterns were also influential. To correct for this, it would be necessary to acquire kite aerial photographs during optimal times of the year (May-October) of the shrub (perennial species) cycle.

The change in shrub cover documented in this study align with findings from arid and semi arid ecosystems elsewhere in the US southwest and globally. The mean rate of percent increase in woody cover per year for the Chihuahuan and Sonoran deserts are approximately 0.40 and 0.35 per year, respectively (Barger et al., 2011). While much of the decadal time scale shrub encroachment research in the Chihuahuan Desert has focused on the encroachment of mesquite into arid grasslands, the majority of these studies have focused on the JER and used similar airphoto interpretation methods as in this study (Buffington and Herbel 1965; Goslee et al 2003; Laliberte et al 2004; Gibbens et al., 2005). Other studies that have documented shrub encroachment in the Sonoran Desert (Goldberg and Turner, 1986; McClaran, 2003; Guo, 2004; Briggs et al., 2007; Browning et al., 2008; Browning and Archer, 2011) in the Southern Great Plains (Ansley et al., 2001; Asner et al., 2003) and other parts of the world also show increases in shrub cover (Liu et al., 2003; Fensham et al., 2005; Sepehr, 2005; Hirche et al., 2011).

A key challenge in shrub encroachment studies is understanding what environmental factors and biotic responses control changes in shrub cover. Goslee et al. (2003) documented an increase in shrub cover and patch number between 1936 and the 1970's, which then stabilized afterward, indicating density dependence at the site was met. The degradation of the land caused by the effects of livestock before the turn of the century have also been linked to shrub encroachment (Brown et al., 1997;

Browning and Archer, 2011). In fact, high losses of grassland due to overgrazing spurred protection from grazing in the 1930's, which actually intensified shrub encroachment in protected areas compared to non-protected areas thereafter (Browning and Archer, 2011). IMRS has a history of grazing and has been protected from grazing since the 1980's. Though this study documents increases in total shrub clumps for all sites, it was the site with the highest impact from disturbance with the lowest change. This might indicate that desertification thresholds were not crossed from the impact of grazing and other human disturbances at the turn of the century, and that recovery is ongoing at the study site. This was further validated by observations of rapid recovery of some of the original grasslands located on the northwest side of the property at the onset of grazing protection (Wynn Anderson, personal communication).

It is also hypothesized that much of the change now occurring is related to precipitation patterns (Sankaran et al., 2005; Barger et al., 2011). Studies in the Chihuahuan Desert (Ludwig et al., 2000; Muldavin et al., 2002), Sonoran Desert (Brown et al., 1997), and even in the arid regions of the world (Fensham et al., 2005) suggest that increases in winter precipitation and drought conditions during the summer promote shrub encroachment. Since multiple spans of wet periods are necessary for desertified shrublands to recover to grassland states (Peters et al., 2012), it is likely that shrub encroachment will prevail throughout the region at the expense of productive grasslands. This is because the climate of the southwest is predicted to become warmer and drier over the next 100 years (Seager et al., 2007; Gutzler and Robbins, 2010). This study shows that increases in the total number of shrub clumps has occurred even in areas of no disturbance, and that increases in total and percent cover were present in the most undisturbed site, mesquite ridge, while opposite trends were true for the most highly disturbed site, the ranch house site. In previous studies (Chapter 2), vegetation was shown to be distributed along an elevational gradient indicating climatic changes would have an impact on vegetation. Mesquite ridge site is located higher in elevation compared to the ranch house site, and previous climate studies at IMRS show the mesquite site to be the warmest in temperature compared to other sites, and tended to have lower precipitation levels (De La Cerda Camargo, 2011). In addition, we hypothesized that the ranch house site would have exhibited the greatest change as it experienced the most extensive historical

disturbance of all the sites in this study, but appears to be recovering as seen in declines in percent cover. Climate studies at IMRS showed that the ranch house site had the highest levels of precipitation compared to the other sites (De La Cerda Camargo, 2011) and is further supported by the knowledge that multiple spans of wet periods are necessary for desertified shrublands to recover to grassland states (Peters et al., 2012). These findings may suggest that climate change affects on vegetation are likely occurring and further change is immenent.

It has also been shown that woody plant encroachment is highly dependent on the woody cover at the beginning of a change interval, with high coverage showing lower rates, even negative rates, of change compared to areas with low coverage (Fensham et al., 2005; Browning et al., 2008). Soil composition and processes such as erosion are also factors in vegetation change dynamics (Okin et al., 2009). Considering all the factors described, it is evident that much of the patterns of change cannot be coupled to any single factor, but have been produced by the interactions of many ecosystem functions and processes, the overall structure of ecosystems, and past land-use histories (Herrick et al., 2006b; Peters and Havstad, 2006). The results for this study show that though the total number of shrub clumps has increased at all sites, the total and percent cover has declined at the site with the highest disturbance history (ranch house) and increased at the site with no disturbance (mesquite ridge). In addition, mixed results have been shown between the two semi-disturbed sites (triple tank shows declines in percent cover while rattlesnake tank shows increases). It is evident that no single factor can be identified as responsible for changes seen at the IMRS, and multiple interacting factors must be at play.

3.5 Conclusion

Shrub encroachment trends are poorly defined for the mountain ecosystems of arid regions, yet these landscapes harbor biodiversity not seen in the lowland landscapes. This study assessed the degree of woody encroachment over the last 68 years of the Indio Mountains Research Station (IMRS), an example of a heterogenous Chihuahuan Desert mountain ecosystem. By assessing changes in shrub density and cover between multi-temporal aerial photographic time series, this study showed the total number of shrub clumps and total perimeter increases, while the total and percent cover declined between 1943 and 2011 for all sites combined. Many factors such as density dependence, livestock

grazing, climate changes, soil composition and processes, among others, have been identified as causal factors of shrub encroachment, and that it is the interaction among and between these factors that explain the complex process. The results of this study demonstrate that these complex interactions are occurring at the study site, and seen as an indicator of global change.

Chapter 4: How does a module-based undergraduate curricula utilizing inquiry-based learning enhance knowledge of desertification, environmental problem solving, and sustainability, and impact student attitude and efficacy?

Abstract: Engaging undergraduate level students with ecological concepts and enhancing their capacity to think holistically and embrace the necessary interdisciplinary approaches and technologies is a challenge, but critical to empowering and readying the next generation of environmental scientists and problem solvers. In this paper, we present a module-based undergraduate curriculum aimed at developing a holistic understanding of environmental science challenges and how technology can be used to aid environmental problem detection, monitoring, and mitigation. The module activities developed here aim to motivate ecological and environmental discovery and are focused on desert ecosystems and desertification, remote sensing, computer modeling and experimental manipulations that explore how ecosystem restoration can improve sustainability. To evaluate the effectiveness of the modules, we used a series of pre- and post-tests to measure changes in student knowledge, perception of ecology and technology, and their sense of efficacy regarding those topics. Significant increases were observed in almost all categories of evaluation, with marked increases and a large effect size in knowledge acquisition, and technological and environmental efficacy. We infer, therefore, that the modules effectively enhanced student content knowledge and changed their attitudes towards environmental science and technology.

4.1 Introduction

Dramatic human and environmental change is altering the world we live in and the sustainability of ecosystem goods and services available to humans (Millennium Ecosystem Assessment, 2005). Humans are altering the radiative forcing properties of the Earth's surface and its atmosphere that alters global climate (IPCC, 2007). Regional climate change such as that documented in the Arctic illustrate decisively the capacity of such change to stimulate cascading affects and complex feedbacks through the physical, biological, and human subsystems and interactions between these (ACIA 2005; Chapin et al. 2005; Hinzman et al. 2005). In many regions, such as the desert southwest, where desertification has resulted in the replacement of productive grasslands with shrublands (Barger et al., 2011) feedbacks

from ecosystem change appears to be positively reinforcing of such processes (Peters and Havstad, 2005), indicating that critical tipping points have been passed and that management and other practices focused on reversing such trends will be difficult, if not impossible (Bestelmeyer et al., 2009). Not surprisingly, synthesis of such change provokes many researchers to suggest that the earth is entering a new state (Crutzen and Steffen 2003; Ehlers and Krafft 2006). Although there remains a high degree of uncertainty as to how this state change will affect humans (IPCC, 2007), the current generation of students will be among the first generation of societal leaders and decision makers to witness and make critical environmental decisions in response to global mean temperature rising above that known from the last million years (IPCC, 2007; Chapin et al., 2011) and global population topping 10 billion people (UN, 2009). Clearly, there is a need in improving understanding of the future state of the Earth System and how humans will need to adapt concomitantly with new education capacities focused on environmental science and problem solving (National Research Council, 2009).

In recent years, higher education has been challenged to play a critical role in catalyzing societal change towards environmental sustainability (Junyent and Geli, 2010; Chapin et al., 2011). Action for sustainability is needed because human activities are strongly impacting the Earth System to the point of threatening the ecological well being (Chapin et al., 2011). The concept of sustainability conveys maintenance of the long-term integrity of the Earth system while meeting the long-term needs of human well-being in a changing world (National Research Council, 2010; Chapin et al., 2011). The knowledge needed to improve sustainability requires an interdisciplinary science approach that depends on the observations, skills, and creativity of a range of scientists, practitioners, and society in general (Chapin et al., 2011). This makes sustainability an emerging and important concept that should be integrated into science curricula with an interdisciplinary science approach to teach future generations of scientists, practitioners and society (Junyent and Geli, 2010; Chapin et al. 2011). It is necessary to teach all students in their respective fields on environmental and sustainability concepts and values in order to foster a "sustainability viewpoint" for future careers and lifestyle choices (Tilbury, 2004; Junyent and Geli, 2010). Incorporating sustainability concepts into STEM (Science, Technology, Engineering, and Mathematics) courses is even more important because STEM students tend to participate in campus

sustainability programs (Hopkins and James, 2010). In addition, their careers will likely provide opportunities to add to the advancement of ‘greener’ lifestyles and technologies, and they will probably contribute to the broader public and science policy debates in the future (Hopkins and James, 2010).

Engaging undergraduate students in ecology with ecological and environmental concepts and enhancing their capacity to think holistically and embrace the necessary interdisciplinary approaches and new technologies is a challenge (National Research Council, 2009; Smith, 2010). Uniting the teaching of ecology with discussions of real world environmental issues has been shown to engage students in the study of ecology and ecological concepts (Pallant, 1996; Gill and Burke, 1999; Battles et al., 2003). This approach to engaging students along with preparing them as new scientists to think holistically and work interdisciplinarily is key to empowering students to deal with the ecological challenges of the 21st century (Tilbury, 1995; Chapin et al., 2011). In addition, education based on the environment and environmental issues favors student-centered and activity-based learning (Tilbury, 1995). This coincides with the National Research Council’s (NRC) National Science Education Standards (2000, 1996), which endorse a science curriculum promoting active learning, inquiry and other instructional methods that engage students.

Inquiry-based learning is not a widely used teaching approach but has demonstrated success in the development of critical thinking skills, problem solving capabilities, and student creativity (Abdelraheem and Asan, 2006). Inquiry-based learning supports the development of 1) learning experiences relating to the scientific method, such as observing phenomenon, asking questions, generating hypothesis, designing an experiment and collecting data (Keller, et al., 2000; Abdelraheema and Asan, 2006) and 2) critical thinking skills, conceptual understanding, and scientific reasoning that generates conclusions based on analysis of real data collected to answer specific questions related to relevant science concepts and trends in the environment (National Research Council, 2000; Cavallo, et al., 2004). Thus, developing inquiry based learning opportunities for university courses is important for improving student learning outcomes and is further enhanced when activities include technology (Abdelraheem and Asan, 2006).

This chapter describes the implementation of a module-based undergraduate curriculum that was aimed at developing a holistic understanding of environmental problems, solutions, and the use of technology in ecology. A module-based approach has been shown to work well in ecology because it places abstract ecological concepts into concrete and relevant contexts that demonstrate how global or local environmental issues can be addressed (Smith, 2010). We chose to use desert ecosystems and desertification as the theme for ecological and technological discussion in this study because it was performed at the University of Texas at El Paso in the northern Chihuahuan Desert where desertification has dramatically altered local landscapes and is a key topic area of environmental science (UNEP, 2012) and problem solving (National Research Council, 2009). In addition, desertification and land-use management were identified as two of several of the environmental and development problems society faces today (UNESCO, 1992, 2010).

The inquiry-based modules developed for this chapter span a broad range of academic and practical activities in which ecologists are professionally involved. The activities present in the modules include ecological and environmental discovery in relation to local desert ecosystems and the process of desertification active in the region, remote sensing using satellite imagery, computer modeling and experimental manipulations that explore how ecosystem restoration can improve sustainability. The first three modules acquaint 50 students in an ecology class with desertification as a world-wide and local environmental problem. Within these three modules, methods for characterizing and modeling ecological processes were introduced. The fourth module presented learning challenges focused on developing solutions to the problems described in the first three modules. Student performance was measured in terms of a) ecological content knowledge (both content knowledge acquisition and students' confidence in their knowledge of ecological concepts), b) attitude and appreciation of ecology as a science, c) appreciation for technologies used by ecologists, d) attitude associated with ecological self-efficacy (the ability to take actions beneficial to the environment) and e) attitude associated with technological self-efficacy (the ability to apply technologies competently). We measured these aspects of student performance through a series of pre- and post-tests that students took immediately before and

after participating in each module. This study was approved by the University of Texas El Paso IRB review committee (IRB reference #224211-1).

4.2 Overview of modules created and adopted into the curriculum

We designed four 2.5 hour-long interactive and story-based curriculum modules that focused on a) Chihuahuan Desert ecosystems, b) ecosystem monitoring and management, c) technologies in ecosystem monitoring and management, and d) restoration ecology and sustainable living practices. A brief overview of the modules is given below and in Table 4.1.

4.2.1 Module 1-Impacts on our environment: land cover change in the southwest desert

This module (see Appendix 2) aimed to teach the students about the Chihuahuan Desert and the natural structure, function and processes of this ecosystem. The students were introduced to the topic of landscape ecology and the types of land cover change occurring in the Chihuahuan Desert, specifically: desertification and shrub encroachment. The module also introduced how land cover change is caused by both natural events and human activities and how these affected biodiversity and cycling of water and nutrients.

4.2.2 Module 2-Assessing and monitoring ecosystems: ecological modeling

The focus of this module (see Appendix 3) was to teach students about assessing the state of ecosystems, and utilizing ecosystem modeling as one of the tools for effective monitoring and management practices. The module teaches basic modeling concepts such as biotic and abiotic components of an ecosystem as model components, component interactions and determining whether those interactions are positive or negative feedbacks. Students were also taught whether the ecosystem model illustrates a positive or negative feedback cycle. The module also introduced examples of other modeling approaches and how these technological advances are helping to improve our understanding of ecosystem properties and processes.

4.2.3 Module 3-Technological advances for monitoring ecosystems

The aim of this module (see Appendix 4) was to teach students about some of the technological advances used in ecosystem monitoring and management. Students were introduced to technological tools such global positioning systems (GPS), aerial photography, satellite imagery, and unmanned aerial vehicles (UAVs). Students saw an example of a UAV and how it collects aerial photographs of terrestrial ecosystems. The students were also introduced to the science of remote sensing and geographic information systems (GIS) and how they can be used for creating land cover maps that are useful for ecosystem monitoring and management.

4.2.4 Module 4-Appropriate technologies for restorative human ecology

This module aimed to teach students about other technologies used in the ecological sciences relevant to assessing ecosystem sustainability and restoration ecology. Students were introduced to the concepts of sustainable living and restoration ecology and because we have reached a “tipping point” in the history of humans on Earth, why these practices are necessary to preserve the state of ecosystems and the world. The students were introduced to a range of appropriate technologies and learned real-world benefits of employing each technology to promote sustainable living.

Table 4.1. Table of module objectives and student activities.

Module	Module Objectives	Module Activities
1: **Impacts on our Environment**	a) students will learn that deserts are valuable, provide ecological goods, and produce ecological services b) students will learn that human activities and natural events can change the natural world	Students perform a lab activity (plant growth experiment) testing nutrient rich soil against eroded soil and the effects these soils have on plant growth. Students collect data, analyze, and communicate written and oral conclusions based on their results, tying these conclusions to the overall theme of the module.
2: **Assessing and Monitoring Ecosystems**	a) students will learn that modeling is necessary to understand physical phenomenon sufficiently well enough for scientists to make good decisions b) students will learn that ecosystem structure, function, and processes interact and can affect one another	Students create their own ecosystem models using any present, past, or make believe ecosystem of their choice. The models have to contain both the living (biotic) and non-living (abiotic) components of the ecosystem and depict how the components interact with one another either positively or negatively. Students were then asked to introduce a "disturbance" into the model and assess how it would affect the model itself and the outcome of the health of the ecosystem. Students presented and explained their models to the class in the form of a Power Point presentation.
3: **Technological Advances for Monitoring Ecosystems**	a) students will learn that technology is useful because it helps us solve problems	Students were asked to complete a tutorial on land cover mapping utilizing remote sensing and GIS software. The end product was an actual and usable land cover map of a Chihuahuan Desert mountain ecosystem completed by each student.
4: **Appropriate Technologies for Restorative Human**	a) students will learn that technology is useful because it helps us solve problems and that creative thinking about the implementation of technologies is key to employing the most resourceful solutions for the problem at hand	Students were asked to complete a short quiz on the topics discussed

4.3 Methods

4.3.1 Participant selection and experimental design

Participants in this study included 15 male and 35 female adults, 18 years of age and over, of all ethnic backgrounds, and enrolled as students in the undergraduate Biology 3416 (Ecology) course for

the Spring 2011 semester at the University of Texas El Paso (UTEP). Recruitment from the class pool (50 students) was conducted through an oral invitation by the principal author of this study, who was also a TA for the course. To minimize coercion, extra credit was awarded to students if they participated in the study. If the students chose not to participate, they were allowed to earn the extra credit through an alternative means. Active written consent was obtained from all participants. Due to IRB restrictions, we were unable to collect demographic data from the students but the class was typical for UTEP, where 76.4% of the student body is Hispanic (Table 4.2).

An exploratory study model was used, which consisted of a one group pre-post survey design. The student participants recruited for this study represent a non-random sample of the student population at UTEP. We explored the outcomes of a given treatment, namely the incorporation of the modules we created. The outcomes were assessed by comparing the results of a pre-test with the results of a post-test.

Modules were presented during scheduled classes on the UTEP campus and incorporated Power Point presentations, documentary movies, lab activities, and practical demonstrations. A pre-test was given prior to each module to assess students' baseline knowledge and attitudes on the selected topic. Following each module, an identical post-test was given to the students to allow for the relative impact of the module to be assessed.

For modules 1, 2, and 3 there were two parts to the survey. The first part consisted of multiple choice content knowledge questions that assessed prior and acquired student knowledge. The second part was a 5-point Likert scale questionnaire that assessed student attitudes and beliefs prior to the module (as the pre-test) and how the module impacted attitudes and beliefs after the module (as the post-test). Students ranked themselves on a scale of 1 to 5 (5 representing strongly agreeing and 1 as strongly disagreeing) in response to various statements dealing with the module topics. For module 4, the survey was a series of eight questions pertaining to content knowledge, and three questions focused on assessing student interest and feelings of efficacy towards the various technologies presented in the module.

Table 4.2. Demographics for the student population at the University of Texas El Paso (2007 Academic Year).

Gender		Ethnicity						
Male	Female	Non-resident aliens	Black, non-hispanic	American Indian/ Alaskan Native	Asian/ Pacific Islander	Hispanic	White, non-hispanic	Unknown
44.2%	55.8%	9.9%	2.8%	0.2%	1.0%	76.4%	9.2%	0.6%

4.3.2 Data analysis

For modules 1, 2, and 3, content knowledge was scored by marking answers as correct or incorrect. The percentage of correct answers in pre and post tests was then calculated for each of the modules and for all modules combined. For module 4, each question in the content knowledge portion of the survey (n=8 questions) had more than 1 correct response and, therefore, was scored independently as percent correct, with 0% being no answer given or an incorrect answer and 100% being completely correct. The total percentage of correct points was then totaled for all eight questions to obtain an overall score in pre and post tests.

For the attitude portion of the survey in modules 1, 2 and 3, the questions were broken into 5 subcategories: a) ecological content knowledge, b) appreciation of ecology, c) ecological efficacy, d) appreciation of technology, and e) technological efficacy. The mean score was calculated for each category for each student by summing the scores and dividing by the total number of questions in each category. The mean overall scores and standard deviations were then calculated for each category. The same method was used for assessing all the attitudinal portion of each survey for these three modules. In module 4, the questions pertained to technological efficacy and were subjective in nature. For each question of module 4, each category of a question was tallied by counting the total number of responses in each category by the students. The content knowledge and attitudinal portions of the survey were combined in modules 1, 2, and 3 to generate an omnibus score of each student for the pre- and post-test

surveys (*see* Equation 1). The mean overall score and standard deviation was then calculated for each module (1, 2, or 3) and all three modules combined.

Equation 1: *Total score* = (((a / b) + (c / d))/2)*100, where a = total correct, b = total questions, c = total attitude score, and d = total points of the attitude portion of the survey.

Both pre- and post-test surveys for modules 1, 2, 3, and these three modules combined were analyzed and compared to determine if participants' content knowledge and attitude changed significantly. Both pre- and post-test surveys for module 4 were analyzed to determine if there was a significant change in mean content knowledge. Significant differences in mean scores of the pre- and post-tests using t-values and p-values were assessed using independent sample t-tests using Minitab version 16 and SPSS version 13.

Effect sizes were calculated to better quantify the effectiveness of the modules. Effect sizes describe 'how well the modules worked', not just 'how the mean scores differed' (Coe, 2000). For this analysis, we used Equation 2 to calculate Cohen's effect size (d) and categorized results using Cohen's (1992) classification: small (d >= 0.20), medium (d >= 0.50), or large (d >= 0.80).

Equation 2: *D* = (x - y) / z, where x = mean of the post-test survey, y = mean of the pre-test survey, and z = pooled standard deviation.

4.4 Results

Significant increases in mean scores were observed between the pre- and post-test surveys in almost all evaluation categories, especially with respect to knowledge acquisition, overall attitude, and the technological and environmental efficacy. These results suggest the modules collectively had a significant impact on students learning. Results are presented in further detail below, aligning with the five attitudinal subcategories examined.

4.4.1 Content knowledge

For students' acquisition of content knowledge, there was a significant increase in all modules (Fig. 4.1A). For Module 1, mean scores for the pre- and post-test surveys were 62.9 and 79.2 respectively (t-value = -5.77; p-value < 0.01) and the effect size was large (d = 1.21). The mean scores for Module 2 and 3 pre-and post-test surveys were 48.8 and 65.7 (t-value = -3.80; p-value < 0.01) and

52.3 and 61.2 (t-value = -2.41; p-value < 0.05) respectively and there was a medium effect size (d = 0.79 and d = 0.50 for Modules 2 and 3 respectively). After pooling results for all questions from all modules, the mean scores for the pre- and post-test surveys were 54.45 and 68.75 (t-value = -6.29; p-value < 0.01) with a medium effect size (d = 0.75) (Table 4.3). In Module 4, there was a significant increase in average post-test scores (3.14 to 7.24) for lesson content knowledge with a large effect size (n = 41; t-value = -12.13; p-value <0.01; d = 2.46) (Table 4.4).

4.4.2 Ecological content knowledge

For the attitudinal portion of the survey, we broke the questions into 4 subcategories. Ecological content knowledge solicits students' confidence in their knowledge of ecological concepts and is present in all modules. The results indicate a significant increase from the pre- to post-test surveys (Fig. 4.1B). The mean scores for Module 1, 2, and 3 pre- and post-test surveys were 2.52 and 3.69 (t-value = -7.70; p-value < 0.01), 2.24 and 3.93 (t-value = -10.98; p-value < 0.01), and 2.63 and 3.76 (t-value = -6.15; p-value < 0.01) respectively, and there was a large effect size (d = 1.70, d = 2.74, and d = 1.34 for Module 1, 2, and 3 respectively). After pooling all confidence questions for all modules, the mean scores for the pre- and post-test survey were 2.46 and 3.79 (t-value = -13.87; p-value < 0.01) with a large effect size (d = 1.77) (Table 4.3).

4.4.3 Ecological efficacy

The ecological efficacy assessment measures the confidence of the students in their ability to take actions beneficial to the environment. It is present in all modules and results indicate a significant increase between the pre- and post-test surveys (Fig. 4.1C). The mean scores for Module 1, 2, and 3 pre- and post-test surveys were 2.48 and 3.72 (t-value = -6.71; p-value < 0.01), 2.29 and 3.68 (t-value = -6.90; p-value < 0.01), and 2.65 and 3.72 (t-value = -5.34; p-value < 0.01) respectively, and there was a large effect size (d = 1.47, d = 1.49, and d = 1.15 for Module 1, 2, and 3 respectively). When all ecological efficacy questions in this subcategory for all modules 1, 2, and 3 were combined, the mean scores for the pre- and post-test surveys were 2.47 and 3.71 (t-value = -10.93; p-value < 0.01) with a large effect size overall (d = 1.37) (Table 4.3).

4.4.4 Technological efficacy

The technological efficacy assessment tests the students' confidence in their ability to apply appropriate technologies, and other technologies, competently. It is present in modules 2, 3 (Fig. 4.2B), and 4 only (Table 4), due to the nature of the modules themselves. The mean scores for Module 2 and 3 pre- and post-test surveys were 2.12 and 3.80 (t-value = -10.17; p-value < 0.01) and 2.22 and 3.51 (t-value = -6.42, p-value < 0.01) respectively, and there was a large effect size (d = 2.20 and d = 1.40 for Module 2 and 3, respectively). When pooling all the technological efficacy questions from the two modules containing them, the mean score for the pre- and post-test surveys were 2.17 and 3.65 (t-value = -11.33; p-value < 0.01) with a large effect size overall (d = 1.74) (Table 4.3).

In Module 4 the students indicated that they were moved to incorporate appropriate technologies confidently into their lives, as both personal endeavors and as professional entrepreneurship opportunities. In all three questions in Module 4 that addressed this, the number of students responding positively increased by either double or triple from the pre- to post-tests. Technologies most favored by students were Kefir culturing, Kombucha culturing, cooking using a parabolic mirror, and the food culturing system known as aquaponics (Table 4.4).

4.4.5 Ecological/Technological appreciation

The ecological appreciation assessment tests the students' attitude in terms of appreciation for the science of ecology. It is present in Module 1 only. This is again due to the nature of the modules themselves with Module 1 being more ecologically themed in nature. For Module 1, the ecological appreciation mean score for the pre- and post-test surveys was 3.82 and 4.22 (t-value = -2.12; p-value < 0.05) and had a small effect size (d = 0.45) (Fig. 4.1D; Table 4.3).

The technological appreciation assessment tests the students' attitude in terms of appreciation for technologies used by ecologists. The technological appreciation assessment is present in all modules (Fig. 2A). For Module 1, the difference in mean scores from the pre- to post-test survey was 3.86 and 4.06 (t-value = -1.00; p-value = 0.32) and was not statistically significant. The mean score for Module 2 and 3 pre- and post-test survey were 3.50 and 4.00 (t-value = -2.52; p-value < 0.05) and 3.44 and 4.03 (t-value = -2.88; p-value < 0.01) respectively, and there was a medium effect size (d = 0.60 for both

Module 2 and 3). When all technological appreciation questions were combined for all modules, the mean scores of the pre- and post-test survey were 3.59 and 4.03 (t-value = -3.76; p-value < 0.01) and had a small effect size (d = 0.45) (Table 4.3).

4.4.6 Total attitude

The scores for all attitudinal subcategories were combined to provide a measure of the overall change in the attitude of the students and indicated a significant increase between the pre- and post-test surveys (Fig. 4.2C). The mean scores for Module 1, 2, and 3 pre- and post-test surveys were 3.26 and 3.98 (t-value = -5.28; p-value < 0.01), 2.36 and 3.90 (t-value = -10.54; p-value < 0.01), and 2.71 and 3.74 (t-value = -6.08, p-value < 0.01) respectively, and there was a large effect size (d = 1.13, d = 2.64, and d = 1.32 for Module 1, 2, and 3 respectively). After pooling all questions for Module 1, 2 and 3, the mean score for the pre- and post-test surveys were 2.76 and 3.87 (t-value = -11.93; p-value < 0.01; d = 1.50) and had a large effect size overall (Table 4.3).

4.4.7 Overall assessment

To make the most general, overall assessment of student change, we combined the scores of content knowledge and attitude for the surveys of Module 1, 2, and 3 and the results showed the overall score increased significantly between the pre- and post-test surveys (Fig. 4.2D). The mean scores for Module 1, 2, and 3 pre- and post-test surveys were 64.08 and 79.36 (t-value = -7.60; p-value < 0.01), 48.02 and 71.79 (t-value = -8.24; p-value < 0.01), and 53.26 and 67.97 (t-value = -5.58; p-value < 0.01) respectively, and had a large effect size (d = 1.60, d = 1.71, and d = 1.16 for Module 1, 2, and 3 respectively). Lastly, after pooling all questions from these modules we calculated a single mean overall score. The mean scores for the pre- and post-test surveys were 54.86 and 73.07 (t-value = -7.60; p-value < 0.01) and had a large effect size as well (d = 1.37) (Table 4.3).

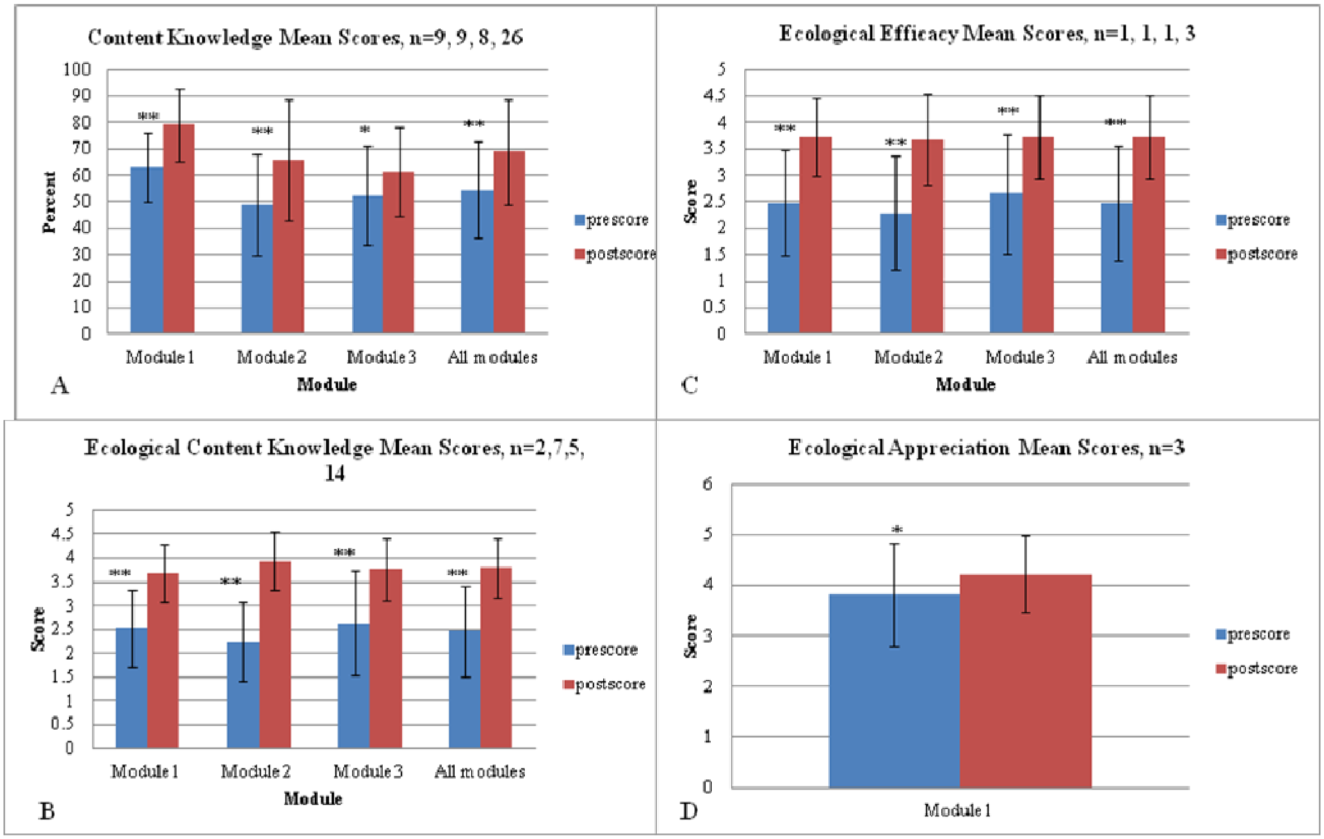


Figure 4.1. Mean scores and standard deviations (denoted by error bars) for each module and all modules in each category of the survey. N refers to the number of questions in each module for each category. (*) denotes significance at $\alpha<0.05$ and (**) denotes significance at $\alpha<0.01$. Categories shown are content knowledge (A), ecological content knowledge (B), ecological efficacy (C) appreciation (D).

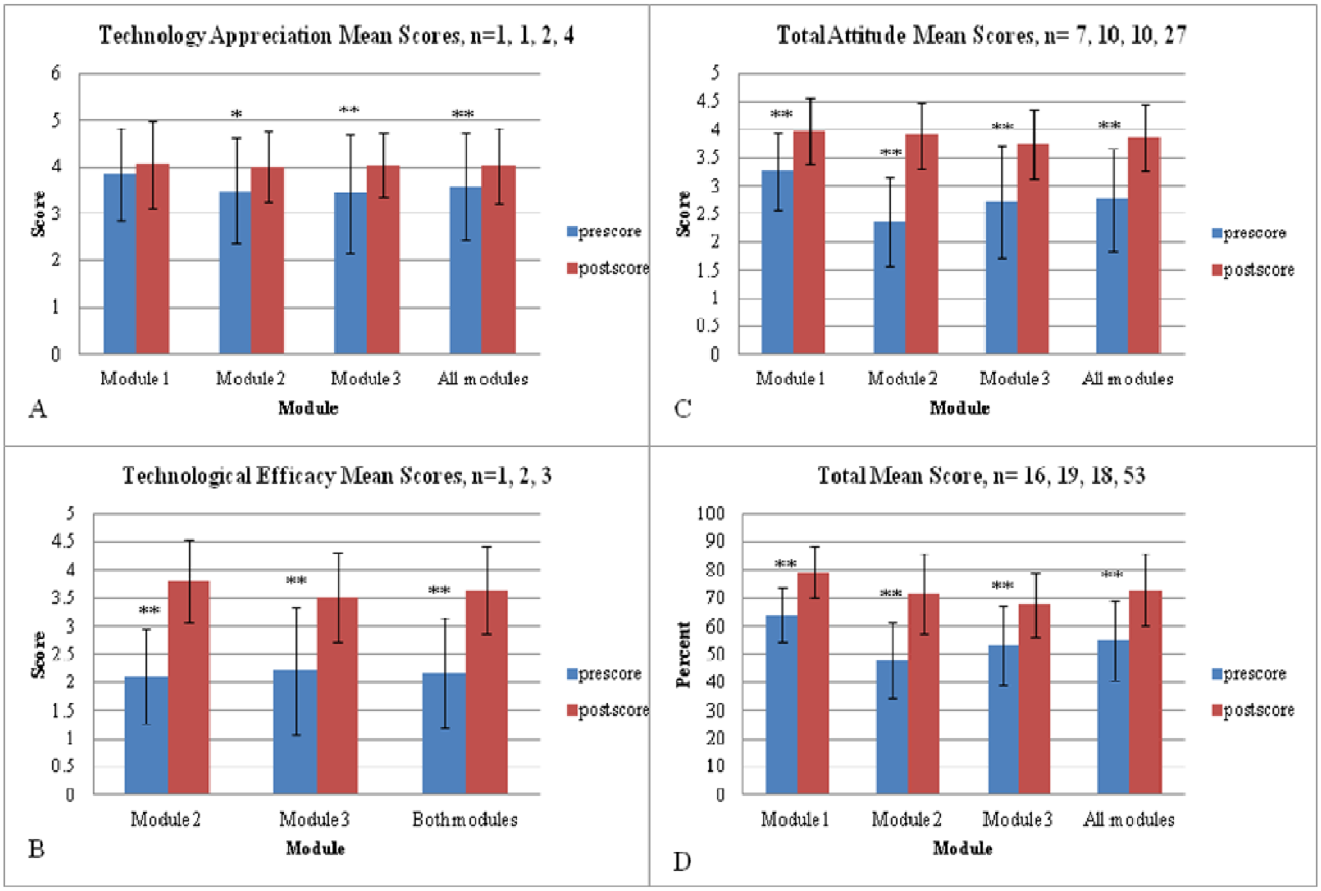


Figure 4.2. Mean scores and standard deviations (denoted by error bars) for each module and all modules combined in each category of the survey. N refers to the number of questions in each module for each category. (∗) denotes significance at $\alpha < 0.05$ and (∗∗) denotes significance at $\alpha < 0.01$. Categories shown are technological appreciation (A) and efficacy (B), total attitude score (C), and total survey score (D).

Table 4.3. Modules with t-test scores, p-values, and Cohen effect size scores.

Survey Category	Question Category	Module	T-value	p-value	DF	pooled variance	d index	Cohen Effect Size
Content	Content Knowledge 1-9	Impacts	-5.77	0.000	88	13.5195	1.21	large
Content	Content Knowledge 1-9	Assessing	-3.80	0.000	84	21.4062	0.79	medium
Content	Content Knowledge 1-8	Technological	-2.41	0.018	92	17.7508	0.50	medium
Content	Content Knowledge	All	-6.29	0.000	273	19.0257	0.75	medium
Content	Content Knowledge	Appropriate Tech	-12.13	0.000	69	1.6674	2.46	large
Attitude	Ecological Cont. Knowledge	Impacts	-7.70	0.000	79	0.6889	1.70	large
Attitude	Ecological Cont. Knowledge	Assessing	-10.98	0.000	86	0.6170	2.74	large
Attitude	Ecological Cont. Knowledge	Technological	-6.15	0.000	76	0.8455	1.34	large
Attitude	Ecological Cont. Knowledge	All	-13.87	0.000	243	0.7511	1.77	large
Attitude	Ecological Efficacy	Impacts	-6.71	0.000	79	0.8408	1.47	large
Attitude	Ecological Efficacy	Assessing	-6.90	0.000	88	0.9334	1.49	large
Attitude	Ecological Efficacy	Technological	-5.34	0.000	83	0.9324	1.15	large
Attitude	Ecological Efficacy	All	-10.93	0.000	254	0.9027	1.37	large
Attitude	Technological Appreciation	Impacts	-1.00	0.318	87	0.9495	0.21	small
Attitude	Technological Appreciation	Assessing	-2.52	0.014	82	0.8316	0.60	medium
Attitude	Technological Appreciation	Technological	-2.88	0.005	73	0.9802	0.60	medium
Attitude	Technological Appreciation	All	-3.76	0.000	247	0.9672	0.45	small
Attitude	Technological Efficacy	Assessing	-10.17	0.000	89	0.7630	2.20	large
Attitude	Technological Efficacy	Technological	-6.42	0.000	84	0.9210	1.40	large
Attitude	Technological Efficacy	Both	-11.33	0.000	178	0.8499	1.74	large
Attitude	Ecological Appreciation	Impacts	-2.12	0.037	78	0.8917	0.45	small
Attitude	Total Attitude 10	Impacts	-5.28	0.000	84	0.6351	1.13	large
Attitude	Total Attitude 10	Assessing	-10.54	0.000	85	0.5832	2.64	large
Attitude	Total Attitude 9	Technological	-6.08	0.000	77	0.7832	1.32	large
Attitude	Total Attitude	All	-11.93	0.000	239	0.7382	1.50	large
Total	Total	Impacts	-7.60	0.000	87	9.5550	1.60	large
Total	Total	Assessing	-8.24	0.000	88	13.8604	1.71	large
Total	Total	Technological	-5.58	0.000	89	12.6783	1.16	large
Total	Total	All	-11.29	0.000	272	13.3228	1.37	large

Table 4.4. Module 4 questions based on the technological efficacy of the appropriate technologies discussed. The pre total and post total show the number of total responses from all categories. The comment shows the top categories selected by students for each question.

Question	Pre Total	Post Total	Comment
#10. Which of these items are you moved to incorporate into your lifestyle (by beginning to culture, grow, use, consume, this/these items)?	50	152	Kefir, Parabolic mirror, and Kombucha had the student's greatest interest for lifestyle incorporation
#12. Which of the following do you feel would be easy to gain competence in culturing, growing, using, or consuming if you were to attempt to incorporate it into your lifestyle?	66	181	Kefir, Kombucha, and Parabolic Mirror were what students had confidence of their competence with that technology
#15. Which of the item(s) could you see yourself getting involved with as a business entrepreneurship opportunity?	61	143	Parabolic Mirror, Kefir, and Aquaponics were seen as viable business ventures for the students as entrepeneurs

4.5 Discussion

In this study we aimed to assess how the modules developed here impacted student learning. We measured student performance through a series of pre- and post-tests that students took immediately before and after participating in each module in terms of: a) ecological content knowledge (both content knowledge acquisition and students' confidence in their knowledge of ecological concepts), b) attitude and appreciation of ecology as a science, c) appreciation for technologies used by ecologists, d) attitude associated with ecological self-efficacy (the ability to take actions beneficial to the environment) and e) attitude associated with technological self efficacy (the ability to apply technologies competently). For acquisition of knowledge competence, all modules show a statistically significant increase between the pre- and post-test surveys, suggesting students gained knowledge of the ecological and technological concepts presented in relation to desert ecosystems and desertification. However, only modules 1 and 4 had a large effect size, modules 2 and 3 had a medium effect size. For changes in total attitude, all

modules show a statistically significant increase between pre- to post-test surveys and a large effect size. This suggests students' appreciation and confidence in their knowledge about desert ecosystems and desertification, and their ability to apply ecological and technological concepts improved. The attitudinal changes having the largest effect sizes were in the students' confidence in their knowledge of the topics, and ecological and technological self-efficacy. Self-efficacy is one's belief in their ability to succeed in specific situations and can play a major role in how one approaches goals, tasks, and challenges (Bandura, 1997). Since the modules improved ecological and technological self-efficacy, we can say that the modules improved the students' sense of ability to successfully approach goals, tasks, and challenges associated with the topics discussed in the modules. Ecological appreciation present in Module 1 only had a small effect size. However, despite the small effect size, the students initially scored high on the pre-test survey in terms of ecological appreciation. In other words, the students already had a good appreciation for ecology prior to this module. Based on the results from this study, we infer that the modules created for this study were effective in improving content knowledge, and changing the attitude of the students. It is important to note, however, that we had no control comparison group in this study, which could be used in the future to assess how much of an impact the modules made in comparison to students not exposed to these modules. In addition, all the data collected are based on self-reported surveys. Interviews or focus groups could be utilized in the future to gain a better understanding of how students felt the modules impacted them, on a personal level, on their understanding and abilities to take action in leading a more sustainable lifestyle.

The modules presented in this study include inquiry-based activities, and is important because studies have shown that inquiry based education may be vital and valuable for the underrepresented and underserved populations (Rodriguez and Bethel, 1983; Rosebery et al, 1990; Haury, 1993) present in this study. Since the class we tested exemplified a typical UTEP classroom, with UTEP's student population dominated by Hispanics, making up 76.4% of the population (Table 4.2), the inquiry-based modules of this study work to improve the education of underrepresented populations, and try to promote interest in STEM careers. This is also important because STEM students will likely have many opportunities to contribute to research and innovation in greener lifestyles and technologies, and will

thus have influence on future broader public and policy debates (Hopkins and James, 2010), which would allow underrepresented populations to participate in such initiatives.

In today's society huge environmental problems exist. The culmination of many years of global change research suggests that the earth is entering a new state (Crutzen and Steffen, 2003; Ehlers and Krafft, 2006) and there is a high degree of uncertainty as to how this state change will affect human society (IPCC, 2007). One of the challenges we face is the need to increase awareness concerning environmental issues and the concept of sustainability at local to global scales (Chapin et. al., 2011) through improved preparation of the next generation of scientists (Tilbury, 1995). The emerging environmental education for sustainability (EES) program in universities is an example of one such initiative to overcoming this challenge (Hopkins and James, 2010) and educates students in issues surrounding environmental and development problems (Tilbury, 1995, 2004). EES initiates action by challenging students to change parts of their lives to lead a more sustainable lifestyle (Tilbury, 1995, 2004). EES further engages students in the process of identifying issues, investigating issues, seeking solutions to issues, carrying out actions to address issues, and evaluating the impact of the steps taken to resolve these issues (Tilbury, 2004; 1995), all vital components of inquiry based science. The modules in this study were developed to address some of the goals of the EES and to challenge the students to become familiar with sustainable living. The Earth Stewardship initiative is an example of another such approach (Chapin et. al., 2011). If the modules created for this study were integrated with curricula from the EES and ideologies of the Earth Stewardship initiative, this would further enhance the: 1) introduction to multi-scale environmental problems, solutions, and technologies used in Ecology, 2) development of students abilities to think holistically and interdisciplinarily for sustainability, and 3) engagement of students in learning ecology and ecological concepts by connecting ecology with environmental issues.

The culmination of many years of global change research had led many researchers to suggest that the earth is entering a new state (Crutzen and Steffen, 2003; Ehlers and Krafft, 2006). Although there is a high degree of uncertainty as to how this state change will affect human society (IPCC, 2007), the current generation of students will be among the first generation of societal leaders and decision

makers to witness and make critical environmental decisions in response to global environmental change. For this reason, higher education has been challenged to play a critical role in catalyzing societal change towards environmental sustainability (Junyent and Geli, 2010; Chapin et al., 2011). The modules developed in this study and integrated into an undergraduate ecology class, effectively enhanced student content knowledge and changed their attitudes towards environmental science and technology. This study supports the National Research Council's (2009) Vision and Change initiative to improve undergraduate biology education for all students by: 1) developing curricula that integrate global environmental problems and relate these as real-world examples to abstract biological concepts, 2) utilizing innovative pedagogy and create active learning environments for students, and 3) integrating assessment and applying assessment data to improve and enhance the learning environment. The modules also demonstrate one of the broad areas of research identified: the environment with an emphasis on monitoring and restoring ecosystem function and biodiversity despite rapid environmental change (Labov et al., 2010).

Table 4.5. Student response categories and the number of responses in each category for each module. The questions addressed were what students liked best about the modules, and what students felt was the most fun part.

Module Question	Impacts Category	Number of Responses	Assessing Category	Number of Responses	Technological Category	Number of Responses
What did you like best about the lesson?	learning about LCC	10	creating models	15	using RS & GIS software	12
	hands on activities	3	presentation of models	9	learning about RS & GIS	4
	learning about LCC & plant growth experiment	2	learning about models	7	creating LC map	9
	plant growth experiment	6	learning about monitoring and management	2	learning about monitoring	2
	learning about human impacts	8	learning something new	2	hands on activity	1
	learning about deserts	2	connections to real world	4	new learning environment	1
	learning about LCC & the desert	2	STELLA demo	1	learning something new	2
	writing the paper	1			fun lesson	1
	learning about ecosystems	1			grid maps	2
	watching the movie	1			using RS & GIS software and grid maps	1
	learning something new	2			learning about technology	2
	topic interesting	1				
What was the most fun part?	**Impacts Category**	**Number of Responses**	**Assessing Category**	**Number of Responses**	**Technological Category**	**Number of Responses**
	learning about LCC	3	creating models	19	creating LC map	16
	plant growth experiment	22	presentation of models	7	using RS & GIS software	13
	learning about LCC & plant growth experiment	0	creating & presenting models	6	grid maps	6
	writing the paper	1	hands on activity	1	hands on activity	1
	learning something new	4	learning about models	3	fun lesson	1
					learning about RS & GIS	1

Chapter 5: General Discussion

This chapter summarizes the key objectives and questions posed by this dissertation and the research methods employed and results gained. A discussion of how research findings advance current knowledge and understanding is then given along with suggestions for future research.

5.1 Motivation for this dissertation

Much of the expansion in desert landscapes has occurred through desertification, a process that describes a form of degradation in drylands (UNEP, 1994; Eswaran et al., 2001) and has resulted from the complex interplay between many of the causal factors controlling and acting on multiple spatiotemporal scales in association with altered human land use to affect ecosystem structure and function (Herrick et al., 2006b; Peters and Havstad, 2006). In response to desertification, Land Cover Change (LCC) is the form of woody plant encroachment that has been linked to dramatic changes in ecosystem structure and function (MEA, 2005; D'Odorico et al., 2012). Most of the shrub encroachment research conducted in the southwest US have focused on desert basins (Barger et al., 2011), but few have focused on mountain ecosystems in desert regions, also known as hotspots for plant richness and endemism because most of the diversity found in these regions is located in mountains (UN, 1992). This makes shrub encroachment in mountain ecosystem important.

Dramatic human and environmental change is altering the world we live in and the sustainability of ecosystem goods and services available to humans (MEA, 2005; Reid et al. 2010). Although there remains a high degree of uncertainty as to how this state change will affect humans and terrestrial ecosystem structure and function, the current generation of students will be among the first societal leaders and decision makers to witness and make critical environmental decisions in response to global mean temperature approaching million year high values (IPCC, 2007; Chapin et al., 2011) and global population topping 10 billion people (MEA, 2005). The next generation will unmistakably face some challenging environmental decisions. One of those decisions will be that of desertification. Within the lifetime of most current undergraduate students, arid and semi-arid ecosystems will likely become the largest terrestrial biome on the planet as a result of anthropogenic disturbance and climate change

(Archer, 2010; Schimel, 2010). This makes desertification an important component of the educational curriculum with the aim of teaching the next generation of scientists to lead more sustainable lifestyles.

5.2 Overarching goals and objective

The overarching goal of this dissertation is to improve i) understanding of land cover change in a Chihuahuan Desert mountain landscapes, and ii) how knowledge of land cover change could be taught to undergraduate students. Research activities focused on addressing the following objectives and underlying questions:

1. To develop and assess the accuracy of a supervised land cover classification derived from high spatial resolution satellite imagery and plot level species cover and abundance data for a northern Chihuahuan Desert landscape, assess which environmental variables may be associated with the distribution of these land cover types, and using a conceptual modeling approach, develop hypotheses of how environmental change may impact land cover in these landscapes.
2. To assess the degree of woody encroachment over the last 68 years of the Indio Mountains Research Station (IMRS), an example of a heterogenous Chihuahuan Desert mountain ecosystem by a) assessing changes in shrub density and cover between multi-temporal aerial photographic time series, and b) explore the potential utility to use Kite Aerial Photography (KAP) in detailed land cover change assessments of arid landscapes.
3. Implement a module-based undergraduate curriculum that was aimed at developing a holistic understanding of environmental problems, solutions, and the use of technology in ecology. Desert ecosystems and desertification was the theme for ecological and technological discussion because it was performed at the University of Texas at El Paso in the northern Chihuahuan Desert where desertification has dramatically altered local landscapes and is a key topic area of environmental science (UNEP, 2012) and problem solving (National Research Council, 2009).

Field work was conducted explicitly at the Indio Mountains Research Station located south of Van Horn West Texas, and owned and managed by the University of Texas at El Paso. It is well suited

to this study as numerous land cover types common throughout the northern Chihuahuan Desert are represented, surface disturbance from grazing and other activities are minimal, and the land use history over the past 75 years is relatively well documented. The climate of IMRS is that of a Chihuahuan Desert ecosystem, has not been grazed by cattle for at least 30 years (Worthington et al., 2004), and has limited road access and impact from human development.

5.2.1 Vegetation-environment relationships of IMRS

The objectives for the first chapter are to produce a high spatial resolution land cover map and accuracy assessment, establish relationships between land cover and the environment, and develop a conceptual model describing how land cover may be altered in response to environmental change. A land cover map was produced using remote sensing methods. Then using this map, vegetation classes were examined to see how they related to environmental factors. This information was used to produce a conceptual state and transition model of how environmental change could affect LCC.

Vegetation classification and production of a high spatial resolution land cover map for a Chihuahuan Desert mountain landscape?

To determine the types of vegetation classes present, field surveys and analysis of vegetation associations were conducted to determine vegetation associations and improve the quality and accuracy of the vegetation map (Plumb, 1991). Based on the results of this study, the cluster analysis identified a total of eight vegetation classes after 50% of information remaining. The NMS ordination run on the data showed some of the classes, groups 1 and 4, and 6 and 7, overlapping in ordination space (Fig. 2.3). The results of the NMS identified six vegetation classes that are similar to vegetation types described for other locations in the Chihuahuan Desert, including Big Bend National Park (Plumb, 1991), the USDA-ARS JER (Gibbens et al., 2005), and the bajadas of the Guadalupe Mountains (Dick-Peddie, 1993). Classes are also similar to those described by the International Classification for the Chihuahuan Desert (Reid, 2000).

To understand vegetation relationships with the environment in arid and semiarid ecosystems, improved high-spatial resolution, baseline land cover maps are required (Cingolani et al., 2004) – especially in Chihuahuan Desert mountain landscapes, which are important to regional biodiversity and

sensitive to change. The six vegetation classes identified were combined with four derived classes (bare ground, river, river riparian, and shadow) to produce a 10-class land cover map of IMRS using a supervised classification of a 2008 IKONOS high spatial resolution satellite image. The map has good overall and user and producer accuracy (79%, 86%, and 80% respectively), aligns well with landscape features, and appears to delineate relatively fine scale micro-topographic features including roads, tanks, and corrals. The resulting map is in line with other classification maps produced for mountainous terrain in arid regions (overall accuracies range between 78% and 88%) (Cingolani et al., 2004; Wehrden et al., 2006). The classification map produced for the IMRS is unique because it is the only one known for a Chihuahuan Desert mountain landscape. The map also allowed for the development of the conceptual state and transition model for IMRS, which will be useful in future ecological studies at the site.

Relationship between land cover and environmental factors and the production of a conceptual state and transition model for a Chihuahuan Desert mountain landscape.

The land cover maps were then combined with environmental data to gain a better understanding of what environmental factors influence vegetation distribution and helped identify factors and environmental thresholds that affect vegetation distribution (Poulos and Camp, 2005). Such knowledge is key to understanding likely shifts in land cover in response to climate and land use changes (Burke, 2001), and allow the development of conceptual state and transition models. The conceptual state-and-transition model (Bestelmeyer et al., 2003) is a type of conceptual model currently being used as an important monitoring and management tool in rangelands (Carpenter and Brock, 2006; Forbis et al., 2006; King and Hobbs, 2006; Kunst et al., 2006; Barbour et al., 2007). State-and-transition models illustrate ecosystem responses to drivers of both natural events and human effects, and highlights threshold type states, in which crossing a threshold will cause an ecosystem to remain in an alternative state with little hope of reverting to the original state (Bestelmeyer et al., 2009). In this study, the occurrence of each land cover type at IMRS (derived from the high spatial resolution land cover map) was compared to a range of environmental factors including elevation, slope, aspect, latitude and longitude, solar radiation, geology type, and soil type, and regression tree analysis was used to determine the single best environmental factors as predictors for vegetation distribution. This analysis showed that the distribution of vegetation on IMRS is affected by several inter-related environmental

factors including slope, position with respect to latitude, and soil and geology type, and distributed along an elevational gradient. These relationships were used to establish a conceptual state and transition model for land cover at IMRS. The latter suggests that my conceptual model suggests that should projected climate change trends continue (Seager et al., 2007; Gutzler and Robbins, 2010), vegetation distribution patterns at the IMRS will shift grassland environments to shrub dominated communities. This is because mountain ecosystems within the Chihuahuan Desert are high in biodiversity due to the presence of elevational gradients with higher plant species diversity at higher elevations, and subtle changes in climate will affect the occurrence and distribution of vegetation in these landscapes due to wider niche spaces of lower elevation species (Poulos and Camp, 2005; Gitlin et al., 2006). The development of the conceptual state and transition model for IMRS is unique because it is the first of its kind for Chihuahuan Desert mountain ecosystems, and, due to the complex nature of desertification and shrub encroachment dynamics, allows us to determine primary causes for shrub encroachment in a Chihuahuan Desert mountain landscape. Limitation to the model exist, but as long as they are understood, the conceptual model developed here can be applied to a variety of sites and conditions within Chihuahuan desert mountain ecosystems and provide insight on how the environment can influence the distribution of vegetation.

5.2.2 Land cover change assessment of the Indio Mountains Research Station

Shrub encroachment in association with desertification has been documented in arid landscapes throughout the world and linked to climte change and anthropogenic causes. Relatively few shrub encroachment studies have focused on desert mountain landscapes, which typically host higher levels of biodiversity than surrounding desert plains. The objective of this study is to determine likely patterns of shrub encroachment in the Chihuahuan Desert landscape at IMRS using repeat aerial photography, which has been shown to be a valuable tool in detecting change in woody plant cover in rangelands over decadal time scales in other arid landscapes (Browning et al., 2009). Repeat aerial photographs from 1943, 1982, 2004, and kite aerial photographs from 2011 were used in the study. An automated method for detecting shrub cover in GIS was validated and used to delineate shrub cover for each image at five sites chosen for change assessment. Over all sites, there was an overall increase in the number of shrub

clumps, a decline in percent cover, and a decline in the Bowen Burgess ratio, a measure of the overall shape of a polygon (shrub clump). Some results suggest that the method employed had challenges in delineating shrub cover such as geology and soil color and the affects caused by shadow which would be misclassified as shrub cover. Nonetheless, results suggest that overall there has been an increase in the total number of shrub clumps, which concurs with similar studies such as Goslee et al. (2003), Browning and Archer (2011), and Browning et al., (2011). However, it is important to note that my study also shows a decline in total and percent cover which concurs with Browning et al., 2008 (saw % decrease between 1966 and 1996 only due to possibly response to herbicide apllication) but contradicts Goslee et al. (2003), Laliberte et al. (2004), Briggs et al., (2007), Browning and Archer (2011), and Browning et al., (2011) whom all saw increases in percent cover. I also saw a decrease in the irregularity of shrub canopy edges. Both are results I was not expecting and could be attributed to possible stable state or density dependence being reached (decrease in percent cover) and change in species composition (decrease in irregularity of shrub canopy edges). In addition, the kite aerial photographs proved useful to determine species composition at the sites of interest. The results for this study show that though the total number of shrub clumps has increased at all sites, the total and percent cover has declined at the site with the highest disturbance history (ranch house) and increased at the site with no disturbance (mesquite ridge). In Chapter 2, vegetation was shown to be distributed along an elevational gradient indicating climatic changes would have an impact on vegetation. Mesquite ridge site is located higher in elevation compared to the ranch house site, and previous climate studies at IMRS show the mesquite site to be the warmest in temperature compared to other sites, and tended to have lower precipitation levels (De La Cerda Camargo, 2011). In addition, we hypothesized that the ranch house site would have exhibited the greatest change as it experienced the most extensive historical disturbance of all the sites in this study, but appears to be recovering as seen in declines in percent cover. Climate studies at IMRS showed that the ranch house site had the highest levels of precipitation compared to the other sites (De La Cerda Camargo, 2011) and is further supported by the knowledge that multiple spans of wet periods are necessary for desertified shrublands to recover to grassland states (Peters et al., 2012). These findings may suggest that climate change affects on vegetation are likely occurring and further change is

immenent. Lastly, mixed results have been shown between the two semi-disturbed sites (triple tank shows declines in percent cover while rattlesnake tank shows increases). Previous climate data studies at IMRS show the triple tank site to be one of the warmest and also driest sites (De La Cerda Camargo, 2011). It is evident that no single factor can be identified as responsible for changes seen at the IMRS, and multiple interacting factors must be at play.

5.2.3 Incorporation and analysis of desert research education modules

Because land cover change is both impacting arid landscapes globally and is likely to be a key environmental challenge for future generations, there is an urgency to improve undergraduate education in this important field of study. This study assessed the effectiveness of a module-based curriculum based on central research themes covered in this dissertation. The modules aimed at developing a holistic understanding of environmental problems, solutions, and the use of technology in ecology. To evaluate the effectiveness of the modules, changes in student knowledge, perceived values towards ecology and technology, and sense of efficacy regarding those topics were measured using a series of pre- and post-tests. Significant increases between the pre- and post-test surveys in almost all categories, with marked increases and large effect sizes in knowledge acquisition, and technological and environmental efficacy suggest the modules were effective. The development of these modules is important because action for sustainability is needed to correct human activities strongly impacting Earth's life support systems to the point of threatening the ecological well being (Chapin et al., 2011). Uniting the teaching of ecology with discussions of real world environmental issues engages students in the study of ecology and ecological concepts (Pallant, 1996; Gill and Burke, 1999; Battles et al., 2003). This approach to engaging students along with training them as new scientists to think holistically and work in an interdisciplinary manner is key to empowering students to deal with the ecological challenges of the 21st century (Tilbury, 1995; Chapin et al., 2011).

5.3 Conclusions

The research conducted in this dissertation shows that the vegetated mountain landscapes of IMRS are similar to those found in other Chihuahuan Desert landscapes and that there appears to be some interesting vegetation change dynamics occurring. Some of these are similar to dynamics

documented elsewhere in arid landscapes. This is because the IMRS mountain ecosystem is unique, and evidence of changes in vegetation distributions occurring is an indicator of climate change, which will further bring about desertification in a Chihuahuan Desert mountain ecosystem. Or, methodological challenges presented in this study could be affecting the final results giving a false indication of what is really going on. The baseline conceptual state and transition model indicates that likely responses to climate change could affect change in vegetation communities at IMRS, and the preliminary assessment of changes in shrub cover using repeat aerial photography shows some change dynamics occurring in vegetation cover at the sites examined. But to have a good assessment of land cover change and continued monitoring of an area to be used as an indicator to any sort of change, there are a few things that need to be considered.

First, trying to determine disturbance dynamics driving changes in vegetation in any given ecosystem is complex. There are many factors at play and these are best addressed in an integrated research framework, such as the one developed in Peters et al. (2011) for land management practices of a Chihuahuan desert rangeland. There are five components that need to be considered when looking at disturbance dynamics in relation to ecosystem changes: 1) drivers, 2) initial conditions, 3) disturbance mechanisms, 4) legacies, and 5) future states (Peters et al., 2011). Any given disturbance consists of multiple drivers, and each driver can have multiple consequences depending on the physical environment and biota of a given site (Peters et al., 2011). Examples of drivers are climatic (such as precipitation and temperature), physical (such as surface water movement), biotic (such as invasive species), and anthropogenic (such as land use). In addition, it is difficult to assess causes of change when multiple disturbances interact. For example, changes in grasslands to shrublands in the Chihuahuan desert have been attributed to both grazing by livestock and drought, with one intensifying the other, and vice versa (Browning and Archer, 2011). Second, assessing initial conditions from which to compare any change through time is necessary, but often not possible. Determining initial conditions can be difficult to assess before natural disturbance events occur (Peters et al., 2011). Initial site conditions need to include abiotic site conditions (such as soil composition and integrity) and biotic integrity (Herrick et al., 2006b); because land use histories often predate the development of these ecological

principles, this criterion is often never met. Third, historic legacy must also be considered as this can affect outcomes of disturbances, and change the initial states of ecosystems (Peters and Havstad, 2006). This is why a good conceptual state and transition model is vital in the assessment and continued monitoring of ecosystems (Herrick et al., 2006b; Bestelmeyer et al., 2009). From the research conducted in this dissertation, a baseline conceptual state and transition model for the IMRS has been developed that could, upon further refinement, help establish a much needed predictive modeling capability for Chihuahuan Desert mountain ecosystems. This is because conceptual state and transition models pave the way for predictive modeling applications, and an important future challenge in understanding climate changes' effect on biodiversity is that of arriving at a generalized and predictive understanding of those effects (Guisan and Zimmermann, 2000). If change is found to be occurring through future research, the IMRS should be used as an indicator site of coming changes in dryland ecosystems that should be seen as a red flag for global change problems.

Second, an effective tool for quantifying and monitoring change in vegetation cover across broad spatial and temporal scales is necessary for all studies looking at shrub encroachment. Repeat aerial photography has become a preferred method for quantifying change over the landscape scale through time and has been used to monitor dryland environments successfully at multiple locations. A recent study has shown that an automated method that monitors shrub patch changes works best for landscape and plot scales, and will become important in ecosystem management because it can be used as an indicator of imminent shifts in the structure and function of ecosystems (Browning et al., 2011). From the work in this dissertation, I have created an automated method of delineating shrub clumps using aerial photography. This could be an effective tool for quantifying changes in shrub cover and monitoring at the IMRS, though work is needed to refine the method (see below).

Lastly, one of the challenges we face is the need to increase public awareness concerning environmental issues and the concept of sustainability at local to global scales (Chapin et. al., 2011), especially in dryland environments. Recent initiatives have emerged to address this challenge including the environmental education for sustainability (EES) program within universities (Tilbury, 1995) and the Earth Stewardship initiative formed by the Ecological Society of America (Chapin et al., 2011). The

primary goal of the environmental education for sustainability (EES) is to involve students in issues surrounding environmental and development problems (Tilbury, 1995). The primary goal of the Earth Stewardship initiative is to combine people with nature to help plan for a more sustainable future (Chapin et al., 2011). From the work in this dissertation, a module-based curriculum was created that combines both goals of the EES program and the Earth Stewardship initiative, which focuses on the dissemination of information of desert research and sustainability in dryland environments in order to increase public awareness concerning this recognized environmental issue and the concept of sustainability at local to global scales .

The results presented here are important because desertification of arid environments has been dubbed one of the primary global environmental problems society faces today (UNESCO, 2010). Drylands are estimated to cover 40% of the Earth's land surface (Okin et al., 2009) and are home to approximately 2.5 billion people (Reynolds et al., 2007) making improved sustainability in dryland environments especially vital (DeBuys, 2011). Desertification itself will likely lead to threats in agro-ecosystem productivity and food security, threats to freshwater supply and security due to altered precipitation patters brought about by desertification and climate change, loss of biodiversity and ecosystem services, and cause displacement of populations of people, all threatening the human well-being and security (UNESCO, 2006, 2010). This has caused the role of science to evolve to greater societal accountability and relevance, driven by society's own concern for its future (UNESCO, 2006). Together, these factors make the research conducted in this dissertation, and future research initiatives continued from this work, extremely important and necessary for a sustainable future.

5.4 Suggestions for future work

To improve the current understanding of desertification in Chihuahuan Desert landscapes like IMRS, sustained monitoring and an expanded assessment program are needed. Here, suggestions for refining the methodologies and products derived from this dissertation are given to benefit future activities. The vegetation classes derived from field surveys and a cluster analysis (see Appendix chapter) have been thoroughly evaluated, and appear to adequately represent the dominant vegetation classes present at IMRS.

The land cover map was produced using high spatial resolution satellite imagery and supervised classification techniques. It has good accuracy overall and the map is effective at detailing topographic and disturbance features seen on the ground. However, the map can definitely be improved upon. First, the acquisition of a high spatial resolution satellite image that covers the entire study area would be beneficial. It would be interesting to know how the classification developed in this study compares with one that could potentially be derived from the improved WorldView2 eight band imagery using object oriented classification methods. The WorldView2 provides high resolution panchromatic band and eight multi-spectral bands for enhanced spectral analysis and mapping and monitoring applications. Object-oriented image analysis produces more highly accurate maps than pixel based supervised methods because it utilizes texture and shape information, not just spectral properties (Laliberte et al., 2004; Yan et al., 2006; Laliberte and Rango, 2011). With this improved map, a study that compares the vegetation classes with other data such as links to faunal studies could be done. Other studies utilizing the improved map would be scaling of shrub densities, and species identifications utilizing the method above to determine nurse-protégé associations (interactions), and if they vary between community types, along an elevational gradient, on opposite facing slopes, or in disturbed versus undisturbed ecosystems (alluvial fan versus rocky slopes).

The conceptual model that was created for the IMRS is a good baseline conceptual framework that highlights the environmental factors that likely control or are associated with the distribution of vegetation at IMRS. Of course, the model serves as a baseline hypothesis that needs improvement and testing with the inclusion of other environmental factors not considered here. These would include various soil properties such as texture, nutrient status and soil water holding capacity, and finer scale geological map data. In addition, water availability in the form of precipitation, source, and flow would be extremely necessary since water availability is so important in controlling ecosystem properties and processes in arid landscapes. This can be done by relating classes to distances from arroyos or tanks using GIS spatial analysis. More importantly, I would create buffers around existing weather stations located around the IMRS and determine the dominant vegetation class type to be related to the climate data for those stations. Lastly, utilizing a topographic relative moisture index to estimate potential soil

moisture for water availability analysis, such as the one developed by Poulos and Camp (2005) would be a useful alternative in the absence of soil moisture measurements. All of these environmental factors could easily be incorporated into the current model by extracting the datasets for each class type and repeating the regression tree analysis.

The analysis of changes in shrub cover using an automated method of shrub delineation did a good job at delineating shrub clumps in the areas of interest. Also, the utilization of kite aerial photography in the study proved useful in clarifying shrub species identifications and in analysis of repeat aerial photography for change detection. The automated method developed in this dissertation to detect and delineate shrub clumps needs further refinement with the addition of spatial and textural information. Perhaps a classification tree analysis can be used to determine the optimal spectral, spatial, and textural features to classify an image. This method works well in conjunction with object oriented image analysis. An object-oriented classification of the imagery would also be worth exploring as an automated method for delineating shrub cover. This would need to be modified for the kite aerial imagery as it has been shown that the spectral information is not as good as satellite imagery and there are problems with the RGB bands of low cost digital cameras making classification difficult (Laliberte and Rango, 2011). The analysis of imagery must also consider site location. Based on the challenges faced in this dissertation, sites should be carefully located to ensure that geologic characteristics and topographic variation causing shadow will not influence the outcome of the results of the study.

The creation of a module-based curriculum that aimed to develop a holistic understanding of environmental problems, solutions, and the use of technology was easily implemented into the classroom. The activities present in the modules included ecological and environmental discovery in relation to northern Chihuahuan Desert ecosystems and desertification, remote sensing analysis, computer modeling and restorative ecosystem manipulations for sustainability. The modules were shown to be effective, improving both the knowledge and attitude of students. Keeping in line with the goals of the Earth Stewardship initiative and the EES, the development of the modules to span a complete course curriculum with the aim of informing global environmental problems, and teaching practices for living a more sustainable lifestyle could be developed. By ensuring that the developed

curriculum is similar to the modules developed here, which: 1) utilizes innovative pedagogy and integrates authentic research experiences, 2) ensures that learning is student-centered and inquiry-based to make students active participants, and 3) utilizes developed assessment tools to ensure effective learning outcomes by making changes to the curriculum if needed, the recommendations set out by the NSF's National Research Council's Vision and Change in Undergraduate Biology criteria (2009) could be met.

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Appendix 1: Assessing the vegetation classes of the Indio Mountains Research Station for image-based mapping

A.1 Introduction

Land cover change has had a global impact over the last half century as a result of both natural and human causes. In the Chihuahuan desert, the conversion of desert grassland to shrubland appears to have altered the provision of ecosystem goods and services with important social, economic, and ecological implications (Goslee et al., 2003). To improve large-scale change detection capacity and land management practices in the Chihuahuan desert, improved high-spatial resolution land cover maps are required – especially in Chihuahuan Desert mountain landscapes, which are important to regional biodiversity, sensitive to change, and poorly studied relative to lowland landscapes. To improve the quality of these maps, ground based surveys of vegetation must be conducted in order to assess the vegetation types that are present.

To determine apriori the location and types of classes present in an area not previously monitored, field surveys and analysis of vegetation associations are conducted. This improves the quality and accuracy of the vegetation map (Plumb, 1991). The purpose of this chapter is to report on the assessment of plant assemblages through field surveys of the Indio Mountains Research Station, an example of a Chihuahuan desert mountain ecosystem not previously monitored. This data from these surveys allowed for the creation of a thematic map of vegetation classes utilizing supervised classification techniques, which will be used for future LCC research at the Indio Mountains Research Station (Chapter 2).

A.2 Methods

A.2.1 Field measurements and data analysis

During the summers (June-August) of 2008 and 2009, a total of 830 sites where large areas of homogenous communities of vegetation exist were observed (Fig. A.1) within the Indio Mountains Research Station. The sites were chosen to be sure to the best of our ability that all community types were represented and that all environmental conditions were included (slope, aspect, elevation, geology, and distance from a disturbance). The following data were collected at each site: elevation, slope, aspect,

geology type, dominant plant species composition, and estimated percent cover of each dominant species. Ground photographs and GPS coordinates were also taken at each site to help interpret the data and to locate sites on GIS (Geographic Information Systems) and remote sensing software.

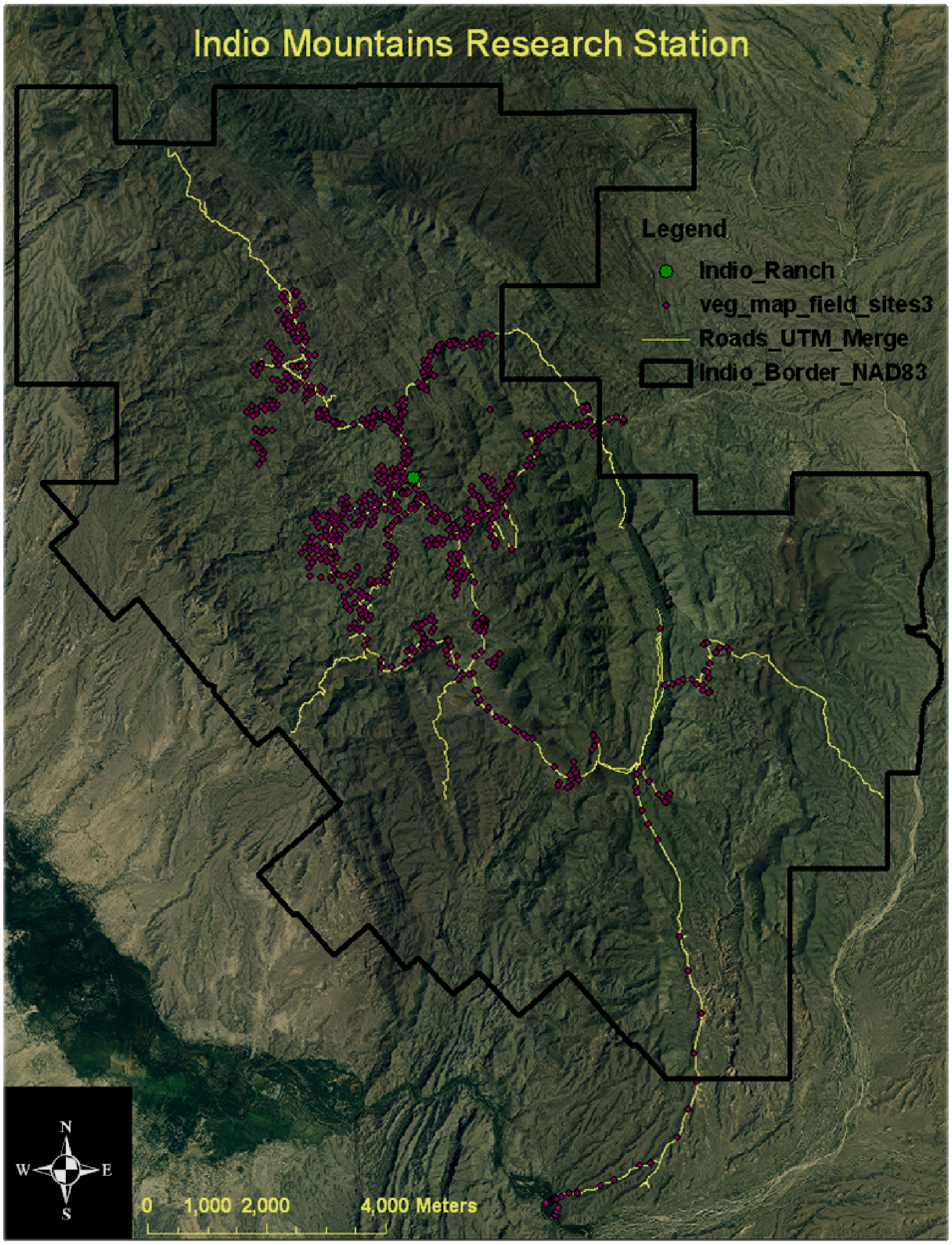


Figure A.1. Map of the Indio Mountains Research Station and the 830 sites (purple dots) visited.

A.2.2 Treatment of derived classes

I outlined the derived classes of the map using ArcGIS 9.2 software. Shapefiles of the roads were created using previously recorded ground-truthed data. Shapefiles of the mines, tanks, corrals, and other disturbed units were created using a 2005 aerial photograph and observations made during the summer field visits.

I created the shapefile of the drainage system (arroyos) for IMRS by utilizing ArcGIS's ArcHydro 1.3 Terrain preprocessing tool using a DEM and shapefile of a major drainage line (Squaw Springs). After importing a DEM of IMRS and Squaw Springs shapefile into ArcMap, I used DEM reconditioning to modify the raw DEM by creating linear features onto it.

A.2.3 Data analysis of vegetation classes

The 830 sites were entered into a data matrix for analysis where the midpoint of estimated percent cover for each species was assigned as 1, 3, 15, 33, 50, 70, or 90% for 0% (or not present), 1-5%, 5-20%, 21-40%, 41-60%, 61-80%, 81-100% cover, respectively. To determine the vegetation classes for vegetation surveys and for image based mapping, a cluster analysis was performed on the data matrix using estimated percent cover of species and sites. I performed the analysis in PCOrd statistical software using Ward's linkage method of clustering based on a Euclidean distance matrix. This method and distance measure was found to be the best for this type of data analysis (McCune and Grace, 2002). An ordination, NMS (Nonmetric Multidimensional Scaling), was also run on "autopilot" set to "slow and thorough" using Euclidean distance measure. The NMS results will be used to determine the appropriate number of classes for image-based mapping by allowing the visually distinct groups in ordination space to indicate where to make the cutoffs in the cluster. These mean NMS axis scores can be later used to find the five sites closest to the mean nodal position of each vegetation class within the scatterplots. These five sites will become the training sites for supervised classification mapping as these sites are most representative of each class.

A.2.4 Interpretation of the dendrogram

The vegetation classes for IMRS were determined by searching for natural breaks in the cluster dendrogram. This allows classes to be assigned to visually distinct groups on the dendrogram (Plumb,

1991). The vegetation class designations were determined from visual interpretations of ground photographs and field visits, and by reviewing the floristic data from field notes.

Broader scale vegetation classes were determined by analyzing the dendrogram at 4 cutoff values: 0%, 35%, 50%, and 65% of information remaining to determine the number of classes at each cutoff point. This information was correlated with the NMS scores to determine the appropriate number of classes for use in satellite image mapping by allowing the groups in NMS to indicate where to make the cutoffs in the cluster. The NMS allows us to see visual grouping of the cluster in ordination space to determine the cutoffs in the cluster.

A.3 Results

A.3.1 Analysis of the cluster dendrogram for vegetation classes

After reviewing the natural breaks in the cluster dendrogram and linking that with the floristic data, I hypothesize that there are 29 vegetation classes (see Description of vegetation classes in section A.3.5 below) present at the Indio Mountains Research Station. These are based on ground observations; with the only difference in one class to another is one species' presence or absence.

A.3.2 NMS analysis for potential map classes

After I combined the results of the NMS with the results from the cluster analysis, I evaluated the following information. At the 0% cutoff, there were two potential classes with little overlap between the two in the scatterplots (Fig. A.2A). When I analyzed at the 35% cutoff value, four potential classes emerged with little overlap between the classes in the scatterplots (Fig. A.2B). Eight potential classes were seen at the 50% cutoff value, and the scatterplots showed some overlap occurring between some of the classes (Fig. A.2C). Finally, at the 65% cutoff value, sixteen potential map classes were present, but the scatterplot at this cutoff showed a great deal of overlap between most of the classes present (Fig. A.2D). Based on this information, the classes present at the 50% cutoff value showed the most promise for use as potential map classes for image based mapping. From the 8 potential classes present at the 50% cutoff groupings, two pairs of classes will be combined because the results of the scatterplot showed there was high overlap between the pairs. This resulted in six potential classes should this combination occur. This combination will include the four complexes (described in section A.3.5 below)

from which the 29 smaller classes from the cluster analysis are combined. This information is given in the synopsis that follows, along with the keys and descriptions of vegetation classes at IMRS.

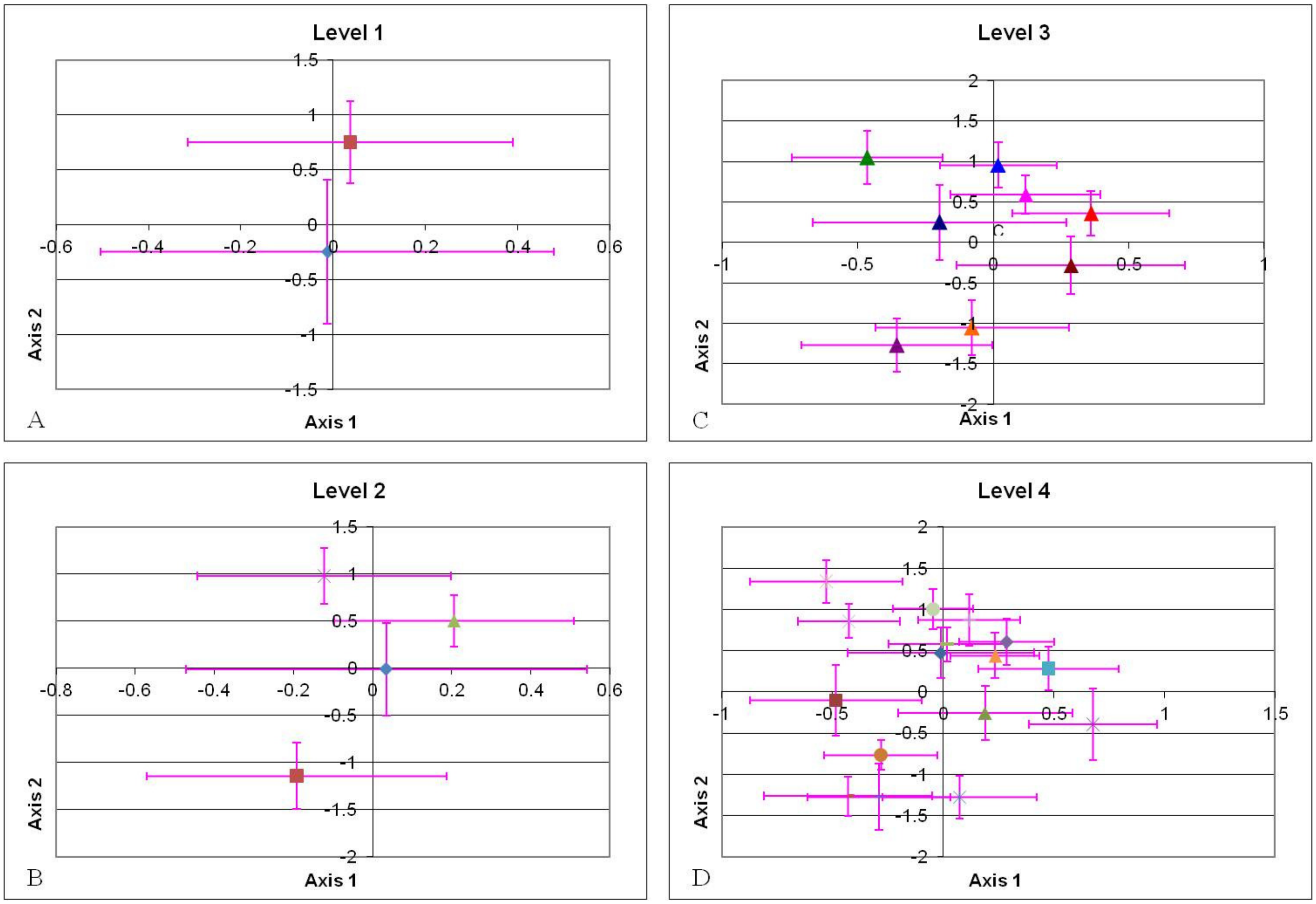


Figure A.2. Results of the NMS scores on scatterplots for each cluster group level.

A.3.3 Synopsis of the Indio Mountains vegetation complexes and classes

Agave Bouteloua complex

ABD: *Agave Bouteloua Dasylirion*

ABYD: *Agave Bouteloua Yucca Dasylirion*

ABFY: *Agave Bouteloua Fouquieria Yucca*

ABFD: *Agave Bouteloua Fouquieria Dasylirion*

AB: *Agave Bouteloua*

ABL: *Agave Bouteloua Larrea*

BLD: *Bouteloua Larrea Dasylirion*

ABO: *Agave Bouteloua Opuntia*

Bouteloua grassland complex

BA: *Bouteloua Agave*

BAAc: *Bouteloua Agave Acacia*

BAc: *Bouteloua Acacia*

BLF: *Bouteloua Larrea Fouquieria*

Agave Bouteloua Viguiera complex

ABVF: *Agave Bouteloua Viguiera Fouquieria*

ABVL: *Agave Bouteloua Viguiera Larrea*

ABVO: *Agave Bouteloua Viguiera Opuntia*

ABVD: *Agave Bouteloua Viguiera Daslyirion*

ABV: *Agave Bouteloua Viguiera*

Larrea Acacia complex

Ac: *Acacia*

AcL: *Acacia Larrea*

LF: *Larrea Fouquieria*

LBAO: *Larrea Bouteloua Agave Opuntia*

LBP: *Larrea Bouteloua Parthenium*

LO: *Larrea Opuntia*

LAcO: *Larrea Acacia Opuntia*

LAc: *Larrea Acacia*

Bare Ground

Arroyo

Tanks

Riparian (derived)

A.3.4 Key to the vegetation classes within Indio Mountains Research Station

1. Dominant vegetation type is *Bouteloua*, but *Viguiera* is not a co-dominant; or *Bouteloua* is not dominant……………………….…………………………..........………………………......2

—Dominant vegetation types are *Agave, Bouteloua* & *Viguiera*………………………………………..18

2(1). Dominant vegetation type is *Bouteloua*………………….………………………………………3

—Dominant vegetation type is *Larrea*; *Bouteloua* is sparse…………...………………...…………16

—Vegetation is very sparse or absent within a small area; vegetation that is present is represented by the surrounding vegetation……………………………..………………..….….………..Bare Ground

3(2). *Opuntia* and *Leucophyllum* are co-dominant……………………………………………………ABO

—*Opuntia* is co-dominant; *Leucophyllum* and *Acacia* are present…………………….……………...…4

—*Acacia* is co-dominant……………………………………………………………………………..8

—*Larrea* is co-dominant or abundant at the site; *Acacia* has light coverage…….……...…………....11

4(3). *Dasylirion* is a co-dominant……………………………………………………………………5

—*Dasylirion* is not a co-dominant, but present with light coverage…………….……………………......6

5(4). *Larrea* is present with light to moderate coverage; *Agave* is co-dominant with *Bouteloua*; *Yucca*, *Fouquieria*, *Ephedra*, *Tiquila*, and various cacti species are present with light coverage……………………………………….……………………………………...……...….ABD

—*Larrea* is absent; *Agave* is co-dominant with *Bouteloua*; similar to class 1 in make-up of vegetation ……………………………………………………………………………..………............ABYD

6(4). *Opuntia* and *Fouquieria* are co-dominants; diversity and abundance of other cacti at the site…………………………….………..………………………………………….…………..7

—*Agave* is co-dominant; *Fouquieria* is absent; *Yucca*, *Ephedra*, *Viguiera*, *Larrea*, and other sub shrubs are present with light coverage …...…………………...……………………………...………...…BA

7(6). *Yucca* is present and conspicuous; other shrubs are occasional and varied…….………......ABFY

—*Dasylirion* is present and conspicuous; *Yucca* and other shrubs are occasional and varied……….……………………………………...ABFD

8(3). *Larrea* is not co-dominant with *Acacia*……………..………………………………….……...9

—*Larrea* is co-dominant with *Acacia*...……………………………………………………………10

9(8). *Leucophyllum* is abundant; *Agave* is abundant; light to moderate coverage of *Larrea*, *Fouquieria*, *Dasylirion*, *Viguiera*, *Ephedra*, *Opuntia*, *Yucca*, other shrubs, and various cacti species……………………………..……………………………………………..……………….....….BAAc

—*Leucophyllum* is replaced by *Parthenium*; *Agave* is occasional; light to moderate coverage of *Larrea*, *Fouquieria*, *Dasylirion*, *Viguiera*, *Ephedra*, *Opuntia*, *Yucca*, other shrubs, and various cacti species…………………………….……………………...…………………………….....…BAc

10(8). *Larrea* has moderate coverage; light to moderate coverage of *Agave* and *Fouquieria*; light coverage of *Opuntia*, *Tequila*, *Ephedra*, various sub shrubs and cacti; *Viguiera*, *Yucca*, and *Dasylirion* are occasional; *Leucophyllum* and *Parthenium* are absent………..……...….…………….Ac

—*Larrea* has dense coverage with *Acacia*; *Bouteloua* has light coverage; light to moderate coverage of *Agave*, *Yucca*, *Dasylirion*, and *Tiquila*; *Opuntia*, *Viguiera*, *Ephedra*, *Fouquieria*, other sub shrubs and cacti have light coverage or are occasional; *Leucophyllum* and *Parthenium incanum* are absent…………………………………………………………….…………..….………..…...….AcL

11(3). *Agave* is abundant…………………………………….………………………………………...12

—*Agave* is absent…………………………….……………….………………………………...…..15

12(11). *Parthenium* is absent…………..……………………………………………………………..13

—*Parthenium* is present……...……………………….…………………………………………...…14

13(12). Light coverage overall from other shrubs with *Bouteloua* and *Agave* dominating the area; *Tiquila* is co-dominant with *Bouteloua*; moderate coverage of *Opuntia*; presence of *Fouquieria*, *Dasylirion*, *Ephedra*, *Yucca*, and *Leucophyllum* ……………………..………………….................….AB

—Moderate to dense coverage overall from other shrubs; *Fouquieria* and *Opuntia* are co-dominants; *Tiquila* is second dominant; *Ephedra* is conspicuous component; other cacti, including cholla, are present with light to moderate coverage; *Yucca*, *Dasylirion*, and *Prosopis* are occasional………………………………………...…………….…………………...………….…...AB

L

14(12). *Parthenium* has light coverage………………...………………………………………………LBAO

—*Parthenium* is a co-dominant……………………...……………………………………………...LBP

15(11). *Dasylirion* is occasional……………………………………………………………..……......…BLF

—*Dasylirion* is a co-dominant……………………………………………………..………......BLD

16(2). *Fouquieria* is co-dominant; *Bouteloua* varies from light to moderate………...………...……....LF

—No co-dominant; all other vegetation is sparse; *Dasyochloa* is conspicuous…………………….…….…LO

—*Acacia* is co-dominant…………………………………………………………………………17

17(16). *Parthenium* is a co-dominant…………………………………………...…......……..…LAcO

—*Parthenium* is occasional……………………...…………………………………………...….LAc

18(1). *Dasylirion* is occasional or absent……………………………………..………...……..…....19

—Abundance of *Dasylirion*; high diversity and abundance of vegetation…………………………...…21

19(18). *Larrea* is absent, but could be occasional; second dominants are *Fouquieria*, *Tiquila*, and *Acacia*……………………………...……………………………………………...……......ABVF

—*Larrea* has moderate to dense coverage………………………………………….……………20

20(19). *Larrea* is co-dominant; *Yucca* is occasional………...……………..……………………......ABVL

—*Larrea* is present but not co-dominant; *Yucca* has light coverage…………….……...……...…ABVO

21(18). *Dasylirion* is co-dominant; second dominants are *Yucca* and *Leucophyllum*; light to moderate coverage of other shrubs; *Parthenium* is occasional……………………….…..………...……ABVD

—*Dasylirion* is not co-dominant; moderate to dense coverage of all other shrubs including *Parthenium*, cane cholla, *Ziziphus*, and *Condalia*; high diversity of cacti species……………………..............ABV

A.3.5 Description of vegetation classes within Indio Mountains Research Station

***Agave Bouteloua* complex**

Description: *Agave* and *Bouteloua* coverage varies between moderate and dense (but always more than 50% coverage) and clearly dominate the class since other shrub coverage varies from sparse to moderate. *Yucca* is also present most of the time. Other species associated with the complex are *Larrea*, *Dasylirion*, and sometimes *Acacia*, which are also common but not dominant. There is less diversity and abundance of vegetation overall than the *Agave Bouteloua Viguiera* complex, except for the abundance of *Bouteloua*.

Class 1: *Agave Bouteloua Dasylirion*

Synonyms: Yucca woodland (Henrickson and Johnston, 1983), *Dasylirion-Agave-Bouteloua* (Plumb, 1991); Sotol-lechugilla association (Deynes, 1956; Lechugilla-Sotol series (Diamond, 1993); Smooth Sotol-shrubland alliance (Reid, 2000).

Description: This assemblage has moderately dense coverage with the dominants of this assemblage being *Agave lechugilla*, *Bouteloua*, *Dasylirion*, *Leucophyllum*, and *Opuntia spp*. *Bouteloua* varies in coverage from moderate to dense. Other species present in this class include *Yucca*, *Fouquieria*, *Ephedra*, *Tiquila*, and other various small cacti with light coverage. *Acacia* and *Larrea* are sometimes present and vary in coverage from light to moderate. Other sub shrubs are occasional and varied (Fig. A.3).

Geology: Mainly found within areas of sandstone-limestone mixed or conglomerate-sandstone-siltstone-limestone mixed geology, but can also include limestone only and sandstone only areas as well.

Figure A.3. Picture of *Agave Bouteloua Dasylirion* class.

Class 2: *Agave Bouteloua Yucca Dasylirion*

Synonyms: Yucca woodland (Henrickson and Johnston, 1983), *Yucca*-Sotol-Grass (Plumb, 1988); *Yucca* Ocotillo shrub (McMahan et al., 1984); *Yucca* shrub savannas (Bezanson, 2008) *Fouquieria splendens* shrubland alliance (Reid, 2000).

Description: This class seems similar to the *Agave Bouteloua Dasylirion* class, but with the absence of *Larrea*. The dominants in this assemblage are *Agave*, *Bouteloua*, *Dasylirion*, *Yucca*, and *Fouquieria*. *Bouteloua* varies in coverage from moderate to dense. Other species include *Opuntia* (moderate to dense), *Tiquila*, *Ephedra*, *Acacia*, *Leucophyllum*, various cacti species, and occasional other sub shrubs (Fig. A.4).

Geology: Mainly found within areas of conglomerate-sandstone-siltstone-limestone mixed geology, but can also be found within sandstone-limestone mixed or sandstone only areas.

Figure A.4. Picture of *Agave Bouteloua Yucca Dasylirion* class.

Class 3: *Agave Bouteloua Fouquieria Yucca*

Synonyms: Yucca woodland (Henrickson and Johnston, 1983), *Yucca* Ocotillo (McMahan et al., 1984); (III.A.5.N.a.17) *Fouquieria splendens* shrubland alliance (Reid, 2000).

Description: The dominants present in this assemblage include *Agave*, *Bouteloua*, *Opuntia*, and *Fouquieria* with various cacti species as second dominant. *Yucca* seems to be a conspicuous component in most sites, while other various other shrubs are occasional and varied (Fig. A.5).

Geology: This class is mainly found within areas of conglomerate-sandstone-siltstone-limestone mixed or conglomerate only. This class can also be found in sandstone-limestone mixed areas.

Figure A.5. Picture of *Agave Bouteloua Fouquieria Yucca* class.

Class 4: *Agave Bouteloua Fouquieria Dasylirion*

Synonyms: Yucca woodland (Henrickson and Johnston, 1983), *Yucca* Ocotillo (McMahan et al., 1984); (III.A.5.N.a.17) *Fouquieria splendens* shrubland alliance (Reid, 2000).

Description: The dominants in this class include *Agave*, *Bouteloua*, *Opuntia*, and *Fouquieria*, with other various cacti as second dominant. *Dasylirion* seems is a conspicuous component in most sites. *Yucca* and other shrubs are occasional and varied (Fig. A.6).

Geology: A majority of the sites are found within the conglomerate-sandstone-siltstone-limestone mixed and sandstone-limestone mixed areas. Occasionally, this class can be found in sandstone only and conglomerate only areas.

Figure A.6. Picture of *Agave Bouteloua Fouquieria Dasylirion* class.

Class 5: *Agave Bouteloua*

Synonyms: Lechugilla scrub (Henrickson and Johnston, 1983), *Agave Bouteloua* (Plumb, 1991).

Description: The dominants in this assemblage are *Agave* and *Bouteloua* (light to dense coverage). *Tiquila* is co-dominant with *Bouteloua*. Various other components include *Fouquieria*, *Dasylirion*, *Larrea*, *Opuntia*, *Ephedra*, *Acacia*, and other sub shrubs and cacti, each contributing light coverage except *Larrea* and *Opuntia* which contribute moderate coverage at times. *Yucca* and *Leucophyllum* are occasional. Overall, this class appears to have less diversity (with *Bouteloua* or *Agave* dominating the landscape) than the other classes (Fig. A.7).

Geology: A majority of the sites in this class are found in conglomerate-sandstone-siltstone-limestone mixed areas, but some are found within sandstone-limestone mixed sites. This class can be occasionally found in conglomerate only, igneous only, limestone only, and alluvium areas.

Figure A.7. Picture of *Agave Bouteloua* class.

Class 6: *Agave Bouteloua Larrea*

Synonyms: Lechugilla scrub (Henrickson and Johnston, 1983), (III.A.5.N.a.17) *Fouquieria splendens* shrubland alliance (Reid, 2000).

Description: In this class the dominants are *Bouteloua*, *Agave*, *Larrea*, with *Fouquieria*, and *Opuntia* as co-dominants. *Tiquila* is also a second dominant to *Bouteloua*. Other various cacti, including cholla cactus, are present and vary from light coverage to moderate. *Ephedra* is also characteristic of this class. *Yucca*, *Dasylirion*, and other shrubs, including *Acacia* and *Prosopis*, are occasional. This class is similar to the *Agave Bouteloua* class, but with denser coverage overall from the dominants (Fig. A.8).

Geology: A majority of the sites are found within the conglomerate-sandstone-siltstone-limestone mixed areas. Some are found in conglomerate only areas, and occasionally in sandstone-limestone mixed areas.

Figure A.8. Picture of *Agave Bouteloua Larrea* class.

Class 7: *Bouteloua Larrea Dasylirion*

Synonyms: Yucca woodland (Henrickson and Johnston, 1983), *Larrea-Yucca-Bouteloua* (Plumb, 1991); ??(III.A.5.N.a.17) *Fouquieria splendens* shrubland alliance (Reid, 2000).

Description: In this class the dominants are *Bouteloua*, *Larrea*, and *Dasylirion*. *Yucca* and *Fouquieria* are second dominant in most sites. This class is similar to the *Larrea Fouquieria* class, except *Dasylirion* is a dominant. Other components include light to moderate coverage of *Opuntia*, *Ephedra*, *Tiquila*, *Acacia*, *Leucophyllum*, and other cacti and sub shrubs. *Agave* is occasional or absent (Fig. A.9).

Geology: This class is found within the conglomerate-sandstone-siltstone-limestone mixed area, but it can also be found in sandstone-limestone mixed areas. This class can also be seen in limestone only and conglomerate only areas.

Figure A.9. Picture of *Bouteloua Larrea Dasylirion* class.

Class 8: *Agave Bouteloua Opuntia*

Synonyms: Lechugilla scrub (Henrickson and Johnston, 1983), *Agave-Bouteloua-Opuntia* (Plumb, 1991).

Description: This class is similar to the *Agave Bouteloua Viguiera Fouquieria* class, but *Viguiera* is absent and replaced with *Leucophyllum*. The dominants are *Agave*, *Bouteloua*, and *Opuntia*. Second dominants are *Fouquieria*, *Tiquila*, and *Leucophyllum* with moderate coverage. Other components include *Acacia*, *Ephedra*, and other cacti and sub shrubs with light to moderate coverage. *Yucca*, *Larrea*, *Parthenium*, and *Dasylirion* (largely absent) are occasional. Similar to the *Agave Bouteloua Dasylirion* class and the *Agave Bouteloua Yucca Dasylirion* class, but *Dasylirion* and *Yucca* are not the dominants (Fig. A.10).

Geology: A majority of the sites are found within the conglomerate-sandstone-siltstone-limestone mixed areas, but this class can also be found in the sandstone-limestone mixed areas.

Figure A.10. Picture of *Agave Bouteloua Opuntia* class.

***Bouteloua grassland* complex**

Description: This class is similar in vegetation make-up to the *Agave Bouteloua* complex. *Agave* is present sometimes and *Bouteloua* coverage is dense (always more than 50% coverage) and clearly dominates the class. Other species are present but coverage is sparse or occasional. There is less diversity of vegetation than the *Agave Bouteloua* complex, but associated species include *Yucca*, *Fouquieria*, *Dasylirion*, and various shrubs and cacti.

Class 9: *Bouteloua Agave*

Synonym: Desert grassland (Henrickson and Johnston, 1983; Dick-Peddie, 1993), *Agave Bouteloua* (Plumb, 1991); Mid-elevation mixed grasslands (Bezanson, 2008); (V.A.7.N.m.6) *Bouteloua eriopoda* xeromorphic shrub herbaceous alliance (Reid, 2000).

Description: The dominant plants in this class are *Bouteloua* and *Agave lechugilla*. Other components include *Yucca*, *Dasylirion*, *Opuntia*, *Ephedra*, *Viguiera*, and other shrubs, including *Larrea* in flat areas, with light coverage. The absence of *Fouquieria* separates this class from the *Agave Bouteloua Fouquieria Yucca* and *Agave Bouteloua Fouquieria Dasylirion* classes (Fig. A.11).

Geology: Geology is mainly unknown.

Figure A.11. Picture of *Bouteloua Agave* class.

Class 10: *Bouteloua Agave Acacia*

Synonyms: Desert grassland (Henrickson and Johnston, 1983; Dick-Peddie, 1993), (III.B.3.N.a.) *Acacia neovernicosa* shrubland alliance (Reid, 2000).

Description: In this assemblage the dominants are *Bouteloua*, *Agave*, and *Acacia*, with moderate to dense coverage of *Acacia*. The presence of *Leucophyllum* and *Fouquieria* further separate this class from the *Bouteloua Agave* class. Other components in this class include *Dasylirion*, *Viguiera*, *Ephedra*, *Opuntia*, *Yucca*, *Larrea*, and various other sub shrubs and cacti with light to moderate coverage for each (Fig. A.12).

Geology: This class is mainly found within the conglomerate-sandstone-siltstone-limestone mixed areas, but also found in the sandstone-limestone mixed areas as well.

Figure A.12. Picture of *Bouteloua Agave Acacia* class.

Class 11: *Bouteloua Acacia*

Synonyms: Desert grassland (Henrickson and Johnston, 1983; Dick-Peddie, 1993), (III.B.3.N.a.) *Acacia neovernicosa* shrubland alliance (Reid, 2000).

Description: The dominants in this class are *Bouteloua* and *Acacia*. This class is similar to the *Bouteloua Agave Acacia* class in makeup. It includes the presence of *Fouquieria*, *Dasylirion*, *Viguiera*, *Ephedra*, *Opuntia*, *Yucca*, *Larrea*, and various other sub shrubs and cacti, with light to moderate coverage for each. It is distinct from the *Bouteloua Agave Acacia* class in that *Leucophyllum* is replaced with light to moderate coverage of *Parthenium incanum* (mariola). In addition, *Agave* is occasional or absent (Fig. A.13).

Geology: This class is evenly distributed between conglomerate-sandstone-siltstone-limestone mixed and conglomerate only areas. Some sites can be found on the sandstone-limestone mixed areas. It is occasionally found on sedimentary or alluvium areas, indicative of sites near arroyos.

Figure A.13. Picture of *Bouteloua Acacia* class.

Class 12: *Bouteloua Larrea Fouquieria*

Synonyms: Desert grassland (Henrickson and Johnston, 1983; Dick-Peddie, 1993), (III.A.5.N.a.17) *Fouquieria splendens* shrubland alliance (Reid, 2000).

Description: The dominants are *Bouteloua*, *Larrea*, *Fouquieria*, and *Opuntia*. *Agave* and *Tiquila* are occasional or absent which separates this class from the *Agave Bouteloua Larrea* class. Other various cacti species, including cholla, are present and vary from light to moderate coverage. *Yucca* is also characteristic of this class. *Ephedra*, *Dasylirion*, *Prosopis*, and *Acacia* are occasional (Fig. A.14).

Geology: Approximately half of the sites in this class are found in the conglomerate-sandstone-siltstone-limestone mixed areas, but can also be found in igneous only areas. Few are found in sandstone-limestone mixed areas.

Figure A.14. Picture of *Bouteloua Larrea Fouquieria* class.

***Larrea Acacia* complex**

Description: The dominant species in this class is *Larrea* and varies in coverage from moderate to dense. This class has moderate dense to dense coverage of *Acacia* and is second dominant. In some sites, the dominant species is *Acacia* with *Larrea* second dominant. *Dasyochloa* is common in these sites. *Bouteloua* and *Agave* are sometimes common. Other species associated with this complex are various cacti species including *Opuntia*, *Condalia*, *Ziziphus*, *Viguiera*, *Parthenium*, *Yucca*, and *Fouquieria*.

Class 13: *Acacia*

Synonyms: (III.B.3.N.a.) *Acacia neovernicosa* shrubland alliance (Reid, 2000).

Description: In this class the dominants are *Acacia* (moderate to dense coverage), *Bouteloua*, *Larrea*, *Agave*, and *Fouquieria* (light to moderate coverage for each). It also includes the presence of *Opuntia*, *Tiquila*, *Ephedra*, and other various sub shrubs and cacti with light to moderate-light coverage. *Viguiera*, *Yucca*, and *Dasylirion* are occasional. Similar to the *Bouteloua Acacia* class, but *Leucophyllum* and *Parthenium incanum* are absent (Fig. A.15).

Geology: A majority of the sites within this class are found within the conglomerate-sandstone-siltstone-limestone mixed areas, but can also be found within the sandstone-limestone mixed areas. It can occasionally be found on conglomerate only or igneous only areas.

Figure A.15. Picture of *Acacia* class.

Class 14: *Acacia Larrea*

Synonyms: Creosotebush-mixed shrub series (Dick-Peddie, 1993), (III.B.3.N.a.) *Acacia neovernicosa* shrubland alliance (Reid, 2000).

Description: The dominants in this class are *Acacia* and *Larrea*. This class is similar to the *Acacia* class, but with denser coverage overall because *Larrea* has moderate to dense coverage in association with *Acacia*. Other components include *Agave*, *Yucca*, *Dasylirion*, and *Tiquila* with light to moderate coverage for each. *Bouteloua* has light coverage or is occasional, which further separates this class from the *Acacia* class. *Opuntia*, *Viguiera*, *Ephedra*, *Fouquieria*, and various other sub shrubs and cacti have light coverage or are occasional. *Leucophyllum* and *Parthenium incanum* are absent. Similar to the *Bouteloua Agave Acacia* class, but with light *Bouteloua* and includes *Fouquieria* (Fig. A.16).

Geology: Approximately half of the sites are found on conglomerate-sandstone-siltstone-limestone mixed areas. Some sites can also be found evenly on both sandstone-limestone mixed and limestone only areas. This class is occasionally found on conglomerate only, igneous only, and alluvium areas.

Figure A.16. Picture of *Acacia Larrea* class.

Class 15: *Larrea Fouquieria*

Synonyms: *Larrea* scrub (Henrickson and Johnston, 1983), Creosotebush series (Dick-Peddie, 1993), (III.A.5.N.a.17) *Fouquieria splendens* shrubland alliance (Reid, 2000).

Description: The dominants are *Larrea* and *Fouquieria*. The loss of *Bouteloua* and *Agave* as dominants separates this class from the *Bouteloua Larrea Fouquieria* class. Coverage of *Bouteloua*, *Agave*, and *Opuntia* vary from moderate to occasional. Other components include *Tiquila*, *Yucca*, *Dasylirion*, *Ephedra*, *Acacia*, *Viguiera*, *Prosopis*, all with occasional coverage. Other sub shrubs and cacti, including cholla cactus are present with moderate coverage. This class has lighter coverage overall at times, which further separates this class from the *Bouteloua Larrea Fouquieria* class (Fig. A.17).

Geology: A majority of sites in this class are found within the conglomerate-sandstone-siltstone-limestone mixed areas and in the conglomerate only zones. Some sites were indicated as alluvium sites, showing proximity to arroyos. This class can be occasionally found in sandstone-limestone mixed and igneous only areas.

Figure A.17. Picture of *Larrea Fouquieria* class.

Class 16: *Larrea Bouteloua Agave Opuntia*

Synonyms: Mixed desert scrub (Henrickson and Johnston, 1983), *Larrea Agave* (Plumb, 1991; (III.A.5.N.a.5) *Larrea tridentata* shrubland alliance (Reid, 2000).

Description: The dominants in this class are *Bouteloua*, *Agave*, *Larrea*, *Opuntia* (also due to presence of other cacti, including cholla), and *Fouquieria*. Other various cacti, including cholla cactus, are present and have moderately dense coverage. *Tiquila*, *Acacia*, and *Prosopis* are present and vary from light to moderate coverage. There is also moderate coverage of other grasses. *Yucca*, *Ephedra*, and *Parthenium* have light coverage and *Dasylirion* is absent. This class is similar to the *Agave Bouteloua*

Larrea class except that *Tiquila* and *Ephedra* are no longer characteristic of the sites. In addition, *Acacia* and *Prosopis* have more coverage and are not occasional (Fig. A.18).

Geology: This class is mainly found within the conglomerate-sandstone-siltstone-limestone mixed areas, but some were found in igneous only zones.

Figure A.18. Picture of *Larrea Bouteloua Agave Opuntia* class.

Class 17: *Larrea Bouteloua Pathenium*

Synonyms: ??Mixed desert scrub (Henrickson and Johnston, 1983), ??(III.A.5.N.a.17) *Fouquieria splendens* shrubland alliance (Reid, 2000)-no other known synonyms, possibly unique to Indio.

Description: The dominants in this class are *Bouteloua*, *Tiquila*, *Larrea*, and *Parthenium*. Other species include *Fouquieria*, *Agave*, *Opuntia*, *Acacia*, *Ephedra*, other sub shrubs, cacti and cholla with moderate coverage. *Yucca* is occasional. *Dasylirion* is absent. This class appears similar to the *Agave Bouteloua Larrea* class as well, but the dominance of *Parthenium* in these sites distinguishes this class from the *Agave Bouteloua Larrea* class (Fig. A.19).

Geology: This class is mainly found within the conglomerate-sandstone-siltstone-limestone mixed areas, but some were found in igneous only zones. Some sites are unknown.

Figure A.19. Picture of *Larrea Bouteloua Parthenium* class.

Class 18: *Larrea Opuntia*

Synonyms: *Larrea* scrub (Henrickson and Johnston, 1983), Larrea Flats (Plumb, 1991), Creosotebush series (Dick-Peddie, 1993), (III.A.5.N.a.5) *Larrea tridentata* shrubland alliance (Reid, 2000).

Description: The dominant plant in this class is *Larrea*, with *Dasyochloa* as a second dominant. Other species include *Opuntia*, *Fouquieria*, *Agave*, and other cacti including cholla. All cover is sparse to light. *Yucca*, *Acacia*, *Prosopis*, *Ephedra*, *Viguiera*, *Dasylirion*, and *Bouteloua* are occasional. The ground is also covered with a tiny cactus (Fig. A.20).

Geology: A majority of the sites are found in conglomerate only and igneous only areas, but this class can be occasionally found in sandstone only and conglomerate-sandstone-siltstone-limestone mixed areas.

Figure A.20. Picture of *Larrea Opuntia* class.

Class 19: *Larrea Acacia Opuntia*

Synonyms: *Larrea* scrub (Henrickson and Johnston, 1983), Creosotebush-Lechugilla shrub (McMahan, 1984); Creosotebush series (Dick-Peddie, 1993), Creosotebush open shrub desert (Bezanson, 2008); (III.A.5.N.a.5) *Larrea tridentata* shrubland alliance (Reid, 2000).

Description: The dominants are *Larrea*, *Acacia*, *Opuntia*, *Fouquieria*, and *Parthenium*. The coverage is moderate to dense for the dominants. Secondary dominants include *Yucca*, cholla and a variety of other cacti, *Prosopis*, *Viguiera*, and various other sub shrub species. *Dasyochloa* (other grasses) is a conspicuous component. *Dasylirion*, *Agave*, *Ephedra*, *Bouteloua*, and *Tiquila* are occasional or absent (Fig. A.21).

Geology: Approximately half the sites are found in igneous only areas, but many are also found in the conglomerate only geology type. It can occasionally be found within the conglomerate-sandstone-siltstone-limestone mixed and alluvium sites.

Figure A.21. Picture of *Larrea Acacia Opuntia* class.

Class 20: *Larrea Acacia*

Synonyms: *Larrea* scrub (Henrickson and Johnston, 1983), Creosotebush-Mesquite shrub (McMahan, 1984); Creosotebush series (Dick-Peddie, 1993), Creosotebush open shrub desert (Bezanson, 2008); (III.A.5.N.a.5) *Larrea tridentata* shrubland alliance (Reid, 2000).

Description: This class is similar to the *Larrea Acacia Opuntia* class and the *Acacia Larrea* class. The dominants are *Larrea*, *Acacia,* and *Opuntia*. The first dominant alternates between *Larrea* and *Acacia*. The second dominant in this class is *Fouquieria*. *Agave*, *Yucca*, *Viguiera*, *Ephedra*, *Prosopis*, *Parthenium*, *Dasylirion*, and other cacti and shrubs are occasional. *Bouteloua* is absent. This class differs from the *Acacia Larrea* class in that the species with light coverage and moderate coverage are

reverse. This class differs from the *Larrea Acacia Opuntia* class in that it has less diversity and geology types (Fig. A.22).

Geology: The majority of sites found in this class are within the conglomerate-sandstone-siltstone-limestone mixed and sandstone-limestone mixed areas. Some of the sites are found in the conglomerate only areas, and occasionally found in the igneous only and alluvium areas.

Figure A.22. Picture of *Larrea Acacia* class.

***Agave Bouteloua Viguiera* complex**

Description: This class has dense coverage overall and is the most diverse of all the classes. It has moderate dense to dense coverage of *Bouteloua*, *Agave*, and *Viguiera*. It has moderate to moderate dense coverage of *Tiquila*, *Opuntia*, *Ephedra*, *Leucophyllum*, other cacti, and various other sub shrubs. Other species present include *Dasylirion*, *Yucca*, *Fouquieria*, *Acacia*, *Parthenium*, cholla cactus and other shrubs such as *Ziziphus* and *Condalia*. The *Salaginella* is present in some sites. *Larrea* and *Prosopis* are occasional.

Class 21: *Agave Bouteloua Viguiera Fouquieria*

Synonyms: (III.A.5.N.a.17) *Fouquieria splendens* shrubland alliance (Reid, 2000).

Description: The dominants of this class are *Agave*, *Bouteloua*, *Fouquieria*, and *Viguiera*. Second dominants are *Opuntia*, *Tiquila*, and *Acacia* and their coverage varies between light and moderate coverage. Other components in this class include *Yucca*, *Ephedra*, and other cacti and sub shrubs (*Leucophyllum* and *Parthenium*) with light to moderate coverage as well. *Larrea* and *Dasylirion* are occasional, but their presence is largely absent (Fig. A.23).

Geology: This class can mainly be found in the conglomerate-sandstone-siltstone-limestone mixed area, but some are found in sandstone only areas. It is occasionally found in sandstone-limestone mixed and conglomerate only areas.

Figure A.23. Picture of *Agave Bouteloua Viguiera Fouquieria* class.

Class 22: *Agave Bouteloua Viguiera Larrea*

Synonyms: Mixed desert scrub (Henrickson and Johnston, 1983), Chihuahuan desert scrub (Bezanson, 2008).

Description: In this class, the dominants are *Agave*, *Bouteloua*, *Larrea*, *Opuntia*, and *Viguiera*. Second dominants are *Tiquila*, *Ephedra*, and other sub shrubs and cacti including cholla. Other components in this class include *Fouquieria*, *Parthenium*, *Acacia*, and *Leucophyllum* with light to moderate coverage. *Yucca* and *Dasylirion* are occasional, though *Dasylirion* is largely absent. The overall coverage of this class is dense (Fig. A.24).

Geology: This class can mainly be found in conglomerate-sandstone-siltstone-limestone mixed areas. Some sites are found in sandstone-limestone mixed and igneous only areas.

Figure A.24. Picture of *Agave Bouteloua Viguiera Larrea* class.

Class 23: *Agave Bouteloua Viguiera Opuntia*

Synonyms: Lechugilla scrub (Henrickson and Johnston, 1983), Chihuahuan desert scrub (Bezanson, 2008).

Description: This class is similar to the *Agave Bouteloua Viguiera Larrea* class. The subtle difference is the abundance of *Larrea*. *Larrea* is no longer a dominant, and becomes a second dominant. Also, *Yucca* has light coverage instead of being occasional (Fig. A.25).

Geology: All the sites in this class are found in the conglomerate-sandstone-siltstone-limestone mixed areas.

Figure A.25. Picture of *Agave Bouteloua Viguiera Opuntia* class.

Class 24: *Agave Bouteloua Viguiera Dasylirion*

Synonyms: Yucca woodland (Henrickson and Johnston, 1983), Chihuahuan desert scrub (Bezanson, 2008); (III.A.5.N.a.4) *Dasylirion leiophyllum-* (*Agave lechugilla, Viguiera stenaloba*) shrubland alliance (Reid, 2000).

Description: The dominants present in this class are *Bouteloua*, *Agave*, *Viguiera*, and *Dasylirion*. Second dominants are *Yucca* and *Leucophyllum*. Other components in this class include *Tiquila*, *Acacia*, *Opuntia*, *Ephedra*, *Fouquieria*, and various other cacti and sub shrubs with light to moderate coverage. *Larrea* and *Parthenium* are occasional. Similar to the *Agave Bouteloua Dasylirion* and *Agave Bouteloua Yucca Dasylirion* classes, but the presence of *Viguiera* as a dominant and the abundance of *Yucca* separates this class. This class is also similar to the *Bouteloua Larrea Dasylirion* class, but with more abundance and diversity of species (Fig. A.26).

Geology: Approximately half the sites in this class are found in the conglomerate-sandstone-siltstone-limestone mixed areas, but it can also be found in the sandstone-limestone mixed and sandstone only areas.

Figure A.26. Picture of *Agave Bouteloua Viguiera Dasylirion* class.

Class 25: *Agave Bouteloua Viguiera*

Synonyms: Lechugilla scrub (Henrickson and Johnston, 1983), *Agave-Bouteloua-Viguiera* (Plumb, 1991); Chihuahuan desert scrub (Bezanson, 2008).

Description: The dominants of this class are *Bouteloua*, *Agave*, and *Viguiera*. This class has dense coverage overall and is the most diverse of all the classes. It has moderate to moderate dense coverage of *Tiquila*, *Opuntia*, *Ephedra*, *Leucophyllum*, various other cacti and sub shrubs. Other species present include *Dasylirion*, *Yucca*, *Fouquieria*, *Acacia*, *Parthenium*, cholla cactus, and other shrubs such as *Ziziphus* and *Condalia*. *Salaginella* is present at some sites. *Larrea* is occasional and *Prosopis* is absent (Fig. A.27).

Geology: This class is mainly found in the conglomerate-sandstone-siltstone-limestone mixed areas, but some can be found in the sandstone-limestone mixed areas.

Figure A.27. Picture of *Agave Bouteloua Viguiera* class.

Class 26: Bare Ground

Description: This class has no visible dominant or plant species. The sites are made up of areas devoid of vegetation or with very sparse vegetation. It can vary from *Larrea*, *Acacia*, *Opuntia*, *Agave*, *Fouquieria*, *Tiquila*, *Bouteloua*, and/or *Yucca*, but depends on the surrounding vegetation (Fig. A.28).

Geology: The majority of sites in this class are found within the conglomerate-sandstone-siltstone-limestone mixed areas. Some sites are found within the sandstone-limestone mixed areas and occasionally found in conglomerate only and alluvium sites.

Figure A.28. Picture of bare ground class.

Class 27: Arroyo scrub

Synonyms: Sandy arroyo scrub and *Prosopis-Atriplex* scrub (Henrickson and Johnston, 1983), Mixed scrub and *Chilopsis* (Plumb, 1991); Apache plum series and Mesquite series (Dick-Peddie, 1993); Viscid *Acacia* and Arroyo scrub (Bezanson, 2008); (III.A.4.N.b.3) *Baccharis sarothroides* intermittently flooded shrubland alliance, and *Fallugia paradoxa* intermittently flooded shrubland alliance (Reid, 2000).

Description: Thick stands of vegetation are found along the banks of arroyos and extend 20 meters from the banks on either side. The mid-arroyo zones are normally bare ground due to the force of water from flashfloods during heavy thunderstorms. Along the banks and extending 20 meters on both sides, vegetation includes two arroyo dominants: 1) *Acacia*, *Fallugia*, *Prosopis*, and *Atriplex*, and 2) *Chilopsis* with *Baccharis* and *Prosopis*. Some arroyos also contain Desert Olive, Littleleaf sumac, Sandpaper Oak, Beargrass, Evergreen sumac, Western Hackberry, Cottonwood, Red berry Juniper, and flowers such as *Tacoma*. These shrubs are unique to the arroyo areas and may not be found anywhere else. Extending 20 meters from the banks, these plants may dominate the area: *Larrea*, *Acacia*, and

Prosopis. Plants characteristic of the particular class will also be denser in these arroyo zones creating a dense mixture of vegetation (Fig. A.29).

Geology: Geology is sedimentary or alluvium.

Figure A.29. Picture of arroyo scrub class.

Class 28: Tanks

Synonyms: *Prosopis-Atriplex* scrub (Henrickson and Johnston, 1983), Mesquite brush (McMahan, 1984); Mesquite thickets (Bezanson, 2008); (II.B.2.N.b.5) *Prosopis glandulosa* temporarily flooded woodland alliance (Reid, 2000).

Description: Tanks are spread throughout various locations within the Indio Ranch property. They are large areas of land where water collects. The center of the tanks can range from bare ground with occasional riparian species to dense coverage of riparian grass and other species. Surrounding the tanks are thickets of *Prosopis*, *Acacia*, and *Larrea* (Fig. A.30).

Geology: Geology is considered sedimentary.

Figure A.30. Picture of tanks class at Mesquite tank.

Class 29: Riparian

Synonyms: Riparian Woodlands (Henrickson and Johnston, 1983), Mesquite-Saltcedar brush (McMahan, 1984); *Chilopsis* and *Populus* Grove (Plumb, 1991); Cottonwood-willow series (Dick-Peddie, 1993), Cottonwood-willow riparian woodlands (Bezanson, 2008).

Description: Squaw Springs is the only riparian zone in the Indio Mountains Research Station. There is a small spring continuously fed with water year round. Cattails (*Typha domingensis*) and riparian grasses are found within the spring. Surrounding the spring are *Chilopsis linearis*, *Baccharis*, and other riparian species including a single *Tamarix sp*. tree. A few meters after and before the spring are arroyo scrub zones. The other riparian area is along the Rio Grande, known as river riparian. The dominant plants are *Populus*, *Tamarix*, and *Prosopis*. Plants that co-dominate the class are various riparian grasses, forbs, and sub shrubs not seen in any other area. Overall coverage of this class is dense (Fig. A.31).

Geology: Geology is considered alluvium.

Figure A.31. Picture of riparian class along the Rio Grande.

A.4 Discussion

For this study, I aimed to identify the vegetation associations that exist at the Indio Mountains Research Station from ground surveys and cluster analysis. Based on the dendrogram utilizing the natural breaks method, I hypothesize a total of 29 vegetation classes present at the IMRS. There were very similar vegetation associations between classes resulting in complexes. The complexes present are groupings of sites with very similar vegetation cover, differentiated only by the dominance or conspicuousness of a particular species. Within the *Agave Bouteloua* complex, all of the classes have *Agave* and *Bouteloua* dominants. The third and fourth dominants divided the complex into eight classes.

Both the *Agave Bouteloua Yucca* and *Agave Bouteloua Dasylirion* classes were the most similar to one another within the *Agave Bouteloua* complex. The conspicuous co-dominance of *Yucca* in the *Agave Bouteloua Yucca* class separates this class from the *Agave Bouteloua Dasylirion* and other classes. The *Agave Bouteloua Fouquieria Yucca* class and the *Agave Bouteloua Fouquieria Dasylirion* class were also very similar to each other, and separate from the first two classes discussed based on the dominance of *Fouquieria splendens*. These classes separate from one another based on the presence or absence of *Yucca* and *Dasylirion*. The *Agave Boutleoua* class loses much of the coverage by other species, and *Tiquila* becomes a co-dominant. The last of the classes in this complex are the *Agave Boutleoua Larrea* class, *Bouteloua Larrea Dasylirion* class, and the *Agave Bouteloua Opuntia* class.

The *Agave Bouteloua Viguiera* complex separates from the rest of the complexes due to the distinct co-dominance by *Viguiera stenaloba* in these classes. The *Agave Bouteloua Viguiera* complex is divided into five classes based on the presence of a fourth dominant. The *Agave Bouteloua Viguiera* class had the most species diversity and abundance of all the classes within the *Agave Bouteloua Viguiera* complex. The *Agave Bouteloua Viguiera Larrea* class had the second highest species diversity and abundance in the complex. This class was found primarily in areas of igneous rock outcropings. The rest of the classes found in this complex are the *Agave Bouteloua Viguiera Dasylirion* class, the *Agave Boutleoua Viguiera Opuntia* class, and the *Agave Boutleoua Viguiera Fouquieria* class.

In the *Larrea Acacia* complex, *Larrea tridentata* was the dominant species followed by *Acacia spp.* as second dominant. In some cases, *Acacia spp.* dominated the landscape with *Larrea tridentata* as the second dominant. This character divides this complex into two groups: the *Larrea* shrublands and *Acacia* shrublands. The complex itself is divided into eight classes according to the third and fourth dominants. The *Larrea Acacia* and the *Larrea Acacia Opuntia* classes are the most similar in this complex. The only features that distinguish these classes are diversity and geology. The *Larrea Opuntia* class and the *Larrea Fouquieria* class were also very similar. The presence of *Fouquieria splendens* and various cacti species in the *Larrea Fouquieria* class are what separate these classes. In addition, the *Larrea Opuntia* class has the sparsest coverage of all classes at the study site. No other associations were found in the literature to be similar to the *Larrea Bouteloua Parthenium* class, and may be unique to

IMRS. The last class in the *Larrea* shrublands group is the *Larrea Bouteloua Agave Opuntia* class. The last two classes in this complex are the *Acacia* class and the *Acacia Larrea* class, part of the *Acacia* shrublands group.

The last complex is the *Bouteloua* grasslands. These grasslands are more of a mixed grasslands type classes than pure *Bouteloua* grassland. The classes in this complex are the *Bouteloua Agave* class, the *Bouteloua Agave Acacia* class, the *Bouteloua Acacia* class, and the *Bouteloua Larrea Fouquieria* class. These classes seem similar to classes in other complexes, but what makes them unique is their highly dense coverage of *Bouteloua* grass.

Some of the classes derived from this study can also be seen in other studies conducted within the northern Chihuahuan desert. For example, the most similar vegetation types are seen in the Big Bend National Park, Texas (Plumb, 1991). There are 11 similar associations, among these are *Larrea* flats, *Larrea Agave*, *Agave Bouteloua Opuntia*, *Larrea Yucca Bouteloua*, *Agave Bouteloua*, *Agave Bouteloua Viguiera*, *Dasylirion Agave Boutleoua*, mixed scrub, *Chilopsis*, *Populus* grove, and *Prosopis* thickets (Plumb, 1991). In Casaday (2001) Chihuahuan desert scrub was one classes found at the Amistad National Recreation Area in Val Verde county Texas, similar to classes in this study with dominant *Agave lechugilla*, *Acacia*, and *Opuntia*. Many of the classes in this study also align with the vegetation classes of Texas (Benzanson, 2008; McMahan, 1984) and with the International Classification of Ecological Communities for the Chihuahuan desert (Reid, 2000).

Some challenges were encountered in this analysis of vegetation classes. First, a high degree of similarity exists among some of the vegetation classes and complexes. This is because the groupings resulting from the natural breaks method possess varying degrees of similarity among and between groupings (Plumb, 1991). For example, in Plumb (1991) they found it difficult to differentiate between classes within the *Agave Bouteloua* complex because of the varying degrees of coverage by the dominants *Bouteloua* and *Agave*. In addition, the *Larrea* flats and *Larrea Agave* classes were similar in vegetation cover and diversity, but separated as unique classes (Plumb, 1991). Similar issues arise in this study as well within complexes such as the *Agave Bouteloua* complex and the *Larrea Acacia* complex. These challenges also occur between complexes such as the *Agave Bouteloua* complex, the *Bouteloua*

grassland complex, and the *Agave Bouteloua Viguiera* complex. Second, the presence of environmental gradients and ecotones can create these varying degrees of similarities. Environmental gradients can cause varying degrees of coverage by any plant species, such as *Bouteloua*, *Agave*, or *Larrea*. Ecotones cause a “mix” of two or more vegetation classes as one class transitions into another. Both of these were seen in Big Bend National Park (Plumb, 1991) as well as this study. Because of these challenges creating similarities among and between classes, I had instances of sites being misclassified in the cluster analysis. But most importantly, because of the high degree of similarity between and within classes, this may make image based mapping with these vegetation classes very difficult for me, especially in such heterogeneous and mountainous terrain. Those vegetation classes that are the most closely linked in the cluster analysis, or the most similar, may overlap spectrally in a satellite image and hurt the accuracy of the classification map (Plumb, 1991).

A.5 Conclusion

Through interpretation of field data, ground photographs, and cluster analysis, I hypothesize that there are 29 classes at Indio Mountains Research Station. Some of the classes were combined into complexes due to the high degree of similarity differentiated only by a single species in some cases. Sites within these classes typify the vegetation ground cover and their location can be identified on a satellite image. The results from the NMS showed that only 8 vegetation classes could potentially be used successfully in image-based mapping. The results of this data will allow me to create a vegetation map of the area using supervised classification methods. Because some classes created groupings that were closely linked and were inseparable, it may make classification of a satellite image a challenge. Identifying these linked sites separate from each other spectrally may be difficult.

Appendix 2: Module 1 on "Impacts on our Environment: Land use and land cover change in the southwest desert"

Outline for Lesson created by Rebecca Marin

Abstract: For many years, natural events such as changes in the earth's climate, and human activities such as farming, and tree clearing, have changed the way the surface of the earth looks. Most changes have affected the vegetation on the ground, also called land cover, and transformed a once existing community of plants into an entirely new community. This is known as land cover change. The two types of land cover change are deforestation, or clearing of forests, and desertification, or the change to a more desert like environment. Both have negative effects on the ecosystem and the earth.

One of the negative effects of land cover change is erosion. The roots of vegetation provide stability to the soil on the ground. When the vegetation is removed or becomes less dense, the roots are no longer there to keep the soil in place. Water from heavy rains and wind can easily wash or blow the top soil away. There are valuable nutrients that a plant needs to survive found in the top soil. When the rain washes the top soil away, or the wind blows it away, it is also washing away these valuable nutrients. This makes it harder for plants to set their roots and grow in an area that is being eroded. This causes more land cover change which in turn causes more erosion. It is a vicious cycle that once is started is nearly impossible to stop.

The purpose of this module is to help students understand land cover change science, what the causes and consequences of LCC are, and to know the type of LCC occurring the southwest deserts, shrub encroachment. They will do this by first establishing a plant growth experiment testing soils from underneath a canopy and from interspace. The experiment will last for about four to six weeks depending on time constraints. During the experiment, students will collect data on germination time and plant growth rate. At the end of the experiment, the students will present their findings in the form of a short presentation to the class following the scientific method. After establishing the plant growth experiment, students will then see an excerpt (first 20 minutes) of the documentary film "Dirt the Movie" followed by a power point presentations on LCC. By the end of the module, students will be

able to explain what land cover change is and the causes of LCC, and explain shrub encroachment and the consequences of this process.

Learning Outcomes: Students will understand what land cover change is, the type of land cover change occurring in the desert southwest, and the effects that land cover change has on the ecosystem including water and nutrient cycling, erosion, and loss of plant and animal diversity.

Unit 9, Earth Systems and Unit 10, Natural Events Altering Earth Systems

Stage 1-Desired Results

Established Goals

<u>Texas Middle Schools TEKS Alignment</u>:

- 8.1.A Demonstrate safe practices during field and laboratory investigations
- 8.2.A Plan and implement investigative procedures including asking questions, formulating testable hypothesis, and selecting and using equipment and technology
- 8.2.B Collect data by observing and measuring
- 8.2.C Organize, analyze, make inferences and predict trends from direct and indirect evidence
- 8.2.D Communicate valid conclusions
- 8.2.E Construct graphs, tables, maps, and charts using tools including computers to organize, examine, and evaluate data
- 8.3.C Represent the natural world using models and identify their limitations
- 8.4.B Extrapolate from collected information to make predictions
- 8.14 Know that natural events and human activity can alter earth systems (8.14.C Describe how human activities have modified soil, water, and air quality)

<u>Objectives</u>

- **Know that deserts are valuable and have ecological goods and produce ecological services.**
- **Know that human activities and natural events can change the natural world.**

Understandings: Students will understand:

1) Land cover change and give examples
2) The causes of land cover change

3) Desertification and shrub encroachment are the types of land cover change occurring in the southwest deserts
4) The causes of land cover change and categorize them as human activities or natural events
5) The potential consequences associated with human activities on ecosystems and land cover
6) That deserts are valuable and have ecological goods and produce ecological services
7) That human activities and natural events can change the natural world

Essential Questions:

1) What do you think land cover change is all about?
2) Can you list 5 examples of land cover change as you defined it?
3) Can you list 5 actions/causes you think is responsible for land cover change?
4) What do you think desertification or shrub encroachment is?
5) Can you categorize the actions/causes into natural events or human impacts?
6) Do you feel like you can appreciate desert ecosystems better?
7) Are you aware of the potential consequences associated with human activities on ecosystems/land cover?
8) Do you feel like you know enough about the issue surrounding land cover change?
9) Do you feel you can pass the knowledge to others well enough to cause public awareness?

Students will know:

1) What land cover change is and give examples
2) What the causes of land cover change are
3) That desertification and shrub encroachment are the types of land cover change occurring in the southwest deserts

4) The causes of land cover change and categorize them as human activities or natural events
5) The potential consequences associated with human activities on ecosystems and land cover

Students will be able to:

1) Define land cover change, desertification, and shrub encroachment
2) Give other examples of land cover change
3) List the causes of land cover change and categorize them as natural events or human impacts
4) Identify the potential consequences associated human impacts on ecosystems and land cover
5) Better appreciate the desert ecosystem

Stage 2-Assessment Evidence

Performance Tasks: A pre evaluation form will be given prior to the lesson to assess students' knowledge, understanding, and attitude of land cover change. A post evaluation form will also be given at the end of the lesson to assess how much they learned and understood from the lesson and activities.

Other Evidence: The students' presentation of their final results on the plant growth experiment and their ability to connect the results of the study with LCC will be part of the student's assessment.

Stage 3-Learning Plan

Learning Activities:

1) Pre survey
2) Establish plant growth experiment (canopy vs interspace)
3) Collection of data for time to germination and plant growth rate for about 4-6 weeks
4) Watch documentary film "Dirt the Movie"
5) Power point presentation on LCC
6) Post survey. Following is the lesson for this module.

Impacts on Our Environment: Land Use and Land Cover Change in the Southwest Desert

Lab created and performed by Rebecca Marin
March 23, 2011
University of Texas El Paso, Biology 3416
Undergraduate Ecology

Texas Middle School TEKS Alignment:

- 8.1.A Demonstrate safe practices during field and laboratory investigations
- 8.2 Students will use scientific inquiry methods during field and lab investigations (A, B, C, D, E)
- 8.2.D Communicate valid conclusions
- 8.4.A Collect, analyze, and record information to explain phenomenon using tools including field equipment, computers, and compasses
- 8.11.A Identify that change in environmental conditions can affect survival of individuals and of species
- 8.14 Know that natural events and human activity can alter earth systems: Analyze how natural or human events may have contributed to the extinction of some species (B) and Describe how activities have modified soil, water, and air quality (C)

Texas High School TEKS Alignment:

- **9.1 A, 10.1 A, 11.1 A, 12.1 A** Demonstrate safe practices during laboratory and field investigations, including chemical, electrical, and fire safety, and safe handling of live and preserved organisms
- **9.1 B, 10.1 B, 11.1 B, 12.1 B** Demonstrate an understanding of the use and conservation of resources and the proper disposal or recycling of materials
- **9.2 B, 10.2 B, 11.2 B, 12.2 B** Know that scientific hypotheses are tentative and testable statements that must be capable of being supported or not supported by observational evidence. Hypotheses of durable explanatory power which have been tested over a wide variety of conditions are incorporated into theories
- **9.2 E, 10.2 E, 11.2 E, 12.2 E** Plan and implement investigative procedures, including asking questions, formulating testable hypotheses, and selecting, handling, and maintaining appropriate equipment and technology
- **9.2 F, 10.2 F, 11.2 F, 12.2 F** Collect data individually or collaboratively, making measurements with precision and accuracy, record values using appropriate units, and calculate statistically relevant quantities to describe data, including mean, median, and range
- **9.2 G, 10.2 G, 11.2 G, 12.2 G** Demonstrate the use of course apparatuses, equipment, techniques, and procedures
- **9.2 H, 10.2 H, 11.2 H, 12.2 H** Organize, analyze, evaluate, build models, make inferences, and predict trends from data
- **9.2 J, 10.2 J, 11.2 J, 12.2 J** Communicate valid conclusions using essential vocabulary and multiple modes of expression such as lab reports, labeled drawings, graphic organizers, journals, summaries, oral reports, and technology-based reports
- **9.3 B, 10.3 B, 11.3 B, 12.3 B** Communicate and apply scientific information extracted from various sources such as current events, news reports, published journal articles, and marketing materials
- **9.3 C, 10.3 C, 11.3 C, 12.3 C** Draw inferences based on data related to promotional materials for products and services
- **Biology 11 B** Investigate and analyze how organisms, populations, and communities respond to external factors
- **Biology 12 D** Recognize that long-term survival of species is dependent on changing resource bases that are limited
- **Biology 12 F** Describe how environmental change can impact ecosystem stability
- **Earth and Space Science 11 A** Compare the roles of erosion and deposition through the actions of water, wind, ice, gravity in constantly reshaping the Earth's surface

Objectives:

- Know what land cover change is and be able to list examples of LCC
- Understand the causes of land cover change
- Know that desertification and shrub encroachment are the types of land cover change in the southwest deserts
- Be able to categorize the causes of land cover change as natural events or human impacts
- Be aware of the potential consequences associated with human activities on ecosystems/land cover
- **Know that deserts are valuable and have ecological goods and produce ecological services**
- **Know that human activities and natural events can change the natural world**

Background Information:

For many years, natural events such as changes in the earth's climate, and human activities such as farming, and tree clearing, have changed the way the surface of the earth looks. Most changes have affected the vegetation on the ground, also called land cover, and transformed a once existing community of plants into an entirely new community. This is known as land cover change. The two types of land cover change are deforestation, or clearing of forests, and desertification, or the change to a more desert like environment. Both have negative effects on the ecosystem and the earth.

One of the negative effects of land cover change is erosion. The roots of vegetation provide stability to the soil on the ground. When the vegetation is removed or becomes less dense, the roots are no longer there to keep the soil in place. Water from heavy rains and wind can easily wash or blow the top soil away. There are valuable nutrients that a plant needs to survive found in the top soil. When the rain washes the top soil away, or the wind blows it away, it is also washing away these valuable nutrients. This makes it harder for plants to set their roots and grow in an area that is being eroded. This causes more land cover change which in turn causes more erosion. It is a vicious cycle that once is started is nearly impossible to stop.

References:

- Analyzing land use change in urban environments http://landcover.usgs.gov/urban/info/factsht.pdf
- Quantifying changes in the land over time http://landsat.gsfc.nasa.gov/education/resources/Landsat_QuantifyChanges.pdf
- Earth as Home Lesson "An Island Home" http://interactive2.usgs.gov/learningweb/pdf/globalchange/island.pdf
- http://www.geography4kids.com/files/land_erosion.html
- http://teacher.scholastic.com/dirtrep/erosion/index.htm
- http://teacher.scholastic.com/dirt/erosion/whateros.htm
- http://www.brainpop.com/science/theearthsystem/erosion/preview.weml

Vocabulary:

1) *land cover change*- a change in vegetation (plants) covering the ground through time (6-8th grade definition); change in the Earth's biological and physical cover of the surface (college definition)
2) *desertification*- the degradation of land in arid and dry sub-humid areas resulting in a loss of biodiversity and the land's productive capability
3) *deforestation*-the conversion of forested areas to non-forested land and can result in arid land and wastelands

4) *shrub encroachment*- the slow invasion of shrub species into other ecosystems not previously occupied by shrubs
5) *erosion*- movement of sediment by wind, water, ice, or gravity
6) *topsoil*- upper layer of soil, often the richest in plant nutrients
7) *soil nutrients*- mineral nutrients found within the soil on the ground and includes nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, and 7 other micro elements

Materials Required: potting soil with fertilizer, eroded soil from shrub interspaces, fertile soil from shrub canopies, seeds of fast growing plants, water, clear plastic cups, trowels or shovels, trays, ruler, marker, paper, pencils, “Dirt” the movie

Prior Preparation:

- Acquire eroded soil from shrub interspaces in creosote bush community and fertile soil from underneath the shrub canopy.
- Place eroded soil in bucket A and label as soil A, and place fertile soil in bucket B and label as soil B
- Purchase fertile potting soil for control experiment
- **In case soil from creosote bush community cannot be collected, you can substitute the purchased fertile potting soil as soil B and sand as soil A.**
- Have experimental materials ready prior to class
- Acquire “Dirt” the movie
- Setup of Impacts on our Environment PowerPoint presentation on a desktop and projector is needed prior to class

Safety Information:

General lab safety

DAY 1:

Students first complete a pre survey of Impacts on Our Environment.

Focus Question: What is land cover change? How does it impact our environment?

I. Engage

- Show students the lab investigation materials (eroded soil labeled as Soil A and fertile soil labeled as Soil B). Ask students which soil type they think the seeds will emerge the fastest and grow the best in? How do they know? **Do not let students know which the fertilized soil is and which the eroded soil is. Allow the students to discover this through the duration of the experiment and presentation of power point.**

II. Explore:

- Allow students to set up their investigation.
- Students should plant seeds in a cup with fertile potting soil (this will act as the control). Students should also plant seeds in a cup with soil A and seeds in a second cup with soil B (see student worksheet for methods). Students should ideally have at least 5 replicates, but depends on the availability of materials.
- Allow students to water their plants.
- Have students establish observations and measurements, and begin their chart set ups.

DAY 2 (if needed):

III. Explain

- Show students the first 20-30 minutes of “Dirt” the movie.
- Show students Impacts on our Environment Powerpoint presentation which discusses land cover change, causes, and consequences

IV. Extension:

- Class discussion as to benefits and drawbacks for this model of investigation
- Allow students to make observations for the duration of the year until adequate data has been collected (approximately 4-6 weeks).
- Students must also keep watering plants and measure plant height once seedlings emerge
- Once investigation is completed, students can graph the data to compare and analyze the data.

V. Evaluate:

- Student participation and use of scientific method, including completion of graphs will be part of assessment
- Student explanations of experiment outcome.

Peer Review

This laboratory has been peer reviewed by National Science Foundation-University of Texas, El Paso GK-12 partnership fellow Mr. Arturo Montes. Additional review by Wiggs Middle School science teachers Ms Tracy Fernandez and Ms Maribel Chavez, along with the Wiggs Middle School science department coach, for Texas Middle Schools assessment.

Reformed Teaching Observation Protocol:

This document has been used to evaluate the effectiveness of this lesson.

Name____Period_______Date_______________

Impacts on our Environment: Land Use and Land Cover Change in the Southwest Desert

Focus Question: What is land cover change? How does it impact our environment?

In this lab you will be investigating the effects of erosion caused by land cover change on plant survival, namely the survival of a seed. You will also learn how humans alter the land.

Engage

Describe how you will test Soil A versus Soil B on plants:
____
____
____
____
____
____
____
____
____

Explore

1. Gather the materials described in the lab by your teacher.
2. Punch a few small holes at the bottom of 3 plastic container cups.
3. Fill the 3 clear plastic cups, one with Soil A, one with Soil B, and the last with potting soil. Be sure to use the trowels provided to scoop up soil.
4. Be sure to label your cups as soil A, soil B, and control.
5. Place seeds in each cup of soil. Also include date and group name/number.
6. Water the plants/cups and place on the trays provided.
7. Make observations on what you will see each day including sprouting of seeds and plant height. Don't forget to keep your plants watered.
8. Graph your data at the end of the experiment.

Table 1. Seed and plant observations

Day	Plants in Soil A	Plants in Soil B	Plants in Control
1			
2			

3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			

Explain

What is land cover change?

List some examples of land cover change?
1.
2.
3.
4.
5.

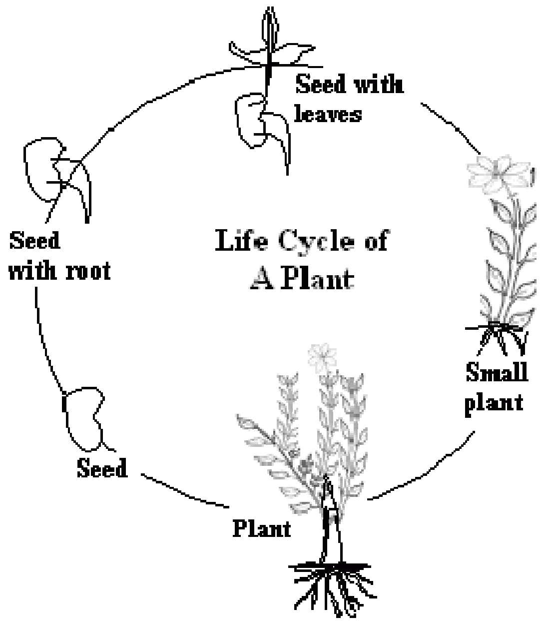
What do you think can cause land cover change to occur? Generate a list below:

Now, put the causes above into two categories: one for human activities and the other for natural events.

<u>HUMAN ACTIVITIES</u> <u>NATURAL EVENTS</u>

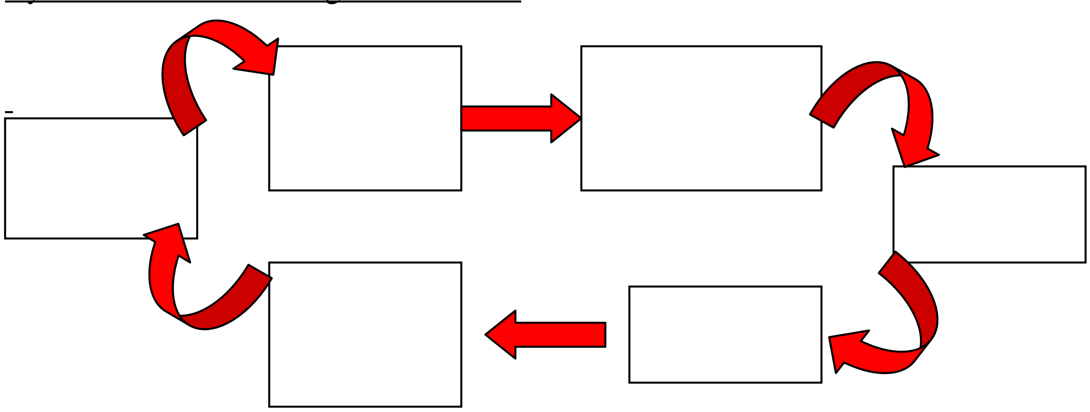
What is erosion?

Plant Life Cycle:



What are the important soil nutrients for plants?

Cycle of land cover change and erosion:



TEACHER KEY

Name____________________________________Period______Date_____________

Impacts on our Environment: Land Use and Land Cover Change in the Southwest Desert

Focus Question: What is land cover change? How does it impact our environment?

In this lab you will be investigating the effects of erosion caused by land cover change on plant survival, namely the survival of a seed. You will also learn how humans alter the land.

Engage

Describe how you will test Soil A versus Soil B on plants:

ANSWERS MAY VARY

Explore

1. Gather the materials described in the lab by your teacher.
2. Punch a few small holes at the bottom of 3 plastic container cups.
3. Fill the 3 clear plastic cups, one with Soil A, one with Soil B, and the last with potting soil. Be sure to use the trowels provided to scoop up soil.
4. Be sure to label your cups as soil A, soil B, and control.
5. Place seeds in each cup of soil. Also include date and group name/number.
6. Water the plants/cups and place on the trays provided.
7. Make observations on what you will see each day including sprouting of seeds and plant height. Don't forget to keep your plants watered.
8. Graph your data at the end of the experiment.

Table 1. Seed and plant observations

Day	Plant in Soil A	Plant in Soil B	Plants in control
1			
2			
3			
4	ANSWERS	WILL	VARY
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			

Explain

What is land cover change?

A change in the vegetation (plants) covering the ground through time; a change of the Earth's biological and physical cover of the surface

List some examples of land cover change?
1. **Deforestation**
2. **Desertification**
3. **Urbanization**
4. **Agriculturalization**
5. **Change from an aquatic to terrestrial environment**

What do you think can cause land cover change to occur? Generate a list below:

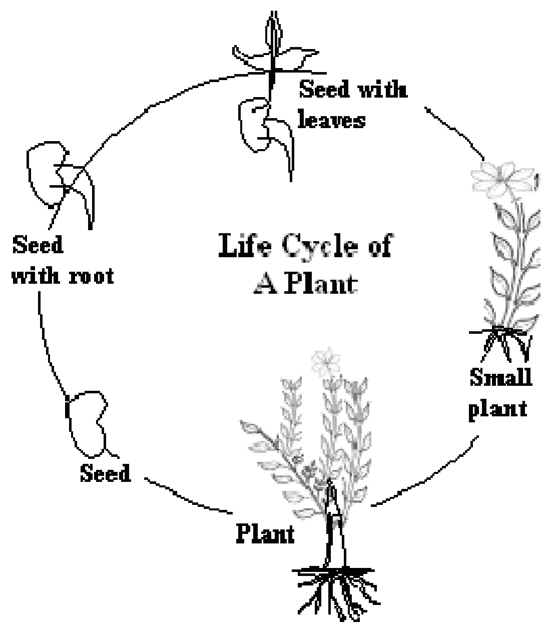
Fire Drought Farming Grazing Ranching Land Clearing Urbanization Industry Burning of Fossil Fuels Mining Climate change Insect Infestations Erosion Animal Activities

Now, put the causes above into two categories: one for human activities and the other for natural events.

HUMAN DISTURBANCES	NATURAL EVENTS
Ranching and Grazing	**Animal Activities**
Farming Mining Fire	**Drought Climate Change**
Land Clearing Urbanization	**Erosion Fire**
Industry Burning Fossil Fuels	**Insect Infestations**

What is erosion?
Movement of sediment by wind, water, ice, or gravity

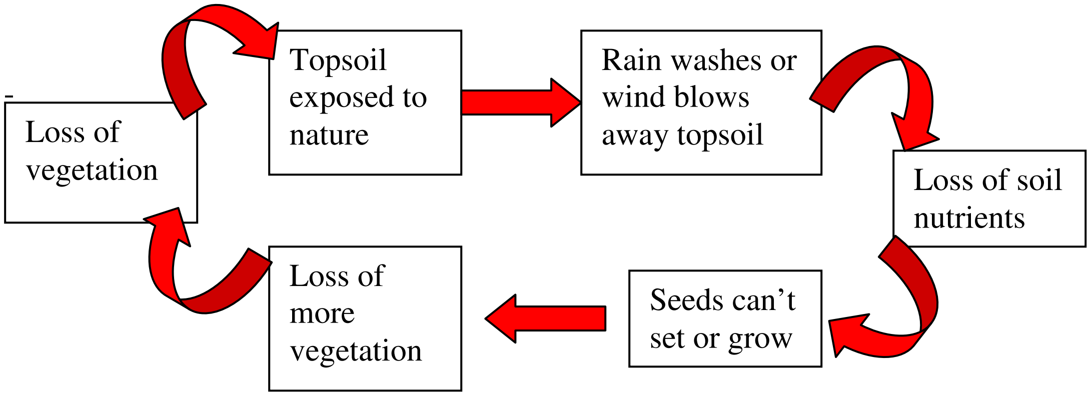
Plant Life Cycle:



What are the important soil nutrients for plants?

Nitrogen, phosphorus, potassium, calcium, magnesium, sulfur

Cycle of land cover change and erosion:



Appendix 3: Module 2 on "Assessing and Monitoring Ecosystems: Ecological Modeling"

Outline of Lesson created by Rebecca Marin

Abstract: For many years, natural events such as changes in the earth's climate, and human activities such as farming, and tree clearing, have changed the way the surface of the earth looks. Most changes have affected the vegetation on the ground, also called land cover, and transformed a once existing community of plants into an entirely new community. This is known as land cover change. The two types of land cover change are deforestation, or clearing of forests, and desertification, or the change to a more desert like environment. Both have negative effects on the ecosystem and the earth.

Land change science is the study of land cover change and its effects on ecosystem structure, function, and processes. In order to maintain the health of an ecosystem, especially those prone to human disturbances, monitoring and management practices must be put into play. Ecosystem monitoring is the recording and evaluation of the interaction of living and nonliving elements in a specific environment over time. Ecosystem management is the regulating of internal ecosystem structure and function, plus input and outputs, to achieve socially desirable conditions. In other words, ecosystem management is the actual decision-making and adoption of policies to maintain the health of the ecosystem based on the outcomes of monitoring. Monitoring allows us to:

- understand how the ecosystem and its components change over time,
- has the ability to identify real ecosystem change,
- is a vital step in knowing how human interaction and intervention affects our ecosystem,
- allows us to understand whether our management actions are achieving the goals we set, and
- aids us in creating new solutions to problems that are discovered.

Often, an ecological system or process cannot be directly manipulated in the field. In addition, high costs and inadequate time spans limit tests of community response to environmental disturbances on a large-scale. One tool that has become important in monitoring and management of ecosystems is ecosystem, or ecological, models. Ecological models are a representation of an ecosystem shown in quantitative or qualitative form. They are used by scientists to help them study existing ecosystems and

predict what might happen given certain conditions. They must simplify the system by focusing only on a specific part since ecosystems are very complex. One example of an ecosystem model is the water cycle. Ecosystem models are widely used and some of the practical applications include predator prey relationships, climate science, physiology of bacteria and viruses, nutrient and water cycling, and taxonomic and phylogenetic relationships among organisms.

The purpose of this module is to help students understand what monitoring and management of ecosystems is as it pertains to human impacts of the environment. They will do this by first seeing a power point presentation on assessing and monitoring ecosystems. The students will then have the opportunity to construct their own qualitative ecosystem models based on present, past, or even make-believe ecosystems using poster paper and art supplies, or using power point. The students will then have to introduce a disturbance into their model and demonstrate how that disturbance will affect their ecosystem. Students will do this by giving a short presentation to the class. By the end of the module students will be able to explain what monitoring and management of ecosystems is, understand the components of models, be able to construct their own qualitative ecological models, and explain what happens to the model when a disturbance is introduced.

Learning Outcomes: Students will understand what land cover change is, the type of land cover change occurring in the desert southwest, and the effects that land cover change has on the ecosystem including water and nutrient cycling, erosion, and loss of plant and animal diversity.

Unit 9, Earth Systems and Unit 10, Natural Events Altering Earth Systems

Stage 1-Desired Results

Established Goals

<u>Texas Middle Schools TEKS Alignment</u>:

- 8.1.A Demonstrate safe practices during field and laboratory investigations
- 8.2.A Plan and implement investigative procedures including asking questions, formulating testable hypothesis, and selecting and using equipment and technology
- 8.2.B Collect data by observing and measuring
- 8.2.C Organize, analyze, make inferences and predict trends from direct and indirect evidence

- 8.2.D Communicate valid conclusions
- 8.2.E Construct graphs, tables, maps, and charts using tools including computers to organize, examine, and evaluate data
- 8.3.C Represent the natural world using models and identify their limitations
- 8.4.B Extrapolate from collected information to make predictions
- 8.14 Know that natural events and human activity can alter earth systems (8.14.C Describe how human activities have modified soil, water, and air quality)

Objectives

- **Know that modeling is necessary to understand physical phenomena sufficiently well enough for scientists to make good decisions.**
- **Know that models ecosystem structure, function, and processes interact and can affect one another**

Understandings: Students will understand:

1) What monitoring ecosystems are and how it differs from management
2) Ecosystem modeling and how it is used in monitoring of ecosystems
3) Practical applications of models
4) The components and structure of models
5) Direct and indirect ecological interactions in models
6) How models (ecosystems) are impacted by a disturbance
7) Positive and negative feedback mechanisms in models
8) That modeling is necessary to understand physical phenomena sufficiently well enough for scientists to make good decisions
9) That ecosystem structure, function, and processes interact and can affect one another

Essential Questions:

1) Do you know what it means to monitor an ecosystem?
2) What do you think ecological modeling is?
3) Can you list some practical applications of ecological modeling as you defined it?
4) What is the difference between a quantitative and qualitative model?
5) Can you give an example of or produce a model?
6) Can you restructure the model based on the introduction of a disturbance?
7) Can you determine whether the model is an example of a positive feedback or negative feedback loop?
8) Do you feel like you know enough to implement this into any project associated with monitoring ecosystems?

Students will know:

1) What monitoring ecosystems is and how it differs from management
2) What ecosystem modeling is and understand how it is used in monitoring of ecosystems
3) Examples of models and practical applications of its use
4) The difference between quantitative and qualitative models
5) How to produce a qualitative ecosystem model and restructure the model with the introduction of a disturbance
6) How to Use the models to gain a better understanding of direct and indirect ecological interactions
7) What a positive feedback and a negative feedback mechanism is in models

Students will be able to:

1) Differentiate between monitoring and management
2) Understand what ecosystem modeling is and how it is used in as a monitoring tool
3) List examples of models
4) List practical applications of modeling

5) Differentiate between quantitative and qualitative models
6) Produce their own qualitative ecosystem model
7) Restructure their model with the introduction of a disturbance
8) Understand direct and indirect ecological interactions
9) Identify a positive and negative feedback mechanism in models

Stage 2-Assessment Evidence

Performance Tasks: A pre evaluation form will be given prior to the lesson to assess students' knowledge, understanding, and attitude of monitoring and management practices and ecological models. A post evaluation form will also be given at the end of the lesson to assess how much they learned and understood from the lesson and activities.

Other Evidence: The students' demonstration of their ecological models will be part of the student's assessment.

Stage 3-Learning Plan

Learning Activities:

1) Pre homework: students go to internet sites and complete models on the food web and arctic model

A.http://www.ecokids.ca/pub/games_activities/index.cfm

B.http://teacher.scholastic.com/activities/explorer/ecosystems/be_an_explorer/map/form.htm#

C. http://www.meted.ucar.edu/about_support.htm#C.

2) Pre survey
3) Power point presentation on Assessing and Monitoring Ecosystems
4) Creation and construction of ecological models
5) Presentation of ecological models
6) Demonstration of models in STELLA software
7) Post survey

Following is the lesson for this module.

Assessing and Monitoring Ecosystems: Ecological Modeling

Lab created and performed by Rebecca Marin
March 30, 2011
University of Texas El Paso, Biology 3416
Undergraduate Ecology

Texas Middle School TEKS Alignment:

- 8.1.A Demonstrate safe practices during field and laboratory investigations
- 8.2 Students will use scientific inquiry methods during field and lab investigations (A, B, C, D, E)
- 8.2.D Communicate valid conclusions
- 8.4.A Collect, analyze, and record information to explain phenomenon using tools including field equipment, computers, and compasses
- 8.11.A Identify that change in environmental conditions can affect survival of individuals and of species
- 8.14 Know that natural events and human activity can alter earth systems: Analyze how natural or human events may have contributed to the extinction of some species (B) and Describe how activities have modified soil, water, and air quality (C)

Objectives:

- Know what monitoring ecosystems is and how it differs from management
- Know what ecosystem modeling is and understand how it is used in monitoring of ecosystems
- Be able to list examples of models and list practical applications of its use
- Be able to produce a qualitative ecosystem model and restructure the model with the introduction of a disturbance
- Use the models to gain a better understanding of direct and indirect ecological interactions
- Know what a positive feedback and a negative feedback mechanism is in models
- **Know that modeling is necessary to understand physical phenomena sufficiently well enough for scientists to make good decisions.**
- **Know that models ecosystem structure, function, and processes interact and can affect one another**

Background Information:

For many years, natural events such as changes in the earth's climate, and human activities such as farming, and tree clearing, have changed the way the surface of the earth looks. Most changes have affected the vegetation on the ground, also called land cover, and transformed a once existing community of plants into an entirely new community. This is known as land cover change. The two types of land cover change are deforestation, or clearing of forests, and desertification, or the change to a more desert like environment. Both have negative effects on the ecosystem and the earth.

Land change science is the study of land cover change and its effects on ecosystem structure, function, and processes. In order to maintain the health of an ecosystem, especially those prone to human disturbances, monitoring and management practices must be put into play. Ecosystem monitoring is the recording and evaluation of the interaction of living and nonliving elements in a specific environment over time. Ecosystem management is the regulating of internal ecosystem structure and function, plus input and outputs, to achieve socially desirable conditions. In other

words, ecosystem management is the actual decision-making and adoption of policies to maintain the health of the ecosystem based on the outcomes of monitoring. Monitoring allows us to:

- understand how the ecosystem and its components change over time,
- has the ability to identify real ecosystem change,
- is a vital step in knowing how human interaction and intervention affects our ecosystem,
- allows us to understand whether our management actions are achieving the goals we set, and
- aids us in creating new solutions to problems that are discovered.

Often, an ecological system or process cannot be directly manipulated in the field. In addition, high costs and inadequate time spans limit tests of community response to environmental disturbances on a large-scale. One tool that has become important in monitoring and management of ecosystems is ecosystem, or ecological, models. Ecological models are a representation of an ecosystem shown in quantitative or qualitative form. They are used by scientists to help them study existing ecosystems and predict what might happen given certain conditions. They must simplify the system by focusing only on a specific part since ecosystems are very complex. One example of an ecosystem model is the water cycle. Ecosystem models are widely used and some of the practical applications include predator prey relationships, climate science, physiology of bacteria and viruses, nutrient and water cycling, and taxonomic and phylogenetic relationships among organisms.

References:

- Blackwood, J. Scott, Marion Dresner, Hang-Kwang Luh. April 2006, posting date. Using Student Generated Qualitative Ecological Models. Teaching Issues and Experiments in Ecology, Vol. 4: Experiment #4 [online]. http://tiee.ecoed.net/vol/v4/experiments/ecological_models/abstract.html
- PISCO. June 2009, posting date. Ecosystem Monitoring. http://www.piscoweb.org/research/science-by-discipline/ecosystem-monitoring
- Quantifying changes in the land over time http://landsat.gsfc.nasa.gov/education/resources/Landsat_QuantifyChanges.pdf
- Earth as Home Lesson "An Island Home" http://interactive2.usgs.gov/learningweb/pdf/globalchange/island.pdf
- USDA Forest Service. March 2011, access date. Ecosystem Management: Definitions, Concepts, and Approaches. University of Washington College of Forest Resources. http://silvae.cfr.washington.edu/ecosystem-management/IntroFrame.html

Internet Sites-Online Games:

- http://www.ecokids.ca/pub/games_activities/index.cfm
- http://teacher.scholastic.com/activities/explorer/ecosystems/be_an_explorer/map/form.htm#
- http://www.meted.ucar.edu/about_support.htm#C

Vocabulary:

8) *Ecosystem monitoring*- recording and evaluating the interaction of living and nonliving elements in a specific environment over time
9) *Ecosystem management*- a strategy to maintain ecosystems for all associated organisms
10) *Ecosystem modeling*- a representation of an ecosystem shown in quantitative or qualitative form
11) *Positive feedback loop*- when the output and the input of a system have the same effect thus creating a runaway situation due to the amplification of the original signal
12) *Negative feedback loop*- when the output and the input of a system have the opposite effect thus regulating the system to stability

Materials Required: power point presentation on models, poster paper, crayons, markers, color pencils, internet, STELLA modeling software

Prior Preparation:
- Acquire poster paper and other art supplies for construction of models
- Setup of Assessing and Monitoring Ecosystems PowerPoint presentation on a desktop and projector is needed prior to class

Safety Information:
General lab safety

PRE HOMEWORK:
- Have students go to the following websites and complete the following prior to the lesson:

A. http://www.ecokids.ca/pub/games_activities/index.cfm

There are 2 fun and easy activities for them to do.

#1- click on **wildlife**, then click on **chain reaction**. Read the information on the page and click **play the game**. Hit **start** and read the pages. Then do both the northern food chain and the forest food chain.

#2- click on **water**, then click on **acid lake**. Hit **play the game** and go through the module.

B.http://teacher.scholastic.com/activities/explorer/ecosystems/be_an_explorer/map/form.html
#1- Do the food web activity

C. http://www.meted.ucar.edu/about_support.htm#C.

Students will need to register, but there is no fee and they can choose not to receive anything from them as well. Once registered, they will automatically enter the module. Hit **begin**. Read through the pages to get some background information. Then **launch the model**. A new browser will open and hit **run model**. The page will then show parameters and a table with values. The idea is to change some of the settings to see what happens to the ecosystem. Play around with it and see what happens.

DAY 1:
Students first complete a pre survey of Assessing and Monitoring Ecosystems: Ecological Modeling.

Focus Question: What is an ecosystem model? Can you think of one?

I. Engage
- Ask students to list examples of an ecological model. Show and explain an example of a model; a good one to use is the water cycle.

II. Explain:
- Show students Assessing and Monitoring Ecosystems Powerpoint presentation which discusses monitoring and management, models as a tool in monitoring and management of ecosystems, and breaks down the components of a model.

III. Explore

- Allow students to create their own ecosystem models. The model can be based on any ecosystem (past, present, or make-believe) as long as the components of the model are present
- Inform students that they must introduce a disturbance into their model and demonstrate hot that disturbance will affect their ecosystem (model).
- Allow students to create their models using poster paper and art supplies or using power point.
- Allow students to work on the model for a few days (public school time constraints)

DAY 2:

III. Explore continued

- Give a little time for students to perfect their models

IV. Extension:

- Student presentation of models
- Class demonstration of qualitative models in STELLA to acquire quantitative models

V. Evaluate:

- Student participation and demonstration of models
- Student explanations of disturbance outcome on model.

Students complete post survey of Assessing and Monitoring Ecosystems: Ecological Modeling

<u>Peer Review</u>

This laboratory has been peer reviewed by National Science Foundation-University of Texas, El Paso GK-12 partnership fellow Paul Hotchkin.

Appendix 4: Module 3 on "Technological Advances in the Detection of Land Cover Change"

Outline of Lesson created by Rebecca Marin

Abstract: For many years, natural events such as changes in the earth's climate, and human activities such as farming, and tree clearing, have changed the way the surface of the earth looks. Most changes have affected the vegetation on the ground, also called land cover, and transformed a once existing community of plants into an entirely new community. This is known as land cover change. The two types of land cover change are deforestation, or clearing of forests, and desertification, or the change to a more desert like environment. Both have negative effects on the ecosystem and the earth.

Scientists around the world are interested in keeping track on where the vegetation is changing so they can take steps to protect that ecosystem from further change. Some scientists set up plots for watching changes in vegetation for many years. This type of method is good for a small area, but what if the scientists want to keep track of vegetation over a large area, like a state park or even the earth? In order to keep track of the vegetation all around the world, scientists use aerial photographs and images from satellites flying in space to help them keep track of vegetation, also called vegetation monitoring. Scientists take these images from the sky and space and put them into a geographic information system, or GIS. It is simply an electronic version of a map on a computer. With GIS, scientists can zoom in as close as they can to the ground on the imagery and see where the vegetation is. Then, they can compare an image from today to one that was taken in 1976, and see if the vegetation on the ground has increased or decreased through that time. They do this by creating maps of vegetation types on the ground, also called vegetation maps. Examples of vegetation types, or classes, are trees, shrubs, and grasses, and playa (see figure 1 below).

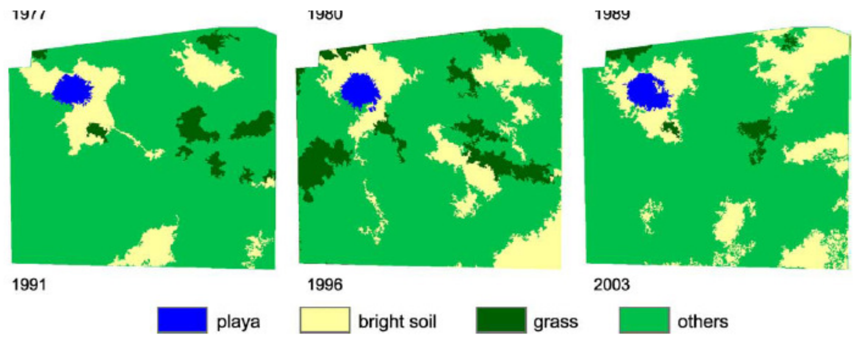


Figure 1. An example of a vegetation maps for 1991, 1996, and 2003. They can be used to see which vegetation types are increasing or decreasing through time. Image courtesy of Laliberte et al., 2004.

Learning Outcomes: Students will understand what land cover change is, the type of land cover change occurring in the desert southwest, and the methods and tools used to detect and monitor land cover change relating to GIS and remote sensing.

Unit 10, Natural Events Altering Earth Systems

Stage 1-Desired Results

Established Goals

<u>Texas Middle School TEKS Alignment</u>:

- 8.1.A Demonstrate safe practices during field and laboratory investigations
- 8.2.A Plan and implement investigative procedures including asking questions, formulating testable hypothesis, and selecting and using equipment and technology
- 8.2.B Collect data by observing and measuring
- 8.2.C Organize, analyze, make inferences and predict trends from direct and indirect evidence
- 8.2.D Communicate valid conclusions
- 8.2.E Construct graphs, tables, maps, and charts using tools including computers to organize, examine, and evaluate data
- 8.3.C Represent the natural world using models and identify their limitations
- 8.4.B Extrapolate from collected information to make predictions
- 8.14 Know that natural events and human activity can alter earth systems

<u>Objectives:</u>

- Know that technology is useful because it helps us solve problems

Understandings: Students will understand:

1) What it means to monitor an ecosystem
2) Some of the technological tools and advances used in monitoring
3) What remote sensing is and its practical applications
4) What geographic information systems (GIS) is and its practical applications

Essential Questions:

1) Do you know what it means to monitor an ecosystem?
2) Can you list some of the tools or technological advances used in monitoring?
3) What do you think remote sensing is all about?
4) Can you list 5 practical applications of remote sensing?
5) What do you think GIS (geographic information systems is all about?
6) Can you list 5 practical applications of GIS?
7) Can you list any other types of tools?

Students will know:

1) What it means to monitor an ecosystem
2) Some of the technological tools and advances in monitoring
3) About remote sensing
4) At least 5 practical applications of remote sensing
5) About geographic information systems (GIS)
6) At least 5 practical applications of GIS
7) Other types of tools used in ecosystem monitoring

Students will be able to:

1) Explain ecosystem monitoring
2) List some of the technological tools and advances used in ecosystem monitoring
3) Define and explain remote sensing

4) List 5 practical applications of remote sensing
5) Define and explain geographic information systems (GIS)
6) List 5 practical applications of GIS
7) List other types of tools used in ecosystem monitoring

Stage 2-Assessment Evidence

Performance Tasks: A pre evaluation form will be given prior to the lesson to assess students' knowledge and understanding of GIS and remote sensing. A post evaluation form will also be given at the end of the lesson to assess how much they learned and understood from the lesson and activities.

Other Evidence: The students' participation and completion of a tutorial on remote sensing and GIS.

Stage 3-Learning Plan

Learning Activities:

1) Pre survey on Technological Advances to Detect Change
2) Land cover classification
3) Kite demo
4) Powerpoint presentation on Technological Advances to Detect Change
5) Tutorial on remote sensing and GIS
6) Post survey on Technological Advances to Detect Change

Following is the lesson for this module.

Technological Advances in the Detection of Land Cover Change

Lab created and performed by Rebecca Marin
April 13-15, 2011; April 27-29, 2011
University of Texas El Paso, Biology 3416
Undergraduate Ecology

Texas Middle Schools TEKS Alignment:

- 7.1.A Demonstrate safe practices during field and laboratory investigations
- 7.2.B Collect data by observing and measuring
- 7.2.D Communicate valid conclusions
- 7.2.E Construct graphs, tables, maps, and charts using tools including computers to organize, examine, and evaluate data
- 7.3.C Represent the natural world using models and identify their limitations
- 7.4.A Collect, analyze, and record information to explain phenomenon using tools including field equipment, computers, and compasses
- 7.4.B Collect and analyze information to recognize patterns such as rates of change
- 7.5. Understand that equilibrium of systems may change
- 7.12 Know that there is a relationship between organisms and the environment
- 7.14 Know that natural events and human activity can alter earth systems

Texas High School TEKS Alignment:

- **9.1 A, 10.1 A, 11.1 A, 12.1 A** Demonstrate safe practices during laboratory and field investigations, including chemical, electrical, and fire safety, and safe handling of live and preserved organisms
- **9.2 E, 10.2 E, 11.2 E, 12.2 E** Plan and implement investigative procedures, including asking questions, formulating testable hypotheses, and selecting, handling, and maintaining appropriate equipment and technology
- **9.2 F, 10.2 F, 11.2 F, 12.2 F** Collect data individually or collaboratively, making measurements with precision and accuracy, record values using appropriate units, and calculate statistically relevant quantities to describe data, including mean, median, and range
- **9.2 G, 10.2 G, 11.2 G, 12.2 G** Demonstrate the use of course apparatuses, equipment, techniques, and procedures
- **9.2 H, 10.2 H, 11.2 H, 12.2 H** Organize, analyze, evaluate, build models, make inferences, and predict trends from data
- **9.2 J, 10.2 J, 11.2 J, 12.2 J** Communicate valid conclusions using essential vocabulary and multiple modes of expression such as lab reports, labeled drawings, graphic organizers, journals, summaries, oral reports, and technology-based reports
- **9.3 B, 10.3 B, 11.3 B, 12.3 B** Communicate and apply scientific information extracted from various sources such as current events, news reports, published journal articles, and marketing materials
- **Earth and Space Science 11 D** Interpret Earth surface features using a variety of methods such as satellite imagery, aerial photography, and topographic and geologic maps using appropriate technologies

Objectives:

- Understand what it means to monitor an ecosystem
- Know some of the technological tools and advances used in monitoring
- Understand what remote sensing is and its practical applications
- Understand what geographic information systems (GIS) is and its practical applications
- **Know that technology is useful because it helps us solve problems**

Background Information:

For many years, natural events such as changes in the earth's climate, and human activities such as farming, and tree clearing, have changed the way the surface of the earth looks. Most changes have affected the vegetation on the ground, also called land cover, and transformed a once existing community of plants into an entirely new community. This is known as land cover change. The two types of land cover change are deforestation, or clearing of forests, and desertification, or the change to a more desert like environment. Both have negative effects on the ecosystem and the earth.

Scientists around the world are interested in keeping track on where the vegetation is changing so they can take steps to protect that ecosystem from further change. Some scientists set up plots for watching changes in vegetation for many years. This type of method is good for a small area, but what if the scientists want to keep track of vegetation over a large area, like a state park or even the earth? In order to keep track of the vegetation all around the world, scientists use aerial photographs and images from satellites flying in space to help them keep track of vegetation, also called vegetation monitoring. Scientists take these images from the sky and space and put them into a geographic information system, or GIS. It is simply an electronic version of a map on a computer. With GIS, scientists can zoom in as close as they can to the ground on the imagery and see where the vegetation is. Then, they can compare an image from today to one that was taken in 1976, and see if the vegetation on the ground has increased or decreased through that time. They do this by creating maps of vegetation types on the ground, also called vegetation maps. Examples of vegetation types, or classes, are trees, shrubs, and grasses, and playa (see figure 1 below).

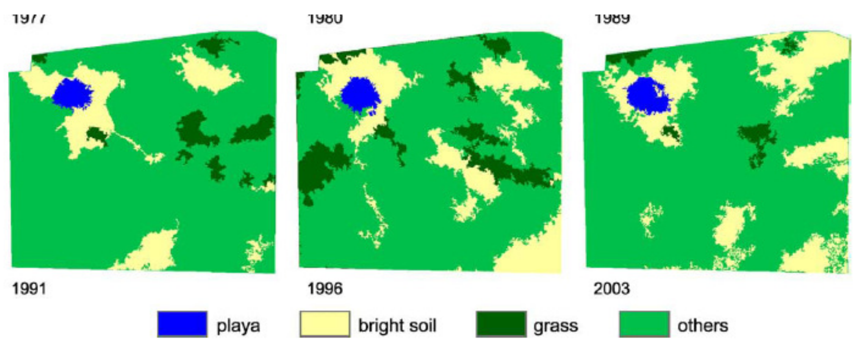


Figure 1. An example of a vegetation maps for 1991, 1996, and 2003. They can be used to see which vegetation types are increasing or decreasing through time. Image courtesy of Laliberte et al., 2004.

In order to make sure that we are seeing what we think we are seeing in the satellite imagery and aerial photography, scientists must go to that site on the ground and take ground control points with a geographic positioning system (GPS). A GPS is an electronic device that gives us the coordinates of our position on the ground in degrees north and west. Ground control points are specific locations on the ground that we record what we see, like a type of tree or a building, and take the GPS coordinates of that tree or building. We take many of them which we can use in our GIS to help us know what we are seeing in the imagery. It is important to do this so that we have the most accurate information possible to help us monitor vegetation from afar.

References:

- Land cover classification http://earthobservatory.nasa.gov/Library/LandCover
- Changing global land surface http://earthobservatory.nasa.gov/Library/LandSurface
- Analyzing land use change in urban environments http://landcover.usgs.gov/urban/info/factsht.pdf
- Landsat change over time http://change.gsfc.nasa.gov
- Landsat gallery http://landsat.usgs.gov/gallery/change
- Quantifying changes in the land over time http://landsat.gsfc.nasa.gov/education/resources/Landsat_QuantifyChanges.pdf
- Telling a pine from a maple…from Space! http://spaceplace.nasa.gov/en/kids/eo1_1.shtml
- Classroom activities http://landsat.gsfc.nasa.gov/education/activity_matrix.html
- Earth as Home Lesson "An Island Home" http://interactive2.usgs.gov/learningweb/pdf/globalchange/island.pdf
- Learning with GPS http://sciencespot.net/Pages/classgpslsn.html
- Classroom resources for GIS/GPS in K12 Education http://www.remc11.k12.mi.us/bcisd/classres/gis.htm
- Satellites, Computers, and Mapping http://www.ncsu.edu/midlink/gis/gis_intro.htm
- Using GPS in the Classroom http://cfa-www.harvard.edu/space_geodesy/ATLAS/classroom.html

Vocabulary:

13) *land cover change*- a change in vegetation (plants) covering the ground through time
14) *monitoring*- to be aware of the state of a system and observe for any changes that may occur over time
15) *aerial photographs*- photographs taken with a camera attached to an aircraft and aimed at the ground; it gives us a "bird's eye view" of the ground below
16) *ground control points (GCP)*- A point on the surface of the earth of known location which is used to geo-reference images, such as remotely sensed images, scanned maps, and aerial photographs; this point is recognizable on all images
17) *geographic information systems (GIS)*- a system for capturing, storing, analyzing, and managing data, such as maps, aerial images, satellite images, and points of interest, which are spatially referenced to the Earth
18) *global positioning systems (GPS)*- a device, or tool, that uses 24 Earth orbit satellites to transmit precise measures of location, speed, direction, and time and is widely used to aid in navigation, map making, and land surveying
19) *remote sensing*- obtains information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation

Materials Required: aerial photographs, UAV (kite) or pictures of UAV's, Google Earth images of El Paso, computers, projector, gridded transperancy, permanent markers, tape

Prior Preparation:

- Need to download imagery package and remote sensing/GIS freeware for student use on computers

- Print out of aerial image of El Paso (or your area) from Google Earth and printing of grid on transparency is needed prior to class time
- Setup of UAV demonstration prior to class

Safety Information:
General lab safety.

DAY 1 (170 minutes):
Students first complete a pre survey on Technological Advances for Monitoring Ecosystems

Focus question: Has anyone ever been on a plane? If so, what do you see when you look down on the ground?

I. Engage
- Show students printouts of El Paso aerial photo
- Ask students if they know what the image shows (do they know it is El Paso)
- Announce that students are part of an ecological and engineering firm contracted to create a color coded map of the El Paso image

II. Explore:
- Pass out aerial photographs of El Paso, gridded transperancy, and permanent markers to let students create their color coded maps
- Ask students to try to pick out landmarks such as roads, buildings, river, agriculture, desert
- Have students tape the gridded transperancy on top of the El Paso image
- Allow students to color the gridded transperancy with the permanent markers using different colors for the different categories (land use classes)
- Be sure to guide the students to creating a good number of classes and a color key
- Give the students about 30 minutes to complete the task
- When students are done, allow students to tape the transperancy (remove the photo) to the board to allow students to see eachother's maps
- Ask the students how well the maps represent the photo

III. Explain:
- Show students Technological Advances for Monitoring Ecosystems Powerpoint presentation which discusses land cover change and the technological tools and advances to detect and monitor this phenomenon; specifically remote sensing and GIS
- Show students kite demo (or images of UAV's can be embedded into the presentation)

DAY 2 (170 minutes):
IV. Extension
- Allow students to complete the remote sensing and GIS tutorial
- Have students submit final map printout as part of evaluation

Students complete a post survey on Technological Advances for Monitoring Ecosystems

V. Evaluate:

- A pre and post survey can be conducted to evaluate their level of understanding in the subject before the activity and again afterwards.
- Student maps for El Paso and from remote sensing and GIS tutorial will be part of student grade

Peer Review

This laboratory has been peer reviewed by National Science Foundation-University of Texas, El Paso GK-12 partnership fellow Mr. S. Chris Benker. Additional review by Mr. Vaughn Courtney with the Wiggs Middle School science department.

Reformed Teaching Observation Protocol:

This document has been used to evaluate the effectiveness of this lesson.

Following is the tutorial used for this module.

Land Cover Classification and Mapping:

An introductory tutorial for remote sensing and GIS using ENVI® and ArcGIS®

Overview of the Tutorial

This tutorial is aimed at providing users not familiar with GIS or remote sensing a brief introduction to remote sensing using ENVI and to geographic information systems (GIS) using ArcMap. This tutorial will provide the user with step-by-step procedures for conducting a supervised classification of land cover at the Indio Mountains Research Station, Van Horn, TX using ENVI 4.4 software, and importing this data into a GIS (ArcMap) to add information files and create a presentation quality map. It is designed to follow the "Technological Advances for Monitoring Ecosystems" module, which introduces remote sensing and GIS concepts and their application in biology, ecology, and environmental science. It is designed to be completed in 3 hours.

Files used in this Tutorial

CD-ROM: Tech Adv_Indio Data Files

File	**Description**
po_386333_blu_00000.tif	IKONOS satellite image blue band
po_386333_grn_00000.tif	IKONOS satellite image green band
po_386333_nir_00000.tif	IKONOS satellite image near infrared band
po_386333_red_00000.tif	IKONOS satellite image red band
IK_Indio2.roi	ROI file
Indio_Border_NAD83.shp	Indio border shapefile
Indio_Ranch.shp	Indio Ranch shapefile
Veg_map_field_sites3.shp	Vegetation sites shapefile
Naip_1-1_2n_s_tx229_2005_1.sid	2005 Aerial photo of Hudspeth county

Getting Started with ENVI

- Select Start → Programs → ENVI 4.7 → ENVI or Double click on the ENVI icon found on the desktop
- Look at the ENVI main menu bar found at the top of the screen. All activities are selected by using the menus in the main menu bar.

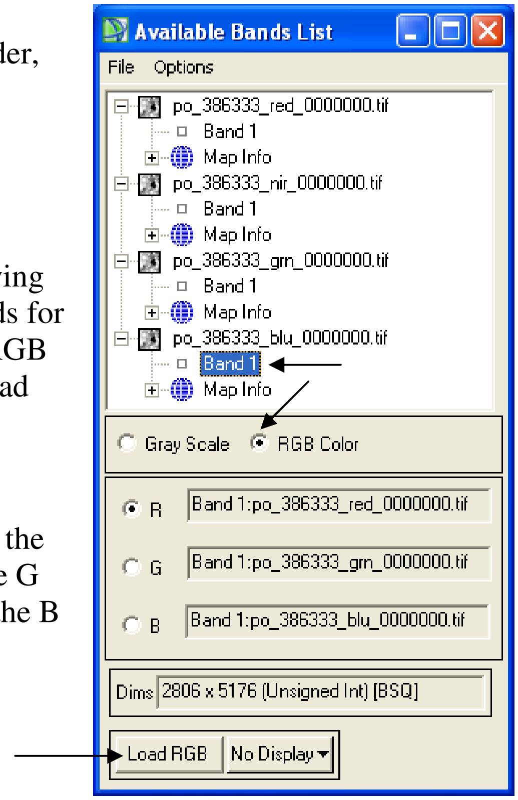
Loading an Image

Open the October 2007 multispectral IKONOS satellite data files representing the Indio Mountains Research Station, Van Horn, TX. The file has 5 separate bands (red, green, blue, near infrared, and panchromatic), and 4 of these bands (red, green, blue, and near infrared) will be used in this exercise.

Opening an Image File

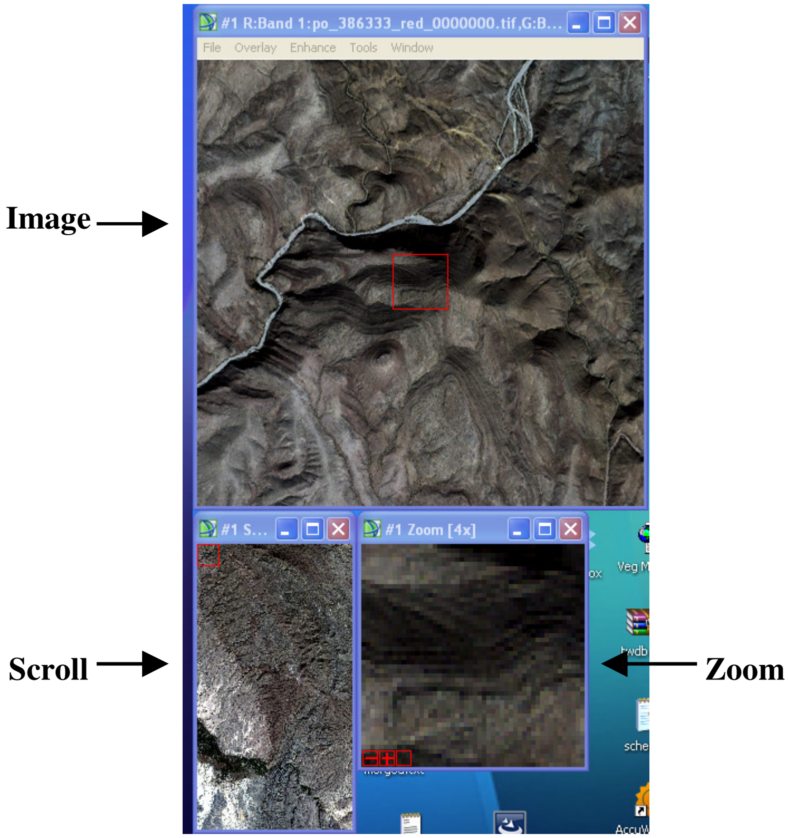
- From the ENVI main menu bar, select File → Open Image File

- Navigate to the Tech Adv_Indio Data Files\IK_Imagery folder, select the following files from the list, and click Open:
  po_386333_blu_0000000.tif
  po_386333_grn_0000000.tif
  po_386333_nir_0000000.tif
  po_386333_red_0000000.tif
- The Available Bands List dialog appears on the screen showing the files available. The list allows you to select spectral bands for display and processing. You can either load a grayscale or RGB (Red Green Blue) color image. For this exercise, you will load the RGB color image
- Click on the RGB radio button, the selected bands field will change from 1 band to three bands
- Click on Band 1 under the po_386333_red_0000000.tif into the R field, Band 1 under the po_386333_grn_0000000.tif in the G field, and Band 1 under the po_386333_blu_0000000.tif in the B field
- Click the Load RGB to load the images into a new display (Display #1)



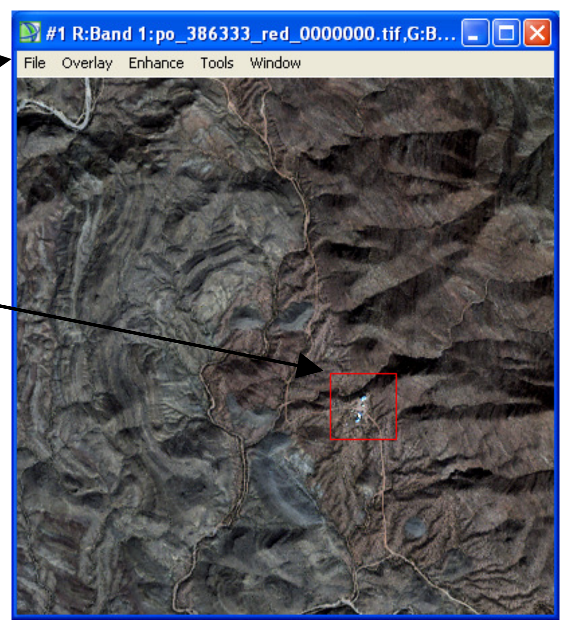
The ENVI Interface

When the image loads, a display group that is linked together appears. The group consists of a large Image Window, a Scroll Window, and a Zoom Window. The Scroll Window is a display of the entire image at a reduced resolution. The Image Window displays a selected portion of the Scroll Window at full resolution. The Zoom Window displays a portion of the image indicated by a highlighted box (the Zoom Box) in the Image Window magnified (magnification indicated by [#x] in the title of the Zoom Window).



The Image Window

The Display Group Menu Bar
The menu bar in the Image Window provides access to many ENVI tools relating to the display image.



The Image Window Zoom Box

The Zoom box (colored box in the Image Window) shows the area displayed in the Zoom Window

- Place the cursor anywhere in the Image Window outside the Zoom box and left click on the mouse. The box will move to that location instantly and be shown on the Zoom Window.

The Zoom Window

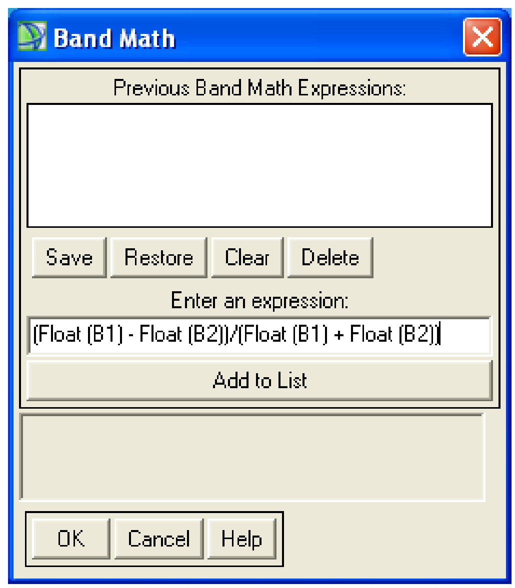
There are three Zoom controls (red) at the bottom left of the Zoom Window.

- The – zooms out of the image. Click on it to give it a try.
- The + zooms into the image. Click on it to give it a try.
- The □ toggles the crosshairs in the Zoom Window on and off.

Zoom controls

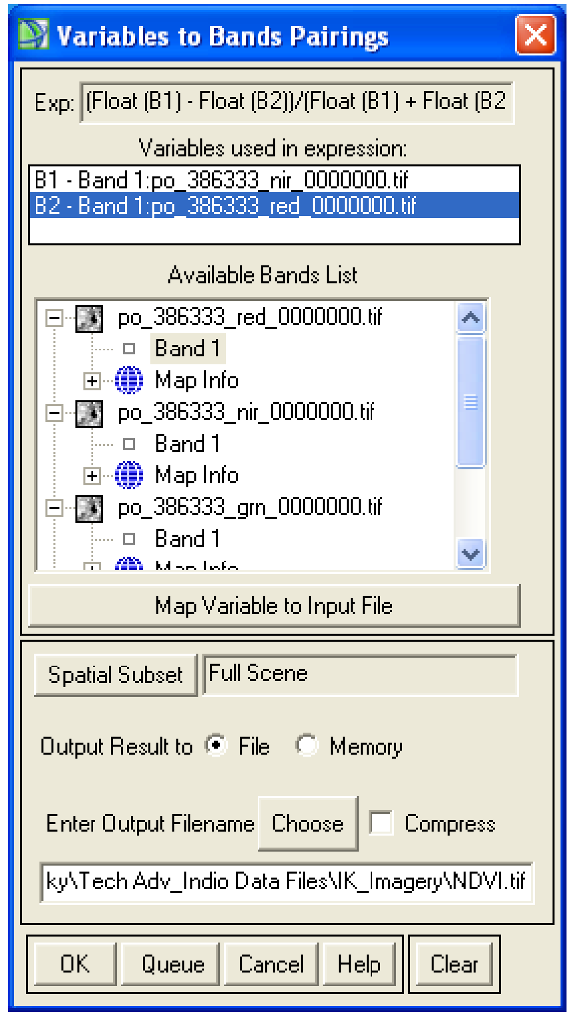
Creating a Normalized Difference Vegetation Index (NDVI) band

NDVI is a measure of plant productivity, or greenness of vegetation in an image. It helps to better classify vegetation in an image, especially in an area like the desert where a lot of the ground is exposed and could add noise to the image. Two bands will be used to create a NDVI of the IKONOS image, red and infrared (nir), where NDVI = (nir – red) / (nir + red). Then the blue, green, red, infrared, and NDVI bands will be stacked to create a single 5-band stacked image to eliminate working with multiple files or images.



Creating the NDVI band

- On the ENVI main menu part click on Basic Tools → Band Math
- The Band Math dialogue opens. In the Enter an expression section, enter the formula below: (Float (B1) – Float (B2))/(Float (B1) + Float (B2))
- Click OK
- The Variables to Bands Pairings dialogue opens. This is where matching the variables with the bands from the image occurs, where B1 = nir and B2 = red.



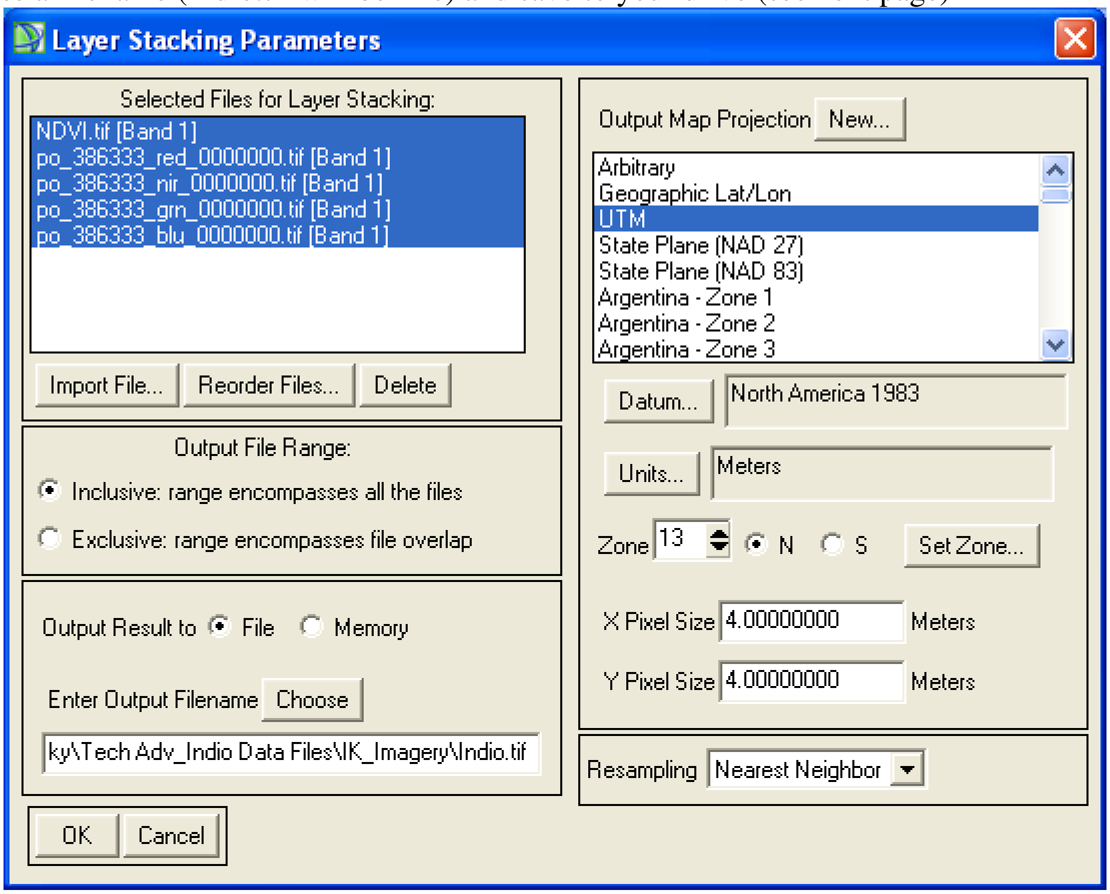
- B1 – (undefined) should be highlighted. In the Available Bands List, select Band 1 under po_38633_nir_0000000.tif
- Select B2 – (undefined) so that it is highlighted. In the Available Bands List, select Band 1 under po_38633_red_0000000.tif
- Keep the Full Scene for Spatial Subset
- Output Result to File and choose a filename (can call it NDVI.tif) and location (preferably to your external hard drive or USB for now)
- Click OK
- It will take a few seconds to calculate. The new band will be added to the Available Bands List
- To view the image, select Band Math under the NDVI image file, make sure the Gray Scale radio button is selected, click Display #1 at the bottom to select New Display, and finally click Load Band
- The NDVI file will be loaded to a second display.
- View the image. The white areas represent highly productive areas indicating large or highly dense vegetated areas. The black represents low productivity areas indicating bare areas or low shrub density. Most of the whitest areas will be located near arroyos, streams, and the Rio Grande. Most of the blackest areas will be located in areas of bare ground, roads, and arroyo centers where there is no vegetation growth.

Stacking the Bands

The blue, green, red, infrared (nir), and NDVI bands will be stacked to create a single 5-band image to eliminate working with multiple files or images for the remainder of the processing.

- On the ENVI main menu part click on Basic Tools → Layer Stacking
- The Layer Stacking Parameters dialogue opens.
- Click on Import File and the Layer Stacking Input File dialogue opens.

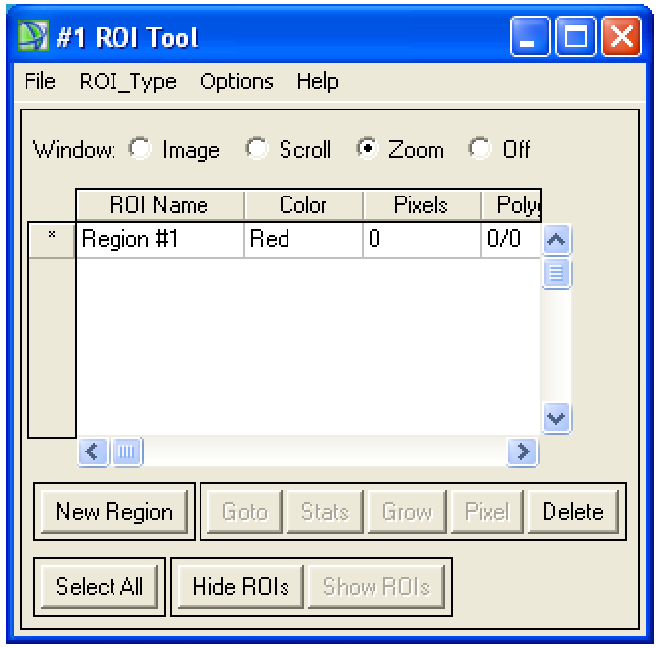
- Select all the tif files (red, nir, grn, blu, and NDVI) by clicking on the first file and then holding the shift key and clicking on the last file (all files should be highlighted), leave the spatial subset as full scene, and click OK
- Make sure that all the files are selected and the Inclusive radio button is selected
- In the Output Map Projection, be sure UTM is selected; Click on Datum and select North America 1983 and click OK; Units should be in meters and the Zone should be 13 with the N radio button selected
- Leave everything else set to the default values
- Choose a filename (Indio.tif will be fine) and save to your drive (see next page)



- Click OK
- The File Map Projection Conversion will run for a few seconds
- When it finishes, the new file will be added to the Available Bands List
- Load the new file into Display #1 by making sure the RGB Color radio button is selected, choosing the red band for R, blu band for B, and grn band for G (bands in the Indio.tif file), and selecting Load RGB
- From now on, the Indio.tif file will be used for processing

Define Regions of Interest as Training Sites

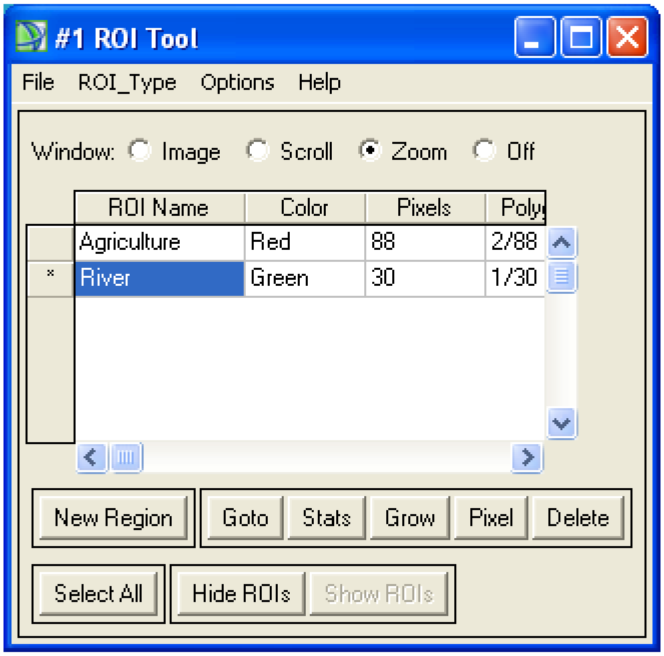
Before running a supervised classification, we must first train the computer, or program the computer, to differentiate between classes by selecting areas, or regions, of interest. The regions of interest are sites found on the ground that the analyzer believes to be the best representative of that particular class. There is much field work involved and requires knowledge of the study area, acquisition of GPS locations, and analysis of the vegetation covering the ground. For this tutorial, selection of regions of interest (ROI's) will be shown. But in order to run the classification, a separate file with pre-selected ROI's will be used due to time constraints.



Defining Regions of Interest (ROI's)

- On the Image menu bar, select Tools → Region of Interest → ROI Tool
- The ROI Tool and dialogue opens (see previous page)
- On the ROI Tool dialogue, be sure to select the Zoom radio button; this will ensure that only areas selected in the Zoom window will be used as ROI's
- In the Scroll Window, move the red box down towards the river by clicking once on the river area; the red box will move automatically
- In the Image Window, you can move the Zoom (red) box in any part of the river you are interested in selecting as an ROI.
- Move the box to an area of dark green vegetation cover
- The Zoom box will show the area selected
- In the Zoom window, left click on an area and create a box; when completed double right click and the box will fill with color
- This is the first ROI to be created; The ROI Tool dialogue will show the number of pixels selected for this ROI
- In the ROI Tool dialogue click twice on Region #1 to rename it anything you want (agriculture could be a good name); Enter when done
- In the RIO Tool dialogue, click on New Region; a new region will appear

- In the Zoom window, create a box in another region of interest. See if you can get the actual river water
- Left click to create the box and double right click to end; the box will be a different color
- Rename Region #1 as River following the steps above.



In practice, there are anywhere between 5 and 20 different classes, with anywhere between 500 and 2000 pixels per class. It is tedious and time consuming work, but the more pixels you have that represent the variability of the class, the more accurate your final map will be for each class.

Loading Regions of Interest (ROI's)

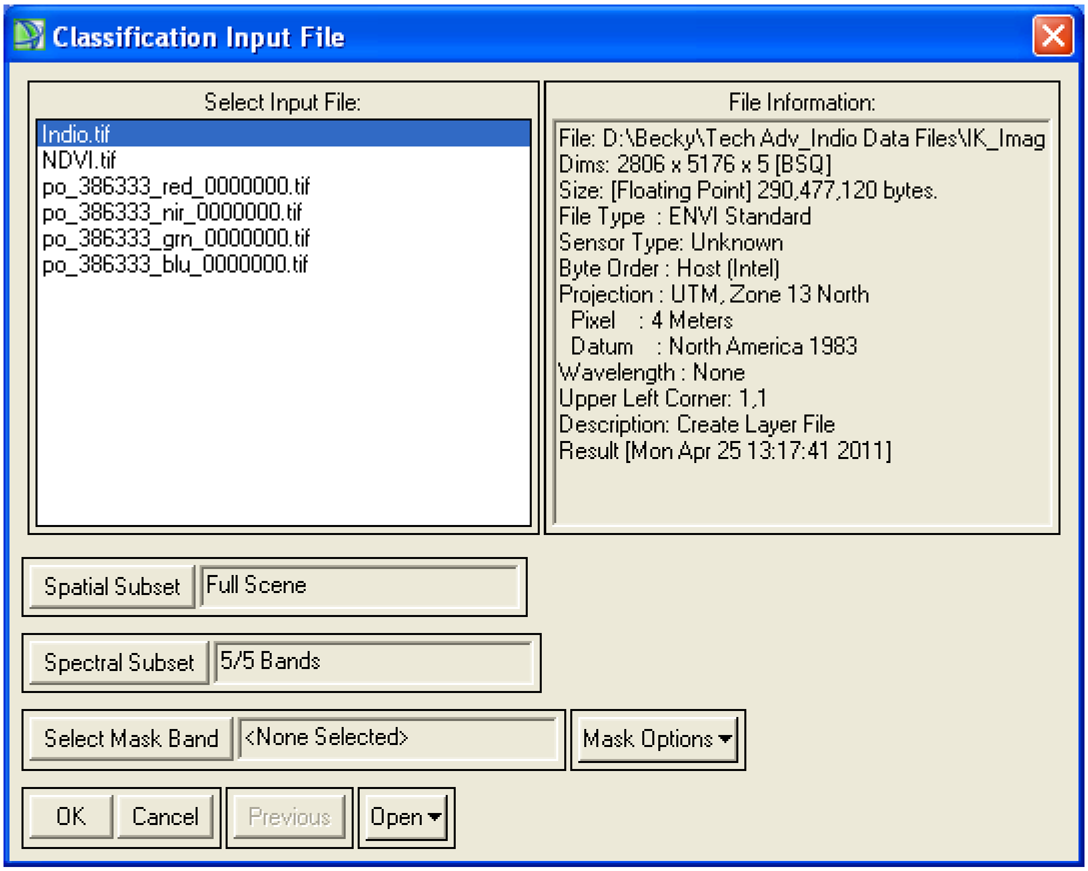
- In the ROI Tool dialogue, highlight each of the regions you just created and select Delete
- In the ROI Tool dialogue menu, select File → Restore ROI's
- Navigate to the Tech Adv_Indio Data Files\IK_Imagery folder and select the IK_Indio2.roi file and click Open
- The ROI's will load into the ROI Tool dialogue; Highlight the first class (Region #1) and click Delete
- Look at the ROI's by scrolling down. In practice, all of these ROI's would have been created by loading a vector file containing the GPS locations of the ROI's and highlighting the areas using the vector file.

Supervised Classification

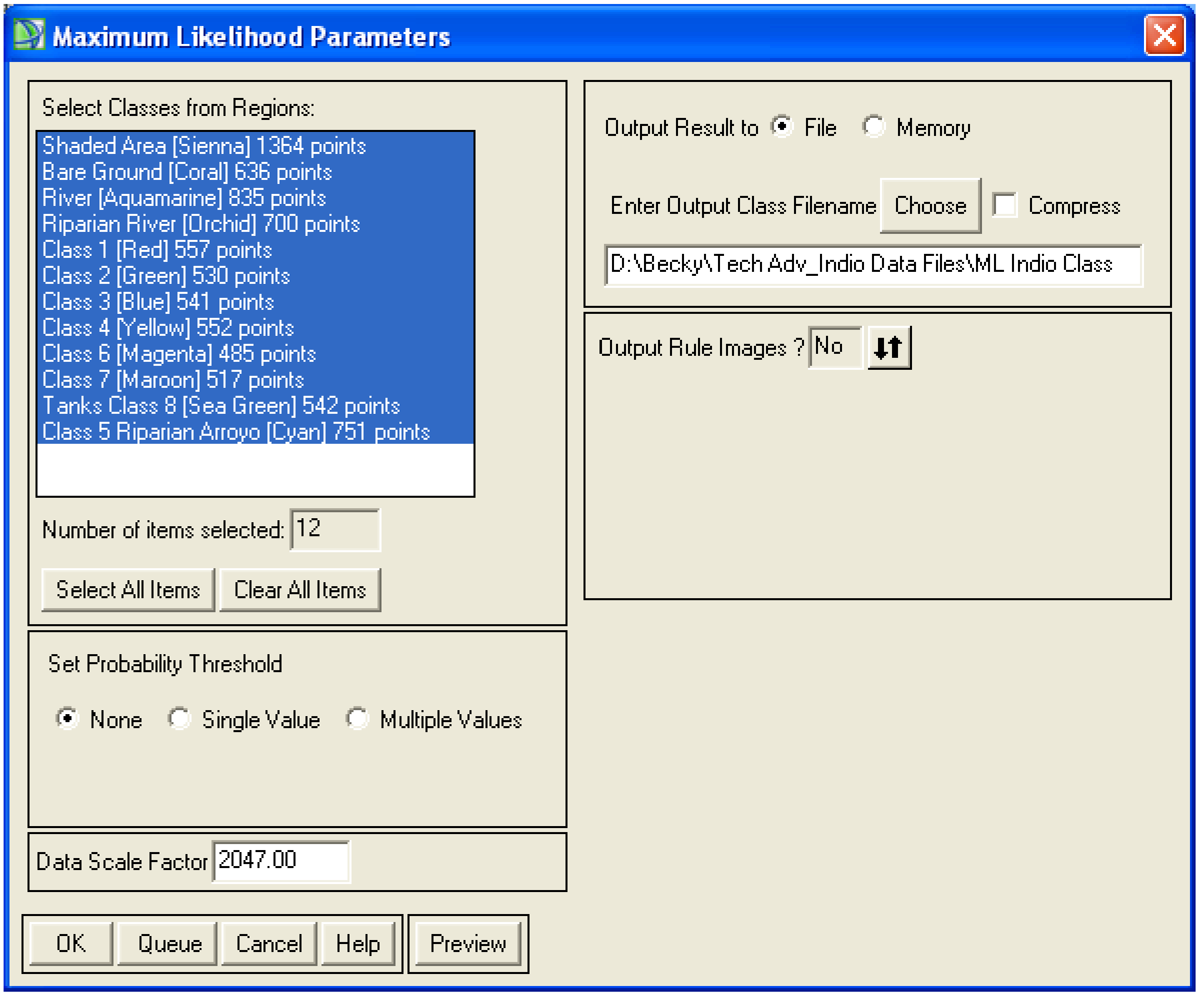
Now the supervised classification will be run using the maximum likelihood algorithm. Maximum likelihood assumes that the statistics for each class are normally distributed and calculates each pixel's probability of belonging to a certain class. Each pixel is assigned to the class with the highest probability or maximum likelihood.

Maximum Likelihood Classification

- In the ENVI main menu bar, select Classification → Supervised → Maximum Likelihood
- The Classification Input File dialogue opens
- Select the file with the bands stacked (Indio.tif, if that is what you called it)
- Spatial Subset: Full Scene
- Spectral Subset: 5/5 Bands and no mask band selected
- Click OK



- The Maximum Likelihood Parameters Dialogue opens
- In the Select Classes from Regions, click Select All Items to choose all the classes
- Set the Probability Threshold to None
- Enter 2047.00 for Data Scale Factor
- Output Results to File and choose a filename (ML Indio Class would work)
- Toggle Output Rule Images to No
- Click OK

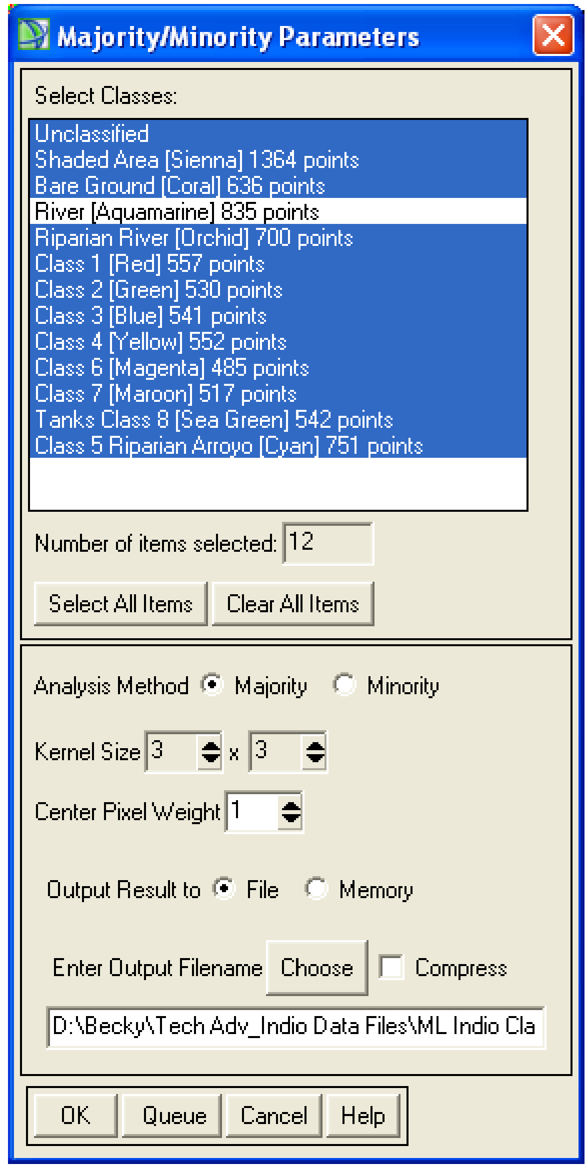


- The classifier will take a few minutes to run
- The Classified image will appear in the Available Bands List
- Load the ML Indio Class band into a New Display and look at the image, especially in the river area

Majority Analysis
Majority Analysis is a tool that filters the image making it smoother. The filter will be run on all the classes except the river class. It has been shown that when the filter is run on the river class, the river loses its distinct shape and blends in with other classes causing the class to become less defined.

- In the ENVI main menu bar, go to Classification → Post classification → Majority/Minority Analysis
- The Classification Input File dialogue opens
- Select the classification file and keep the Spatial Subset to Full Scene
- Click OK
- The Majority/Minority Parameters Dialogue opens
- Select all the classes except the River class
- The Analysis Method radio button should be set to Majority
- Kernel size 3 x 3

- Center Pixel Weight 1
- Choose a filename (Indio ML Filter would be fine) and save to your drive
- It will take a few seconds for the analysis to run
- The file will appear in the Available Bands List
- Load the band into Display #3.
- Look at the image and see how much smoother the classes look



Exporting the File for ArcMap

Now we want to get the file ready to be opened in ArcGIS.

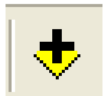
- In the ENVI main menu bar select File → Save File As → ArcView Raster
- Choose the Indio Class Filter file
- Spatial Subset Full Scene
- Click OK
- Select your drive location and filename (Indio class ArcView.bil would be fine)
- Click OK
- **Close the ENVI Program**

If you are interested in remote sensing applications and processing, UTEP offers a remote sensing course through geology, or see your instructor.

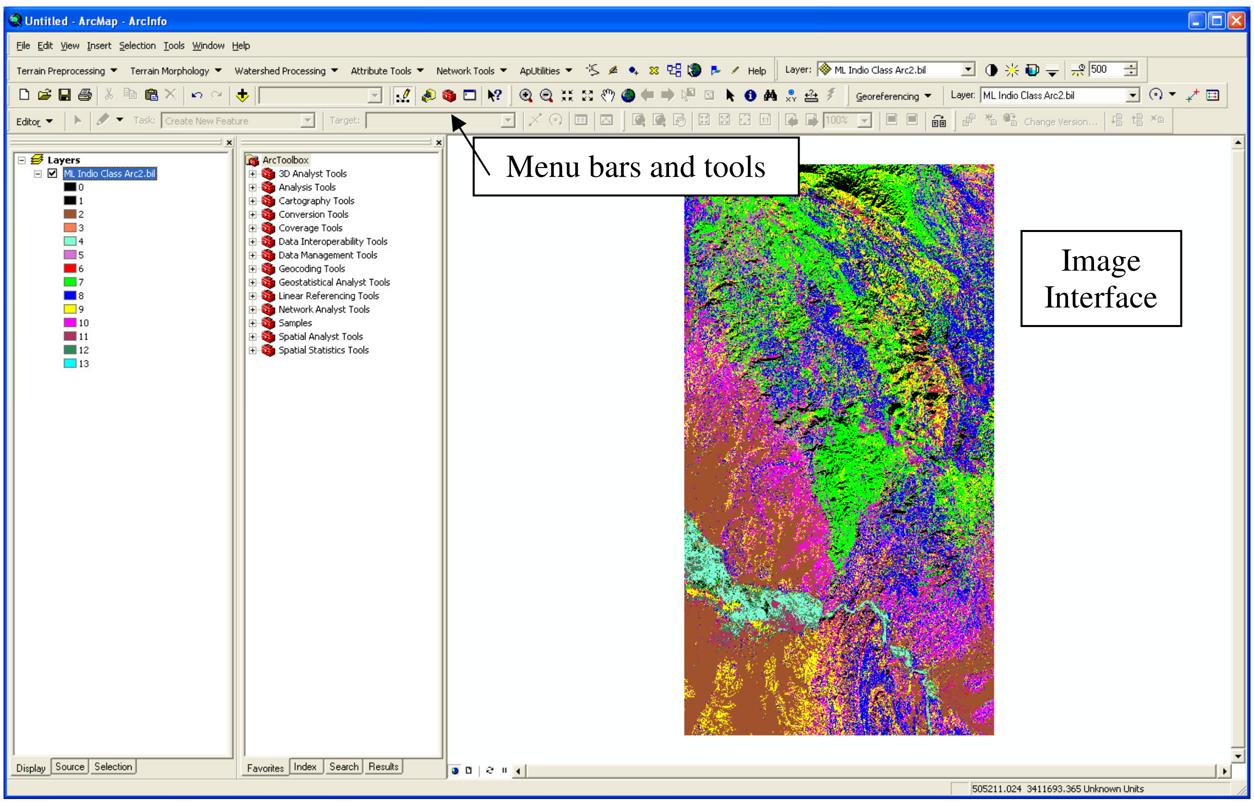
Getting Started with ArcGIS

We will now open the image in ArcGIS to create a map to save for presentation or to print out. There are many other processes that can be done here. We can compare other data sets, like geology, elevation, slope and aspect, or population density, with our classification map to acquire data for analysis. Statistical analysis can also be conducted in ArcGIS. But due to time constraints, these will not be explored. If you are interested in GIS, UTEP offers a GIS course in geology, or see your instructor.

- Open ArcGIS by going to Start → Programs → ESRI → ArcGIS → ArcMap
- Select A new empty map and click OK
- Choose the Add Data icon
- Navigate to the folder where the ArcView.bil file is saved



- A warning saying that there is no spatial reference will appear
- Click OK
- The image will appear in ArcMap
- Click the Add Data icon and add the 2005 sid file
- Click OK
- In the Layers section, click and drag the Indio class on top of the sid file; the image will then appear on top of the aerial photo



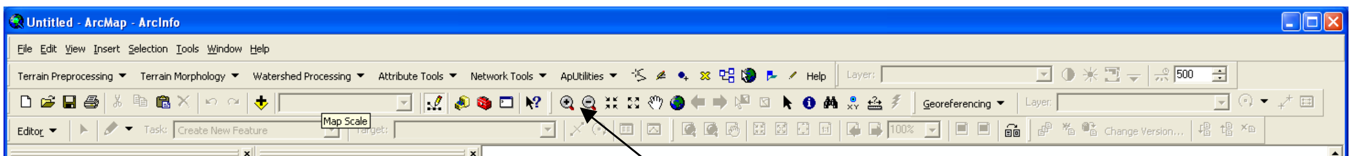
Adding Additional Files

- Click on the Add Data icon and add the following files:
    - Veg_map_field_sites3.shp
    - Indio_Border_NAD83.shp
    - Indio_Ranch.shp
- Double click on the Indio Ranch symbol in the Layers section
    - Scroll down the Symbol Selector and choose School 2
    - Choose a color that will stand out, like hot pink or neon green
    - Click OK
- Double click on the veg map field sites 3 symbol and do the same thing. Choose a symbol and color that will stand out. Click Ok
- Double click on the Indio Border symbol

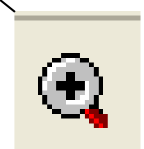
- Choose the Hollow symbol
- Choose a good color (like red or black) and change the width to 1.5 or 2
- Click OK

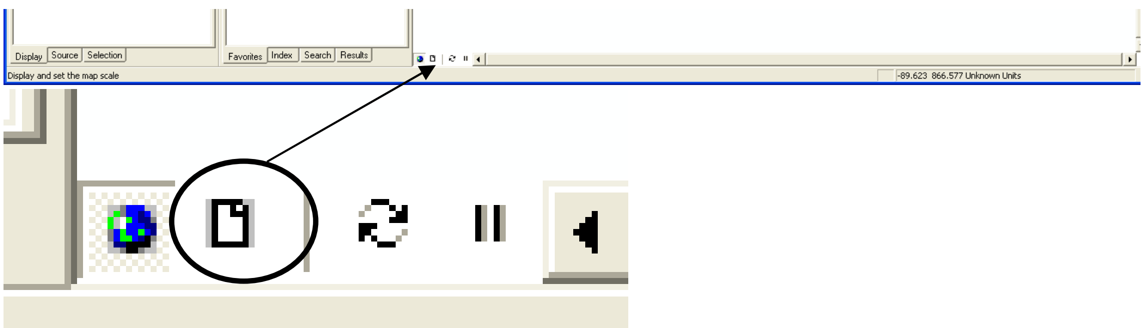
- You can double click on the map colors of the classification to choose colors of your liking to create a good map. Remember, through research and analysis, it was shown that classes 5 and 8 (veg class 1 and 4) were similar and thus were the same class (they should be the same color). Also, class 10 and 11 (veg class 6 and 7) were also very similar, but still distinct. Their colors should be very close, but not the same. Also, class 0 (undefined) and 1 (shaded) should be the same color~black.

Adding other map properties



- Click on the Zoom tool located in the menu bars
- Zoom in the border as close as possible without cutting out the entire color map
- Click on Layout View located at the bottom of the ArcMap Interface





- This will bring the image into map view
- In the ArcMap main menu bar, select Insert; here there a number of things you can add to your map to make it nice for presentation
    - North arrow
        - Choose the style you like and click OK
        - Place it somewhere on the map where it will be visible
    - Scale bar
        - Choose the style you like and click OK
        - Place it somewhere on the map where it is visible
    - Title
        - Enter a title for your map
- You may add other things if you like
- When you are done perfecting your map, go to the ArcMap main menu and select File → Export Map
- The Export Map dialogue opens

- Choose a location (your hard drive or USB) and a filename
- You can save it as a TIFF or JPEG
- Click save
- You will have a map that you can print out and turn in at a later date.

Vita

Rebecca Escamilla was born and raised in El Paso. She earned her Bachelor of Science (*Cum Laude*) degree in Biological Sciences from the University of Texas El Paso (UTEP) in 2002. In 2005, she joined the Biology doctoral program at UTEP.

Rebecca has been the recipient of numerous honors and awards including the Dodson Fellowship, the National Science Foundation GK-12 Fellowship, and the Alliance of Graduate Education and the Professoriate (AGEP) scholarship. She was also the recipient of the GeoEye Foundation Imagery grant and the T & E, Inc. Conservation Biology Research Grant. In 2008, she was one of four women selected by the Dean of the College of Science to represent UTEP at the National Conference for College Women Student Leaders in Washington, D.C.

While pursuing her degree, Rebecca worked as a research assistant for the Systems Ecology Lab, and as an Assistant Instructor for the Department of Biological Sciences. As a National Science Foundation GK-12 Fellow, she had the distinct privilege of working in both 7^{th} and 8^{th} grade science classrooms alongside some of the best science teachers at Wiggs Middle School. For the summer 2011 she was hired as a National Science Foundation GK-12 Summer Institute Project Leader for UTEP.

Rebecca has presented her research at numerous conference meetings including the 2011 First Annual UTEP Doctoral Research Expo, the 2011 Ecological Society of America Conference, and the 2011 Sustainability on the Border Conference hosted by the UTEP. She has also presented at numerous SACNAS (Society for the Advancement of Chicanos and Native Americans in Science) Conferences, and had the privilege of co-presenting at the National Science Foundation GK-12 National Conference in Washington, DC.

Rebecca's dissertation entitled, "An Assessment of Land Cover Change at the Indio Mountains Research Station," was supervised by Dr. Craig Tweedie.

Rebecca plans to continue in academia and acquire a post doctoral opportunity while continuing her research at the Indio Mountains Research Station by implementing long term monitoring programs that can be used for educational, as well as scientific purposes. Rebecca plans to teach at the community

college or university level, which would help her reach her lifelong goal of becoming a scientist, teacher, and mentor to inspire future generations into the science field.

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This thesis/dissertation was typed by Rebecca Anne Escamilla.