BASELINE STUDIES OF INVASIVE AFRICAN BUFFELGRASS (*CENCHRUS CILIARIS*) IN BIG BEND NATIONAL PARK, TEXAS

THESIS

Presented to the Graduate Council of
Texas State University-San Marcos
in Partial Fulfillment
of the Requirements

for the Degree

Master of SCIENCE

by

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San Marcos, Texas
May 2008

DEDICATION

This thesis is dedicated to all of my family, whose unconditional love and support and continued encouragement allowed me to find my way. Words cannot express how much I love and appreciate each and every one of you.

ACKNOWLEDGMENTS

I would like to thank my major advisor, Dr. David Lemke, and my committee members, Dr. Paula Williamson, Dr. Floyd Weckerly, and Dr. Joe Sirotnak, for their unending patience in allowing me to figure things out on my own, and for their comments and expertise along the way. I am forever grateful. I thank the National Park Service for providing the seed money for this project, and the staff at the Science and Resource Management Center and Park Headquarters at Big Bend National Park for their invaluable assistance. I thank the staff in the Biology Office at Texas State University-San Marcos for all of their administrative support, and their friendly willingness to help.

I thank Catherine Crumpton and Fern Daniels, my roommates at Big Bend National Park, for their continued encouragement and support in the field. Catherine taught me desert survival skills, important in the remote backcountry of Big Bend. I thank Minnette Marr for being always willing to lend a hand and advice, and Andrea Wakefield who helped me in the field, even though we got rained out. I thank Amber Harvey for helping to edit the final thesis.

I would especially like to thank Michele Massie and Amylia Williams for their help in pulling hundreds of soil samples and validating the model transects. Those were some of the best trips to the park I made. Michele, I could not have done it without you. Amylia, you are truly an angel and your inspiration will stay with me the rest of my life.

This manuscript was submitted on October 22, 2007.

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ABSTRACT

BASELINE STUDIES OF INVASIVE AFRICAN BUFFELGRASS (*CENCHRUS CILIARIS*) IN BIG BEND NATIONAL PARK, TEXAS

by

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May 2008

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Buffelgrass is a highly invasive weed that is becoming a management concern in Big Bend National Park, which protects over 324,000 hectares of Chihuahuan Desert habitat. The potential problems with this pest include displacement of native species, reduction in species diversity; increased fire hazard, and alteration of ecosystem functions. Baseline studies were conducted to learn about the species in the park, including where it occurs, what habitat it prefers to establish in, and how it may impact other species once established. In the 2001 and 2002 field seasons, 2485 buffelgrass locations were mapped in the southeastern part of the park. Vegetation transects were established in four monitoring units to compare characteristics of buffelgrass and adjacent non-buffelgrass plots. The amount of bare ground in buffelgrass plots is significantly lower than in non-buffelgrass plots ($p < 0.001$). Buffelgrass fills in the typically open spaces between desert plants, creating fuel for fire. Diversity indices,

although not statistically significant, indicate the species is slowly impacting biodiversity. Soil samples taken from the monitoring units show that most of the buffelgrass seeds appear in the litter of buffelgrass plots ($p < 0.001$), with few seeds in the top 2 cm of soil, and no seeds in the non-buffelgrass plots. Seed viability using Tetrazolium staining techniques indicate higher viability in one-year old seeds (83 percent) than 3-month old seeds (64 percent). The vast area and often rugged nature of Big Bend National Park make field mapping of all buffelgrass-infested areas both cost and time prohibitive. A predictive habitat map showing areas where buffelgrass is most likely to occur in the park could reduce the time and effort required to locate infestations, and could aid in guiding management decisions and in prioritizing control efforts. A baseline predictive model was built using geographic information systems (GIS), nine environmental data layers, and characteristics of the 7400 buffelgrass points mapped between 1998 and 2005. The model rates the suitability of the habitat on a scale from 1 to 5, with 1 indicating where buffelgrass is most likely to occur and 5 indicating where it is least likely to occur. The original model predicted 57.61 percent of the known buffelgrass points in value 1, and an additional 38.54 percent in value 2, with 96.15 percent of the 7400 known locations occurring in the two highest values. The original model was then validated in the field, and the results were used to improve the predictability of the model. The improved model predicted 80.07 percent of the known buffelgrass points in value 1, and an addition 16.8 percent in value 2, with 96.87 percent of the 7400 known locations occurring in the two highest values.

CHAPTER I

INTRODUCTION

Exotic Species

Over the past several decades, the introduction of non-native or exotic species has intensified with the global movement of humans, including increased international trade and travel (Beale and Managhan 2004; Brock et al. 1997; Lonsdale 1999; Pysek et al. 1995; Vitousek et al. 1997). As a result, exotic species, specifically those that have become naturalized and invasive in new areas, have been adversely impacting the ecology of native species and local habitats worldwide at an increasing rate (Gordon 1998; Hobbs and Humphries 1995; Westman 1990).

While some habitats are more easily invaded than others, there are few areas in the world that are completely invulnerable to invasion, including natural, pristine, seemingly remote environments (Kuhn et al. 2004; Lake and Leishman 2004). Increased notice and concern by the scientific community has stimulated interest in the study of exotic organisms and in studying potential methods to aid in eliminating or at least mitigating some of their harmful effects (Mack et al. 2000; Soulé 1990).

Invasive organisms cause economic losses measured in billions of dollars each year (Brock et al. 1997; Pysek et al. 1995). A 1993 government study from the Office of Technology Assessment reported damages totaling about $97 billion from 79 exotic species during the period from 1906 to 1991 in the United States alone. The most recent estimates put the cost of environmental damage and other losses from invading species at about $120 billion each year just in the United States (Pimentel et al. 2005).

In addition to economic losses, the invasion of natural communities by exotic organisms poses serious threats to the preservation of biodiversity, with the potential to profoundly alter the structure and functioning of ecosystems (Cronk and Fuller 1995; Dukes and Mooney 2004; Gordon 1998). Plant invasions can be especially noxious, as "weedy" plant species tend to spread easily when introduced to an area outside of their normal range, especially in disturbed habitats, having no natural enemies such as insects or diseases in the new area (Beerling 1995; Brock et al. 1997; Lake and Leishman 2004; Luken and Thieret 1997). Once established, they may out-compete and replace native plant species, reducing local biodiversity and disrupting local ecological processes (Cronk and Fuller 1995; D'Antonio and Vitousek 1992).

Invasive grasses, in particular, often have the potential to alter regional and even global aspects of ecosystem function (D'Antonio and Vitousek 1992; Hughes et al. 1991; Mack et al. 2001; Williams and Baruch 2000). Grasses are easily and actively transported by humans, so invasions are common. Exotic grasses can compete effectively with native species in a wide range of ecosystems, and where they become dominant, they can alter ecosystem processes ranging from nutrient cycling to regional microclimate. Many grass species tolerate or even enhance fire, and many often respond to fire with rapid, increased growth (D'Antonio and Vitousek 1992). The spread of noxious invasives, including grasses, into natural and pristine environments, is especially alarming (Kuhn et al. 2004; Lake and Leishman 2004).

The potential for invasive exotics to impact rare, endangered or threatened local species, or local sensitive habitats, has prompted action by numerous federal, state, and local agencies. Organizations such as the United States Fish and Wildlife Service, the National Wildlife Refuge Association, the Nature Conservancy, and the United States Geological Survey have implemented or participate in programs that map invasive species using global positioning systems (GPS). Many of these agencies use geographic information systems (GIS) to assess the potential harm of invasive species by making use of mapped species data overlaid against different environmental variables to look for spatial patterns. A predictive habitat map showing areas where invasives are most likely to occur could reduce the time and effort required to locate infestations, and could aid in guiding management decisions and in prioritizing control efforts.

Although control efforts aimed at exotic species have been underway for decades, the use of GPS and GIS in managing invasive organisms, including plants, is more recent (Bushing et al. 1997). This combined technology may be helpful in studying the spatial relationships between exotic plant populations and their new habitat and for uncovering correlations between invasive species and different environmental variables, such as climate, elevation, vegetation type, or soils. Such technology may be especially useful in uncovering patterns of invasion not easily otherwise seen over large geographic areas, such as elements of the National Park system (Bushing et al. 1997; Salem 2003).

Within the last decade, there has been an increasing effort to map invasive species in Big Bend National Park as the detrimental effects of invasive exotics become better known. Handheld GPS receivers taken into the field have been used to map several noxious species in the park to date (Sirotnak and Louie 1998).

Efforts to protect threatened or rare species are ongoing in the park, as are efforts to eradicate noxious, invasive species. These efforts are difficult tasks over such a large area, but the use of geographic information systems, along with GPS may be one way to help provide the park with some necessary tools to better address these important ecological issues (Bushing et al. 1997).

Buffelgrass

Forage production is a major land use in more arid regions of the world, with drought-tolerant species being the most successful forage due to the usually low moisture availability in these areas (Wiedenfeld et al. 1985). One such species that has gained popularity in the last 50 years is buffelgrass (*Cenchrus ciliaris* L.; syn. *Pennisetum ciliare* (L.) Link), now widely distributed in the arid and semi-arid parts of the world (Correll and Johnston 1979; Gould 1975; Walker and Weston 1990). Buffelgrass has had a tremendous positive impact on the livestock industry in many areas, allowing dramatic increases in carrying capacities on arid and semi-arid ranges and pastures (Hanselka 1988).

Buffelgrass is a drought-tolerant, subtropical, perennial bunchgrass, widely distributed in Africa (Bogdan 1977), India (Gould 1978), Indonesia (Paull and Lee 1978), and other warm, dry regions of the Old World (Jessop 1985; Snyder et al. 1955). Researchers at Texas A&M University believe buffelgrass originated in South Africa based on the tremendous number of different strains growing in the Transvaal and Cape Provinces of that country (Bashaw 1985). Also, the number of different strains diminishes sharply north of Kenya, and the wide range of plant types is found only in South Africa.

Buffelgrass is characterized by having branches rising from a knotty base and by its purple, bristly seed heads (Figure 1). It is a hardy, vigorous upright grass, 50 to 100 cm tall, with an extensive root system. The inflorescense is a dense, compact panicle, with fascicles containing 2 to 4 spikelets borne on minute peduncles (Gould 1975).

The bristles surrounding the fascicles are fused to the base, distinguishing it from members of the genus *Pennisetum*, where the bristles are described as being free to the base (DeLisle 1963; Hussey 1985; Sohns 1955). Older plants branch profusely and densely at the nodes, attaining a width of 1 m in some cases. These nodal branches produce new leaves and flower spikes very quickly after light rains, making buffelgrass an extremely prolific seed producer.

Figure 1. Typical morphology of buffelgrass. On the left, a buffelgrass patch that has not received moisture for a while. The color can best be described as butterscotch and is distinctive in appearance, making buffelgrass readily identifiable. On the right, a close up of a buffelgrass plant that has greened up considerably, producing its purplish, bristly flower heads, another readily identifiable buffelgrass characteristic.

With its high reproductive potential, palatability to livestock, nutritive value, seed availability, and ease of establishment, buffelgrass has gained wide popularity as a forage species in South Texas (Chippindall 1955; Humphreys 1967; Holt 1985; Rao et al. 1996). It has demonstrated an ability to become established, persist, and reproduce under adverse climatic conditions and is especially tolerant of the periodic droughts characteristic of the South Texas region (Hanselka 1985). Thus, buffelgrass is the most widely planted grass in this area (Mutz and Drawe 1983). The distribution of buffelgrass in Texas is presented in Figure 2. This map is most likely based on herbarium specimens and represents a minimum distribution.

Buffelgrass was introduced into Texas as early as 1917, but it was planted too far north on heavy clay soils and was not successful (Hanselka 1988; Holt 1985). Buffelgrass establishment is limited by its lack of cold tolerance and low survival on poorly drained soils (Holt 1985; Hussey and Bashaw 1996; Wiedenfeld et al. 1985). In the 1940s, the species was successfully introduced in the San Antonio area, and nursery plots of buffelgrass showed sufficient promise for it to be informally released by the U.S. Department of Agriculture, Soil Conservation Service in 1949. Today, buffelgrass is reported to occupy more than 90 percent of the area seeded to grass in Texas south of San Antonio (Holt and Bashaw 1976).

Many buffelgrass cultivars exist, each selected for certain characteristics and each with advantages and disadvantages, depending on environmental conditions in the area of use. About 99 percent of the buffelgrass acreage in South Texas is of the common buffelgrass type, T-4464, collected in the Turkana desert in northern Kenya and introduced into the U.S. in 1946 (Holt 1985). The T-4464 cultivar is known as "American buffelgrass" in other parts of the world and is among the most widely planted buffelgrass varieties.

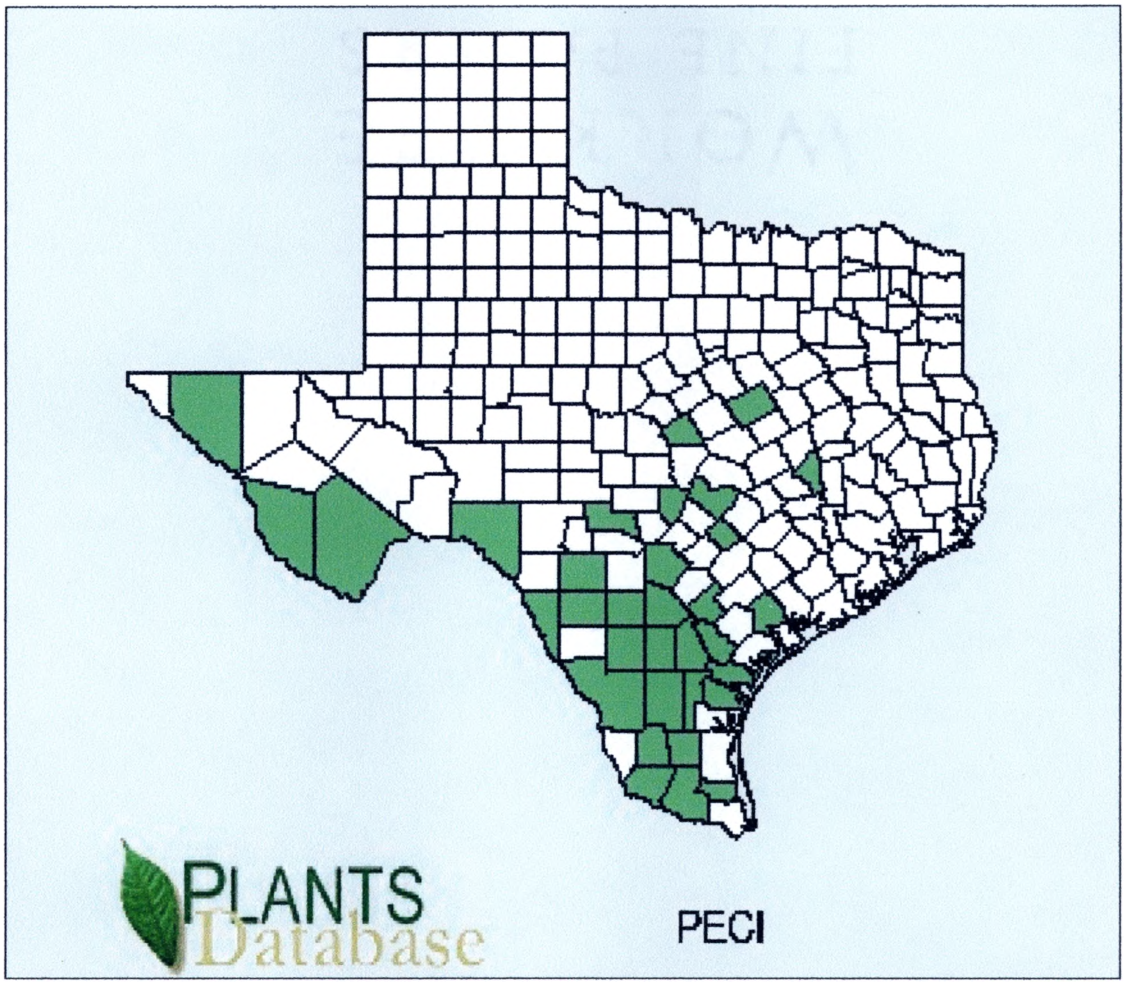

Figure 2. Distribution of buffelgrass in Texas. From the USDA, Natural Resources Conservation Service, Plants Database. URL: <http://plants.usda.gov>.

In the years since it was first planted in Texas, buffelgrass has increased to become the most important forage grass in South Texas. It has been referred to as the wonder grass of South Texas and is often credited with saving the South Texas range cattle industry (Hanselka 1988). Due to its lack of cold tolerance, buffelgrass is generally restricted in Texas to the area south of 28° N latitude and to elevations less than 2000 m (Hanselka 1988; Hussey and Bashaw 1996). Even within this range, periodic low temperatures cause freeze damage. A hard freeze in 1983-1984 destroyed large acreages of the grass in South Texas.

The southern range of buffelgrass extends well into northern Mexico (Hanselka 1988), where it is also widely planted. Around 1.2 million hectares in Mexico are sown to buffelgrass, with more than one-half million hectares in the state of Sonora alone. Buffelgrass is also one of the major forage grasses planted in the arid regions of India (Rao et al. 1996), Pakistan (Noor 1991), Australia (Humphreys 1967; Paull and Lee 1978), New Zealand (Humphreys 1967), and Argentina (Blanco et al. 2005). As a result, it is now naturalized in parts of Australia, North America, South America, and in many other countries. The soil and climatic conditions of these areas are similar to the conditions in its native range, facilitating the success of buffelgrass (Bashaw 1985).

Prior to 1950, the lack of any variability within the numerous morphological buffelgrass types was recognized (Holt 1985). Subsequent research confirmed that reproduction in buffelgrass is by obligate apomixis, a form of asexual reproduction (Fisher et al. 1954; Snyder et al. 1955). Apomictic plants mimic the normal sexual method of pollination and fertilization that takes place in sexual plants, but the male and female gametes do not unite to form an embryo (Bashaw 1985). Instead, the embryo develops from an unreduced somatic cell in the ovule and receives no genetic material from the pollinating plant.

Apomixis in buffelgrass has both negative and positive aspects. On the positive side, an apomictic plant will always breed true, with uniform offspring. However, the reduced genetic variability gives pests and pathogens the ability to attack all plants, since all are equally susceptible. In addition, since there is no variation among progeny, improvement by selection is not possible, and this method of reproduction does not permit hybridization to produce new gene combinations (Holt 1985).

Most of the early cultivars released in the U.S. and Australia resulted from selections among ecotypes rather than among progeny of desired crosses (Hussey 1985). In 1958, a unique buffelgrass plant producing variable progeny was identified and it was determined the plant was reproducing sexually (Bashaw 1962). This discovery led to a successful breeding program in Texas, making hybridization and the development of new buffelgrass types possible (Bashaw 1985; Hussey 1985). Using the sexual plant as the seed parent in controlled hybridizations, it was possible to produce sexual and apomictic F_1 plants, which could then be evaluated as potential cultivars (Taliaferro and Bashaw 1966). The first cultivar released from this program was the "Higgins" cultivar (Bashaw 1968), the first ever warm-season grass cultivar not derived from ecotype selection.

Suitable soil appears to be a very important factor in buffelgrass establishment on rangelands (Williamson and Pinkerton 1985). Buffelgrass is known to grow most readily on sandy loam soils. This has been attributed to the soil's inherent fertility, moderate permeability, and excellent plant/soil moisture relations. Slightly alkaline sandy loam soils appear to be the best suited for establishment (Williamson and Pinkerton 1985). Areas with high water tables, high salinities, deep sand, tight clay, or poor surface drainage, however, will severely inhibit buffelgrass growth (Anderson 1970; Hanselka 1988; Williamson and Pinkerton 1985). As a result, the species does not do well on the Texas coastal plain. Buffelgrass produces poorly on sands due to the low water-holding capacity and low fertility of these soils. Christie (1975) found that phosphorus appears to limit the successful establishment of buffelgrass on sandy sites.

Buffelgrass producers have noted that when nitrogen levels are supplemented, production increases, indicating that nitrogen, along with water availability, appears to be a limiting factor to buffelgrass growth (Wiedenfeld et al. 1985). Increased nitrogen availability appears to enhance the efficient utilization of any rainfall received. It is interesting to note that available nitrogen, which is typically low in semidesert soils, is concentrated under creosotebush (*Larrea tridentata*) canopies (Cox et al. 1984). This may help to explain the common association of buffelgrass and creosotebush in desert areas.

Buffelgrass has been shown to grow exceptionally well where temperatures remain consistently above 0° C and where rainfall is about 63 cm a year or less. In its native range in South Africa, rainfall is 13 cm to 38 cm annually (White and Wolfe 1985).

The most significant problem for buffelgrass producers is the susceptibility of buffelgrass to winter freeze damage (Bashaw 1985; Hussey and Bashaw 1996). Some rhizomatous cultivars are able to escape the cold and survive at higher elevations, however, American buffelgrass (T-4464) does not have this characteristic.

Progress has been made by researchers attempting to extend the range of buffelgrass by improving its cold tolerance through selection for plants that produce vegetative buds deeper in the soil. Two new rhizome-producing hybrids, "Nueces" and "Llano," were introduced in 1977 and have extended the range of buffelgrass north by about 120 km (Bashaw 1980). These cultivars have met with limited success, due to low levels of seed production, especially in the "Llano" variety (Bashaw 1985; Hanselka 1988).

Research continues in an attempt to breed plants with improved adaptation to both cooler climates and poorly drained soils. This could not only increase the northern range of buffelgrass, but also improve its persistence within its present range (Bovey et al. 1980; Hanselka 1988). The cultivar “Frio” is a recent release (Hussey and Burson 2005) that reportedly combines traits for improved cold tolerance and improved seed production.

Unfortunately, buffelgrass escapes easily from cultivation and becomes naturalized, even at elevations beyond its supposed limit. Buffelgrass is starting to cause extensive problems not only in the Sonoran and Chihuahuan deserts due to its invasive qualities, such as the alteration of fire regimes (Burquez-Montijo et al. 2002), but also in other areas of the world where it has also been planted widely as a forage grass (Arriaga et al. 2004; Búrquez-Montijo et al. 2002; Daehler and Goergen 2005; Dixon et al. 2001; Franks 2002). The potential problems with this pest include not only increased fire hazard, but also displacement of native species, reduction in species diversity, and alteration of ecosystem functions.

The current distribution of buffelgrass in the Trans-Pecos region of Texas suggests that this species has migrated extensively along the roadways in the southern desert region and/or along the Rio Grande corridor since the mid-1970s (Powell 2000). First noticed in Big Bend National Park in the 1980s, buffelgrass infestations currently threaten several populations of federally listed plant species such as the endemic Chisos hedgehog cactus (*Echinocereus chisoensis* var. *chisoensis*).

Predictive Modeling

The study of the relationship between a species and its habitat has been central to ecology for over 100 years (Guisan and Zimerman 2000). Current trends in conservation and planning have placed increasing importance on the species-habitat relationship

(Austin 1987; Austin et al. 1996; Morrison et al. 1998; Nicholls 1989; Seoane et al. 2004). Knowledge of the accurate distribution of a species can be a valuable tool in decision-making for land management or conservation issues. Unfortunately, this information is unavailable, incomplete, or difficult to obtain for many species (Dale et al. 2000).

The creation of predictive habitat or species distribution models in ecology can be a viable alternative to making a complete census of a species, especially in remote or large geographical areas where a complete census would be unreasonably expensive and require large amounts of time and other limited resources. Such models can be potentially valuable tools for management planning, especially in unmapped or poorly mapped areas. The availability of good distribution maps can greatly increase the efficiency of resource management (Turner et al. 1995).

In general, predictive habitat models try to relate or correlate the occurrence of a species with a set of predictors or environmental variables, such as elevation, slope, geology, soil type, and precipitation. The model predicts where the species is likely to occur in an area by identifying habitat suitable for the species based on the modeler's input. All predictive habitat distribution models have as a goal the prediction of a species' occurrence in previously unmapped locations based on a set of predictor variables (Guisan et al. 2002). The major difference among models is the method used to build the model.

There are numerous well-developed algorithms available to build predictive habitat models, with many described in recent review articles (Anderson et al. 2003; Elith and Burgmann 2003; Guisan et al. 2002; Guisan and Zimmermann 2000; Rushton et al.

2004; Segurado and Araujo 2004; Vogiatzakis 2003). The choice of modeling technique should be determined by the goal of the study itself (Guisan and Zimmermann 2002). In other words, the model needs to be useful for its intended purpose. From the start of any modeling project, the types of spatial analysis methods available for use in building the model are limited by the type of data that is available.

Models have been built to predict the habitat or occurrence of such diverse organisms as butterflies and moths (Cowley et al. 2000; Fleishman et al. 2001), forest birds (Hashimoto et al. 2005; Lawler and Edwards 2002), dung beetles (Chefaoui et al. 2005), fish (Eastwood et al. 2003); mountain goats (Gross et al. 2002), Lyme disease-carrying ticks (Brownstein et al. 2003), and mushrooms (Yang 2004). Models are being used to predict the occurrence of endangered and rare plant species (Crumpton 2002; Powell et al. 2005) and general vegetation (Franklin 1995, 1998; Palo et al. 2005; Zaniewski et al. 2002). And finally, models are being built to predict the spread of invasive plants, both terrestrial (Cimino 2003; Dark 2004; Higgins et al. 2000; Hrazsky 2005; Peterson et al. 2003; Underwood et al. 2004) and aquatic (Buchan and Padilla 2000; Collingham et al. 2000; Wadsworth et al. 2000).

Recent advances in GIS, including advanced geoprocessing or spatial analysis capabilities, and the development of more powerful statistical techniques have facilitated a rapid increase in the use of predictive habitat distribution models in ecological studies (Austin 2002; Elston and Buckland 1993; Guisan and Zimmermann 2000; Muñoz and Felicisimo 2004). GIS has emerged as an important tool for monitoring biodiversity as it can manipulate many kinds of spatial and non-spatial attribute data (Salem 2003). The process of building a predictive habitat model typically uses a combination of GIS, statistical software and other programs developed specifically for habitat modeling, although the model can be built completely within a GIS, such as the ESRI ArcGIS Desktop 9.0 software package.

The increasing development and use of GIS technology has also improved the quality and quantity of available data, making different predictor or environmental data layers easier to obtain in general. GIS has the ability to produce cartographic representations of predicted species habitat, an important aspect of the modeling process (Guisan and Zimmermann 2000). In other words, the use of GIS, often in conjunction with GPS, can offer a complete modeling package, from data collection and preparation to model processing and graphic representation. This allows for predictive mapping by the user who may not have sufficient expertise with sophisticated mapping techniques, but is equipped with a GPS and GIS and who can, with a little effort, produce useful models to suit a particular need.

Study Objectives

The overall objective of this study was to develop a predictive habitat model for buffelgrass in Big Bend National Park. Buffelgrass was mapped using a GPS to build a database of known buffelgrass locations in the park. Vegetation transects were established to aid in characterizing the environment in which buffelgrass occurs. Soil samples were taken to characterize the buffelgrass seed bank, and viability tests were conducted on buffelgrass seeds to test their longevity. The predictive habitat model was then constructed using a GIS as a tool to aid management decision making concerning buffelgrass within the boundaries of Big Bend National Park.

CHAPTER II

MATERIALS AND METHODS

Site Description

Big Bend National Park, located in southern Brewster County in the Trans-Pecos region of west Texas (Figure 3), is situated wholly within the Chihuahuan Desert. The park is responsible for the ecological management of more than 324,000 hectares of Chihuahuan Desert habitat. This includes the eradication and control of invasive non-native plants. National parks are mandated by federal law (Executive Order 13112, February 3, 1999) to "prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause." All work was done under permits BIBE-2001-SCI-0066 and BIBE 2005-SCI-0011 issued by Big Bend National Park, Texas.

Five stations in the park monitor daily temperature and precipitation. The stations are located at the Basin, Castolon, Panther Junction, Persimmon Gap, and Rio Grande Village. In the Basin, precipitation is consistently higher and temperatures lower than in other areas of the park. Annual precipitation totals between 1986 and 2005 range from about 10 to 85 cm, while daily high temperature ranges from about 20 to 32° C. Precipitation is negligible from November through February and is generally highest in July and September. July and August are the warmest months typically, and December and January the coolest. Figures 4 and 5 show mean yearly precipitation and temperature data for 1986 to 2005. The source data are from John Forsythe, Physical Scientist at Big Bend National Park, Science and Resource Management Center.

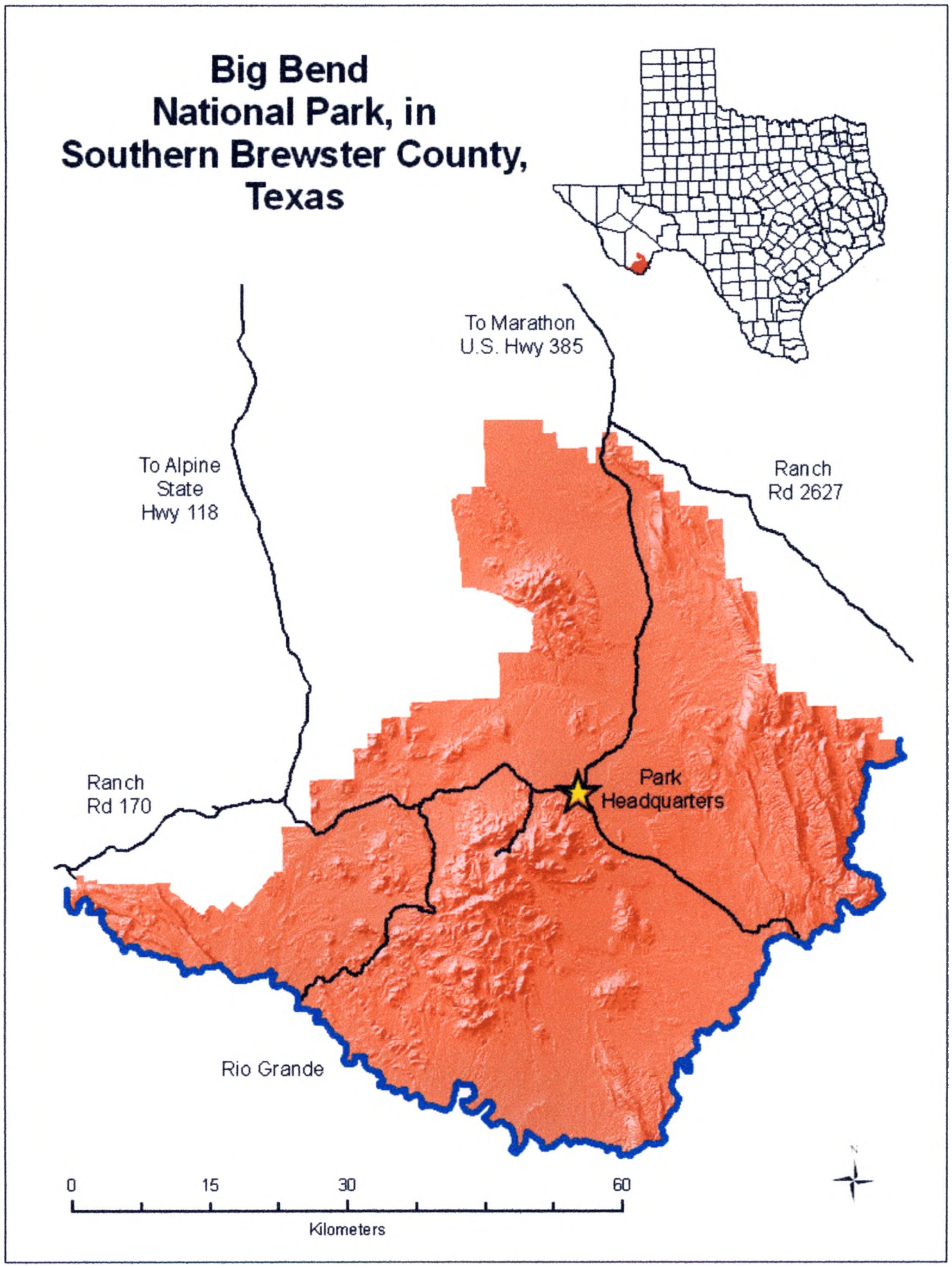

Figure 3. Location of Big Bend National Park, Brewster County, Texas. The map shows only the major roads in the park. The Rio Grande forms the southern boundary of the park.

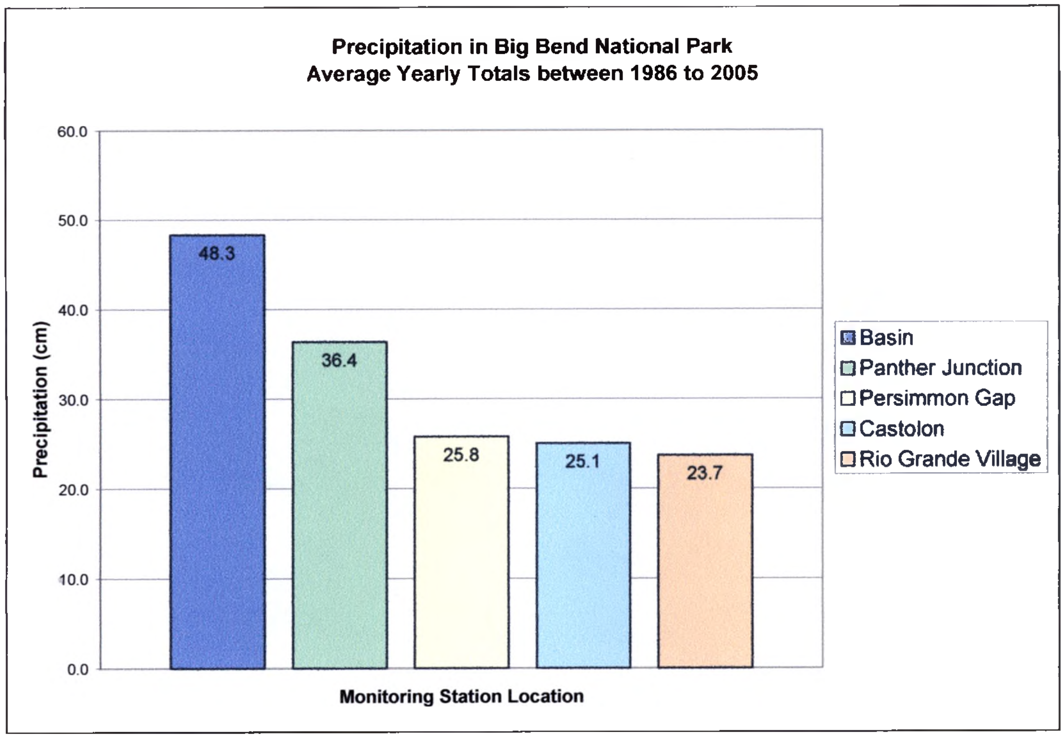

Figure 4. Precipitation in Big Bend National Park. Chart shows average yearly precipitation totals from the five monitoring stations in the park in the park for the years 1986 to 2005.

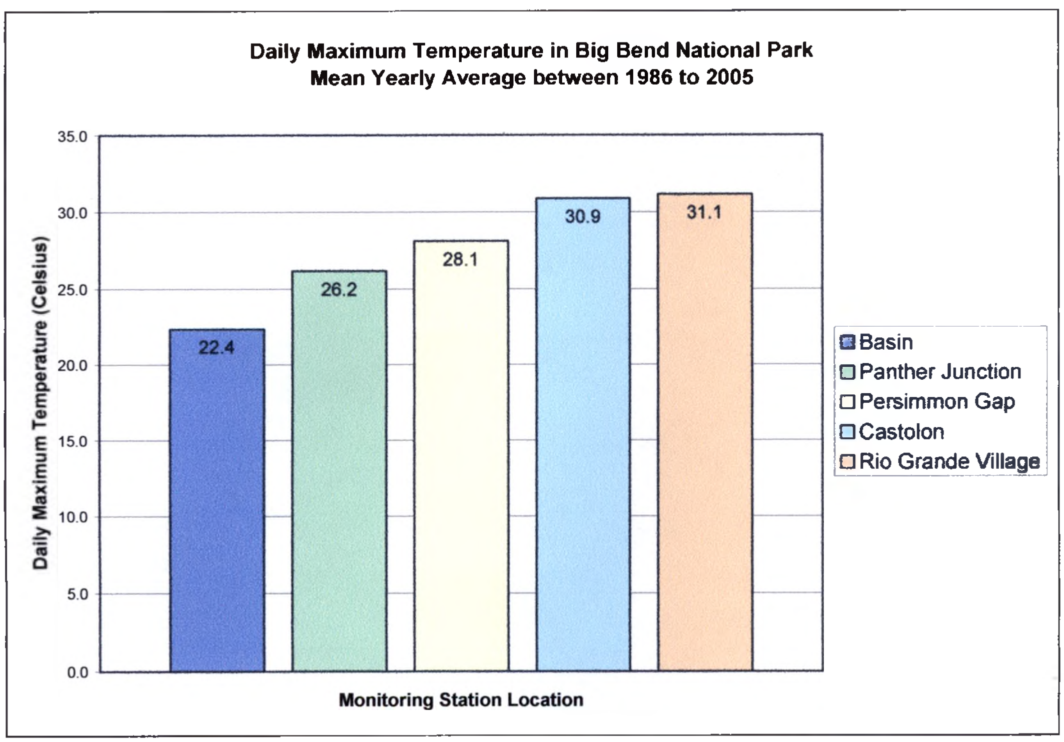

Figure 5. High temperature in Big Bend National Park. Chart shows mean yearly high temperature averages from the five monitoring stations in the park for the years 1986 to 2005.

Mapping

To map the distribution of buffelgrass in Big Bend National Park, a GPS unit (Trimble GeoExplorer 3C) was used to record the location of infestations. In the 2001 field season, major paved and backcountry roads in the southeast quarter of the park were driven slowly and traversed on foot and all roadside buffelgrass infestations were recorded with the GPS. Additional off-road infestations, and those occurring in the drainages that intersect the roads, or any other infestations that could be seen from the roads, were also recorded.

Mapping on the major roads included Park Route 12, from Panther Junction east to the Tornillo Creek bridge (a distance of 26 km). Buffelgrass was known to be well-established from the Tornillo Creek bridge to Rio Grande Village and down Boquillas Canyon Road, so these areas were not included in the 2001 mapping. These areas had both been mapped in 1998 as part of an exotic plant survey conducted by park personnel. In the 1998 survey, several exotic plants, including buffelgrass, were mapped along all the primary roads in the park (Sirotnak and Louie 1998).

The secondary roads included in the 2001 mapping were: Old Ore Road from its intersection with Route 12 north to its end at Dagger Flat Road (42 km), including Ernst Tinaja and Carlota Tinaja; Glenn Spring Road, from its beginning at Park Route 12 south to its end at River Road East (25 km); Black Gap Road from its start at Glenn Spring Road south to its end at River Road (14 km); and River Road from its east end at Route 12 to its west end at Ross Maxwell Scenic Drive (81 km). The secondary shorter side roads starting along River Road and ending at the Rio Grande that were mapped in 2001 included Gravel Pit, La Clocha, San Vicente, Solis, Rooney's Place, Solis, and Talley roads. Also mapped was Hot Springs Road from its start at Route 12 south to its end at the Rio Grande (3 km) and the Hot Springs visitor area.

Mapping in the 2002 field season included new growth of buffelgrasss plants located in the same areas that were mapped in 2001. The Basin was mapped for the first time, as a particularly heavy infestation was found in the Basin group campground area. Another new area included in the 2002 mapping was the large buffelgrass infestation on both sides of Park Route 12 at mile marker 18. Approximately 200 km of roadway, including anything seen away from the road, and several of the Basin trails, including the Window Trail and the trails to the South Rim were mapped in 2001 and 2002.

Differential data post-processing was performed with base-station files to improve the accuracy of all points recorded using GPS Pathfinder Office software (version 2.80; published by Trimble). The base station is located inside the park remaining stationary in a known location. The GPS receiver in the field uses timing signals from at least four satellites to establish a position, each with some error or delay depending on atmospheric conditions. The base station measures the timing errors, providing files that were used to correct positions taken in the field. All mapped points were then exported to GIS software (ArcGIS 9.0; published by ESRI). The results of the 2001 and 2002 mapping effort can be seen in Figure 6.

Vegetation Transects

Monitoring plots were established in the Fall 2002 field season. The plots were established in four different areas, each with a different soil type (Figure 7). The soil types selected for the monitoring units were based on the buffelgrass sites mapped in the Fall 2001 field season. The buffelgrass mapped in 2001 occurred most frequently on the following four soil types: Chamberino (CHC), Tornillo (TOA), Pantera (PNA), and Upton-Nickel (UNC).

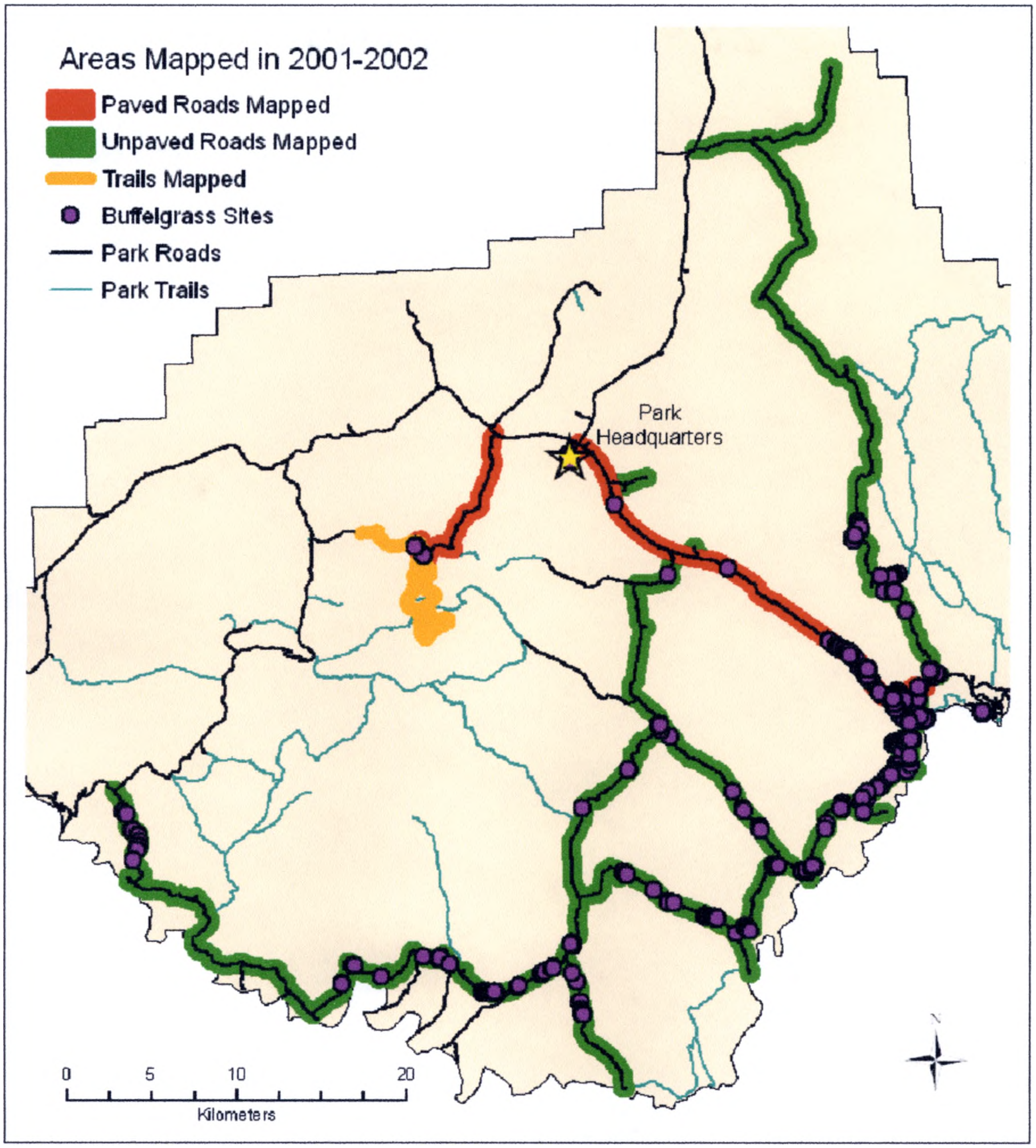

Figure 6. Extent of mapping effort in 2001 and 2002. The map shows all areas that were mapped in 2001 and 2002, including paved roads, unpaved roads, and trails.

Monitoring Unit 1 was located along Park Route 12, about 23.7 km (mile marker 14.7) from Panther Junction towards Rio Grande Village (Figure 8). The soil type is Chamberino, described as a deep, very gravelly, undulating, calcareous soil. It is found in the park mostly between the Chisos Mountains and the Rio Grande (Cochran and Rives 1985).

Monitoring Unit 2 was located along Park Route 12, about 26 km from Panther Junction, just before the intersection with River Road East (Figure 9). The soil type is Tornillo, described as an occasionally flooded, nearly level soil, found on the broad, alluvial flats in valley floors (Cochran and Rives 1985).

Monitoring Unit 3 was located along River Road East, approximately 3.2 km south of Route 12, just past Gravel Pit Road (Figure 10). The soil type is Pantera, described as deep, very gravelly sandy loam, found on broad, flat drainageways or arroyos (Cochran and Rives 1985).

Monitoring Unit 4 was located along Old Ore Road, approximately 0.5 km south of Route 12 (Figure 11). The soil type is Upton-Nickel, described as deep, shallow, and very shallow soil, gravelly to very gravelly and undulating. It is found on broad, dissected piedmont slopes (Cochran and Rives 1985).

In each of the four monitoring areas, both vegetation and seed bank data were collected and used to characterize the vegetative environment and propagule density of buffelgrass infestations. A combination of line and belt transects was used to measure plant density and cover by species in the four monitoring units (Bonham 1989; Brower et al. 1997; Cox 1996).

Within each unit, three discrete buffelgrass plots and three adjacent non-buffelgrass plots were selected (Figure 12). Within each plot, two parallel line transects were placed 2 m apart, creating a 2-m wide belt between the two lines. The length of each transect was determined by the size of the buffelgrass stand. The endpoints of each transect coincided as closely as possible to the expanse of buffelgrass from one end to the other end. The endpoints were marked with steel reinforcing rod and flags, and a meter tape was strung between the endpoints for taking measurements.

The adjacent non-buffelgrass plot was located approximately 2 m away from each buffelgrass plot and in each case the length of the line transects in the non-buffelgrass plot equaled those of the adjacent buffelgrass plot. In each of the plots, cover was measured along the transect lines (line-intercept) and density was measured in the belts (total number of each species of plant). These measurements were used to characterize the vegetation that supports the growth of buffelgrass and the effects buffelgrass may have on its environment.

Measurements of length were recorded to the nearest centimeter. After the raw data were summarized (Appendix 1) the following parameters were determined: plant cover, relative cover, frequency (sometimes called dominance), relative frequency, density, relative density, and importance value.

Bare ground along the transect lines was also recorded, and these data analyzed separately. An ANOVA was conducted to see if there was a statistical difference in the mean amount of bare ground between buffelgrass and non-buffelgrass plots in the four monitoring units.

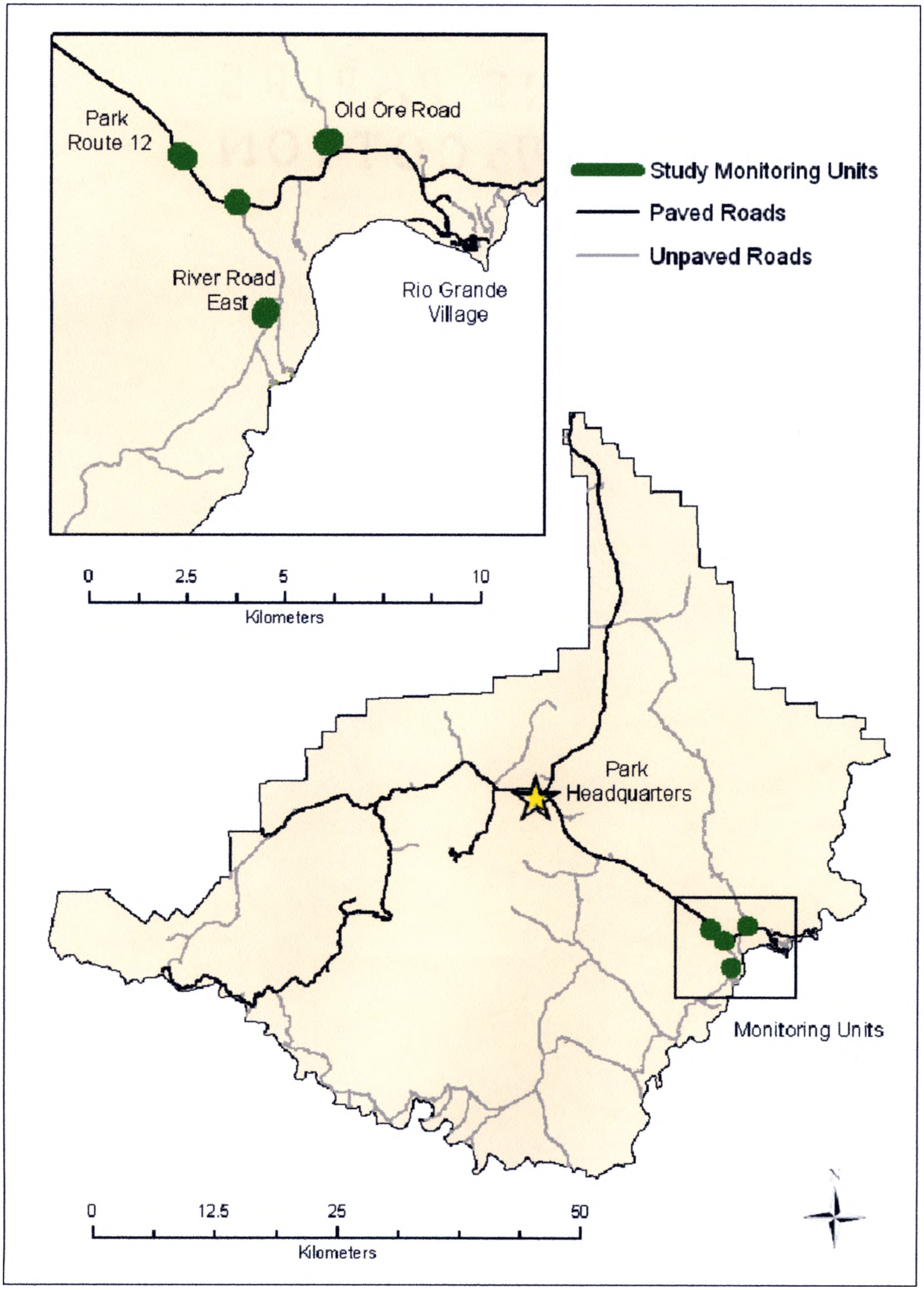

Figure 7. Location of the four monitoring units in Big Bend National Park. All of the monitoring units were located in the southeast area of the park.

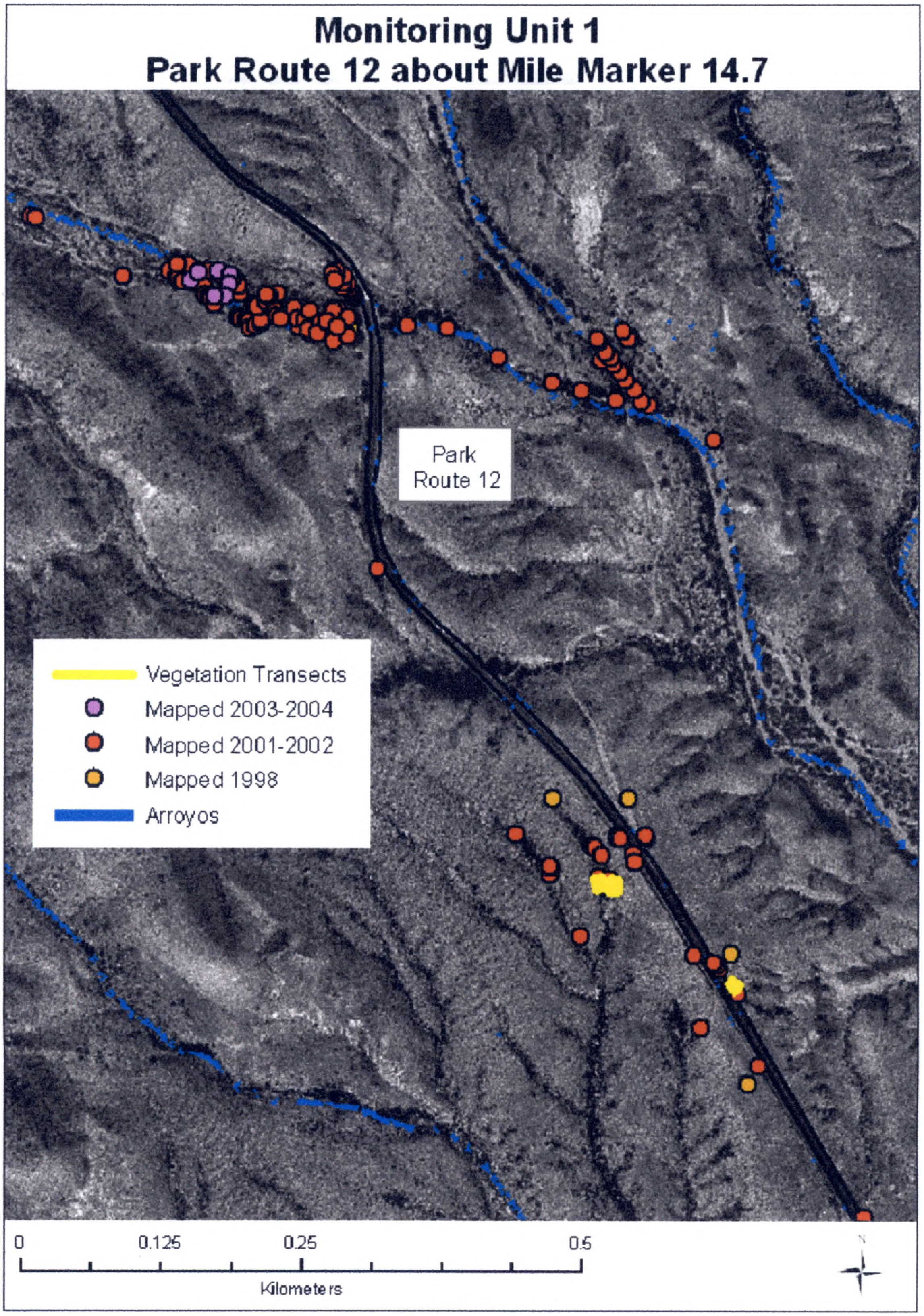

Figure 8. Monitoring Unit 1 located along Park Route 12 with transects on Chamberino soil. Located near mile marker 14.7 east from Panther Junction to Rio Grande Village.

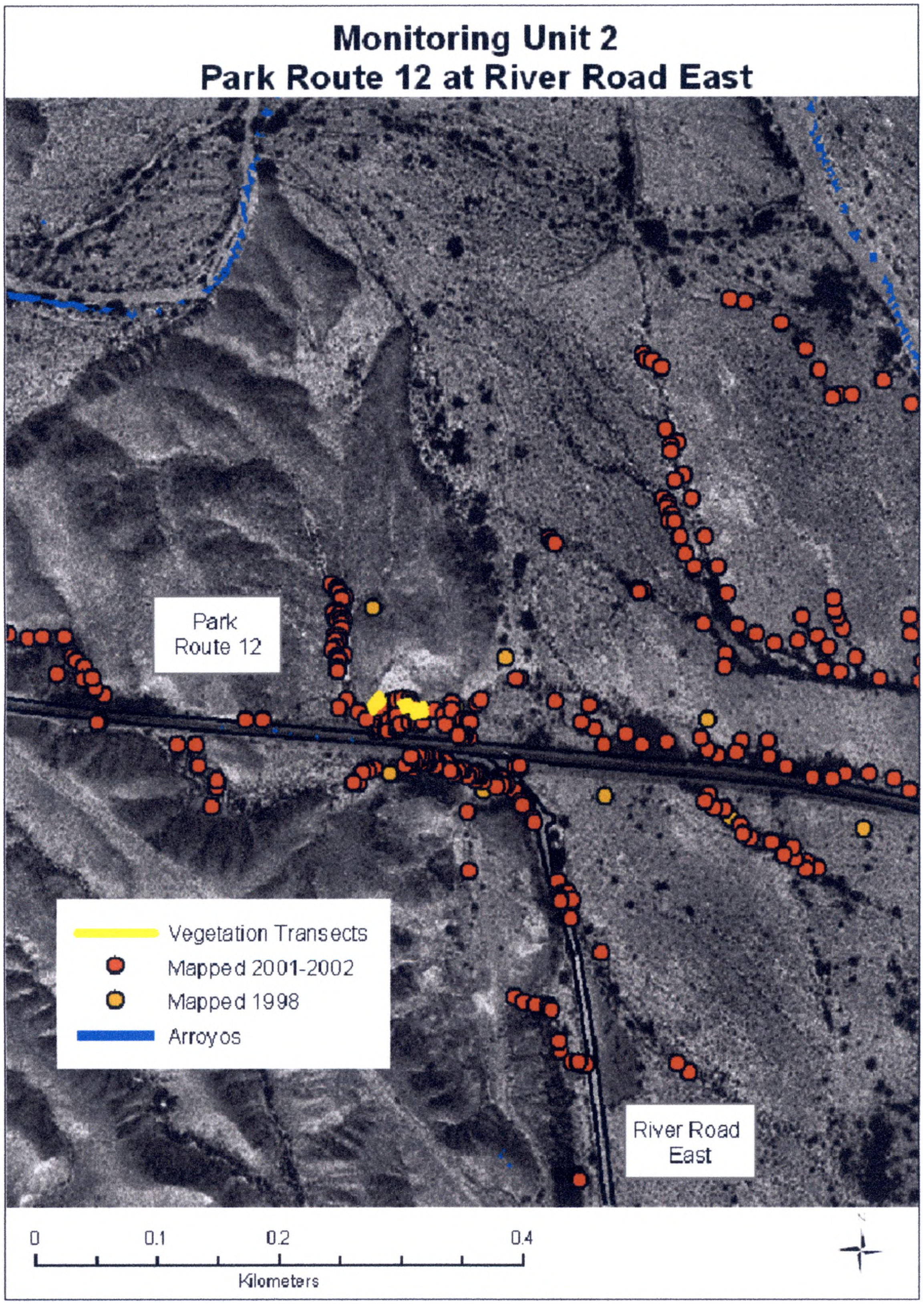

Figure 9. Monitoring Unit 2 located along Park Route 12 with transects on Tornillo soil. Located near mile marker 16, just before River Road East on the way to Rio Grande Village east from Panther Junction.

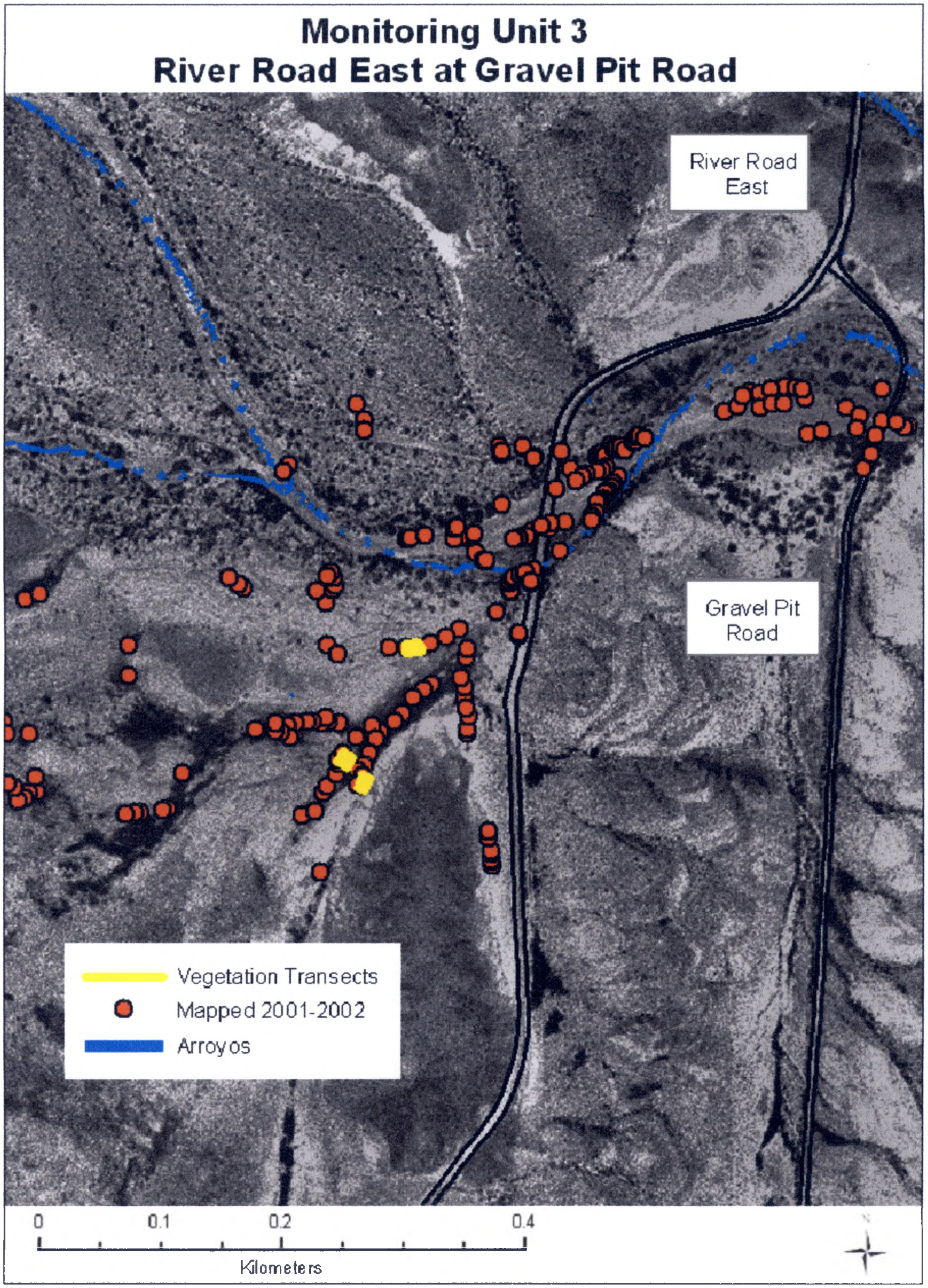

Figure 10. Monitoring Unit 3 located along River Road East with transects on Pantera soil. Located on River Road East, just south of Gravel Pit Road.

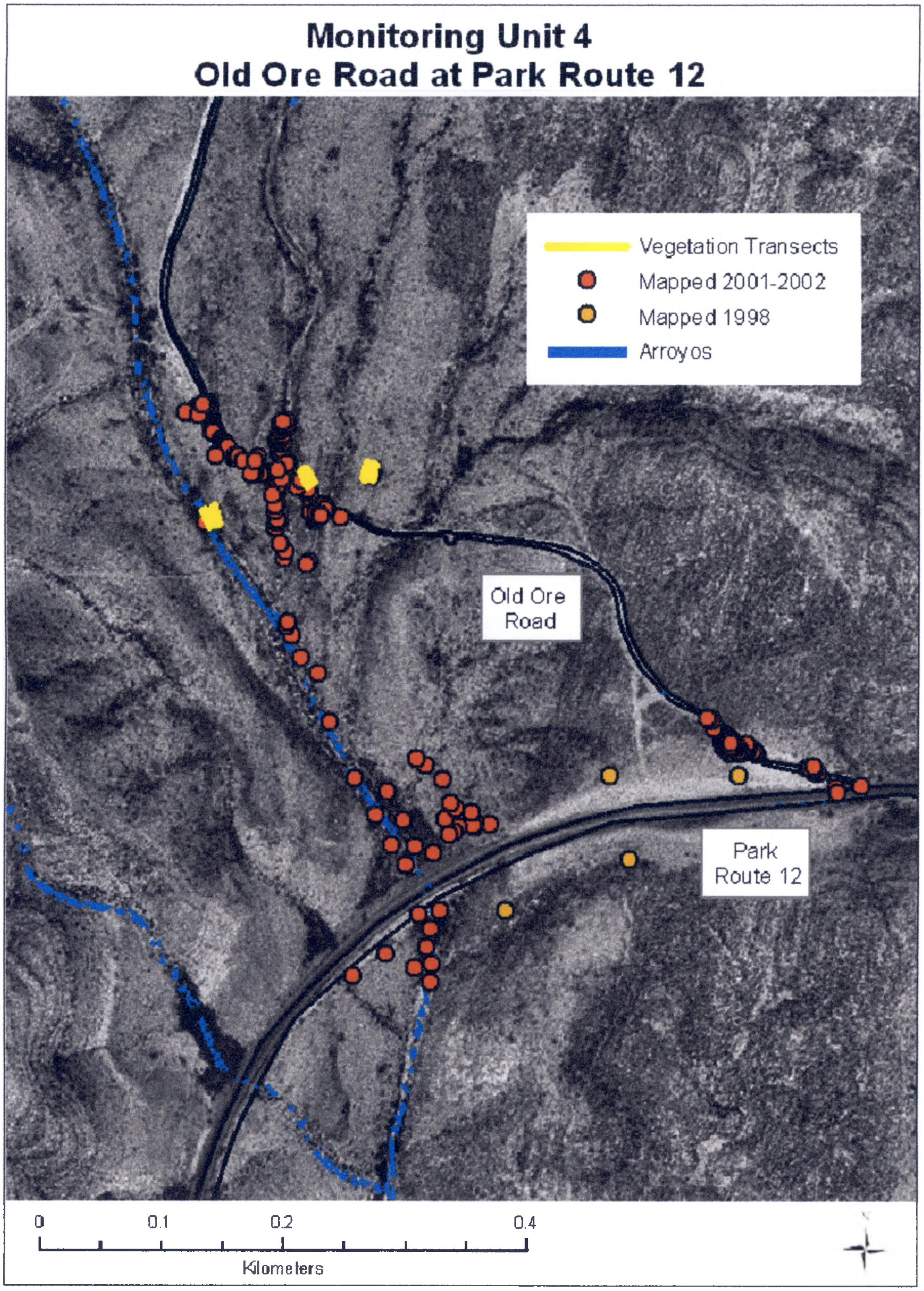

Figure 11. Monitoring Unit 4 located along Old Ore Road with transects on Upton-Nickel soil. Located about 0.5 km from Park Route 12 north on Old Ore Road.

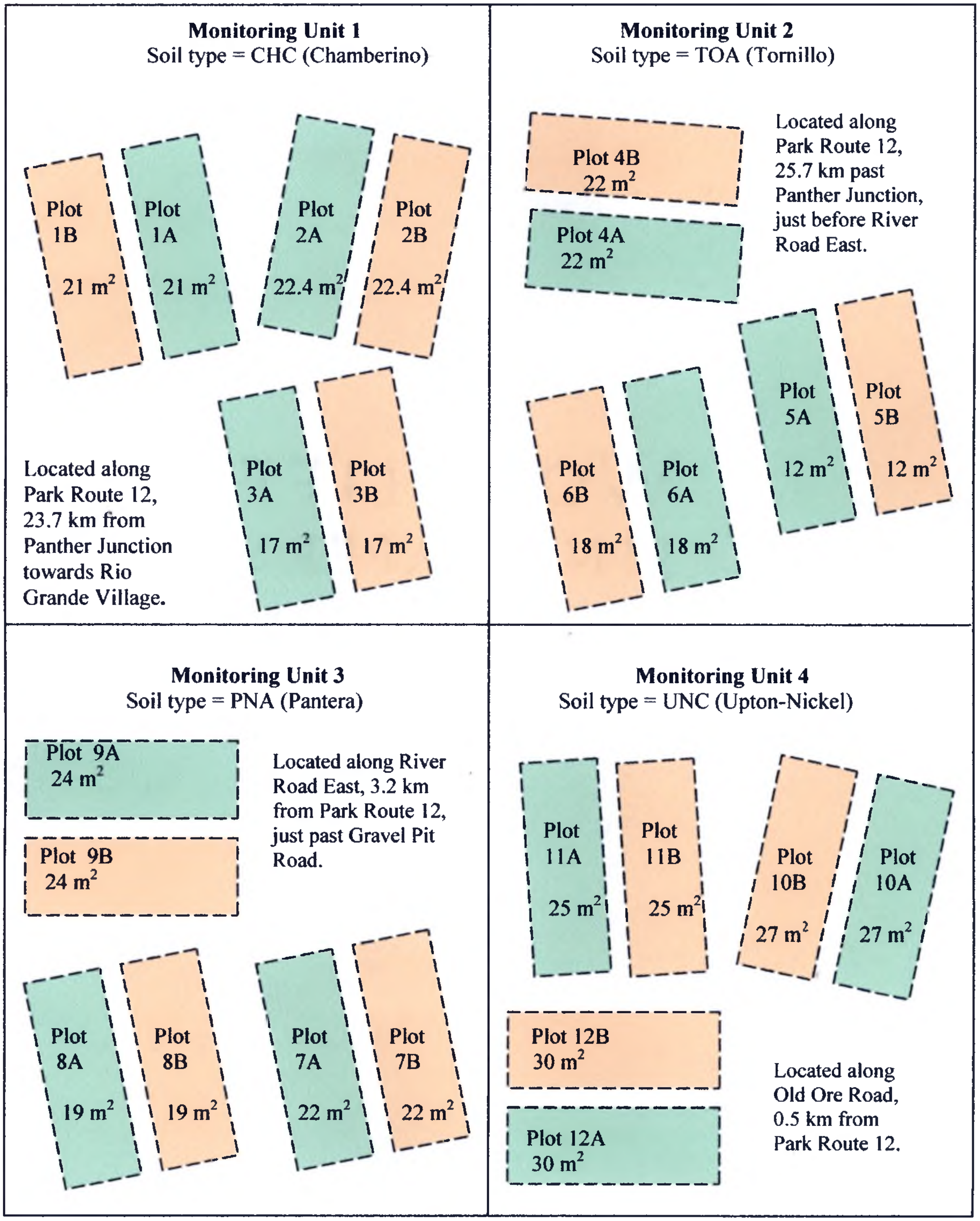

Figure 12. Diagrammatic representation of the layout of the four different monitoring units. Each unit is located on a different soil type. Within each unit are 6 plots of varying lengths (each 2 m wide). Three plots contain buffelgrass and three adjacent plots of the same length do not contain any buffelgrass. The number and size of each plot are shown inside the plot rectangle. KEY: A = plot with buffelgrass, B = plot with no buffelgrass.

Plant cover is defined as the vertically projected area of all aboveground plants parts as a percentage of the total ground area considered (Dietz and Steinlein 2002). It is assumed that a comparison of cover for each species in a given area will reveal the relative control or dominance that each species exerts on the community as a whole, such as the relative amount of nutrients or other resources each species commands (Barbour et al. 1987). An accurate method to assess plant cover is the line intercept method, spreading a meter tape across a plot for measurements (Mueller-Dombois and Ellenberg 1974).

For line interception, a plumb bob was used to achieve a vertical projection of the tape and all plants intercepting the line were measured from one side to the other (the start of intercept to the end of intercept), ignoring any breaks or gaps of any size in their canopies (Barbour et al. 1987). Daubenmire (1968) favored "filling in" internal gaps on the argument that these gaps may be part of the ecological territory of an individual. Overlapping plants can mean more than one species contributes to cover, and the total cover value can exceed 100 percent. Cover values were calculated with the following formulas:

$$C_i = t_i / T$$

where C_i is the cover of species i, t_i is the total length of transect line intercepted by species i, and T is the total length of the transect line, and

$$RC_i = C_i / \sum C$$

where the relative cover (RC_i) for species i is the cover for that species (C_i) expressed as a proportion of the total coverage for all species ($\sum C$).

The frequency (f) of occurrence of a species is provided by the fraction of intervals or belts that contain the species and indicates the chance of finding a given species within a sample (Brower et al. 1997). For line transects, the transect line can be subdivided into sections of any desired length, which will allow for the determination of frequency (Cox 1996). In this study, the transect lines were subdivided into half-meter lengths for the determination of frequency. Frequency values were calculated with the following formulas:

$$f_i = j_i / k$$

where f_i is the frequency of species i, j_i is the number of samples (line intervals or belts) in which species i occurs, and k is the total number of samples taken, and

$$Rf_i = f_i / \sum f$$

where the relative frequency (Rf_i) is the frequency of a given species (f_i) as a proportion of the sum of the frequencies for all species ($\sum f$).

For the belt transects, all individual plants within the belt were counted. Plants lying more than halfway inside the boundary of the belt were counted, while those lying more than halfway outside the belt were not counted. An arbitrary definition of what constitutes an individual plant was needed in some cases (Cox 1996). When counting individual buffelgrass plants, for example, each discrete clump was counted as one plant.

Density is the number of individuals in a given area expressed per unit area (Brower et al. 1997). Density (D) was calculated with the following formula:

$$D_i = n_i / A$$

where D_i is the density for species i, n_i is the total number of individuals counted for species i, and A is the total area sampled.

Frequency in the belt transects was calculated as above, indicating the percentage of belts in which the species occurred, and the following formula was used to calculate relative density:

$$RD_i = n_i/\sum n$$

where the relative density RD_i) for species *i* is the number of individuals of a given species (n_i) as a proportion of the total number of individuals of all species ($\sum n$).

Relative values for density, cover, and frequency can be combined into a single importance value. The importance value gives an overall estimate of the influence or importance of a plant species in the community (Brower et al. 1997). Two of the three values (relative density, relative cover, or relative frequency) may be used to determine the importance value, in which case, the two values to be used are averaged (Cox 1996). For the line transects, the importance value was calculated by averaging the relative cover and relative frequency values:

$$IV_i = (RC_i + Rf_i)/2$$

For the belt transects, the importance value was calculated by averaging the relative density and relative frequency values:

$$IV_i = (RD_i + Rf_i)/2$$

Species Diversity

Studies have shown that one of the negative impacts of invasive species is that they can lower species diversity where they become established, ultimately affecting the whole ecosystem (Cronk and Fuller 1995; D'Antonio and Vitousek 1992; Dukes and Mooney 2004; Gordon 1998). Diversity indices are mathematical measures of species diversity in a community (Henderson 2003, Krebs 1989). They provide information about rarity and commonness of a species in a community, as well as information on community structure.

While species richness (*S*) only represents the total number of different species present in an area, the diversity index also takes into account the evenness of the species. As species richness and evenness increase, diversity increases. Diversity is highest when several species are present and have similar population sizes (Krebs 1989).

Commonly used indices used to calculate species diversity include the Shannon index, Evenness (equitability), and the Simpson index (Henderson 2003, Krebs 1989). Calculating indices such as these can provide an indication of how an exotic plant is affecting the species diversity of an area.

Diversity indices may provide useful information when comparing plant communities (Henderson 2003, Krebs 1989). This study compares the diversity of buffelgrass belt plots with non-buffelgrass belt plots, to see if buffelgrass has had an impact on community diversity.

The Shannon diversity index (*H*) was calculated for each belt transect. The formula used to calculate this index accounts for both abundance and evenness of all species present. The proportion of species *i* relative to the total number of species (p_i) is calculated, multiplied by the natural logarithm of this proportion ($\log n\, p_i$), then summed and multiplied by -1 to derive the index, as follows:

$$H = - \sum p_i \log n\, p_i$$

The highest value for the Shannon index is equal to $\log n\, S$. In reality, values rarely exceed 5 (Krebs 1989).

Evenness, or equitability can then be calculated, with the results ranging from 0 to 1, with 1 being complete evenness of species. The following formula calculates evenness:

$$E_H = H/\log \text{n}\, S$$

where H is the Shannon index, n is total observations, and S is species richness.

The Simpson index was also calculated for each belt transect. This index takes into account abundance and evenness of all species present, measuring the probability that two individuals taken from a sample will belong to the same species. The resulting value ranges from 0 to 1, with 1 being perfect evenness. The following formula calculates the Simpson index:

$$D = \sum (\text{n/N})^2$$

where n is the total number of a particular species, and N is the total number of all species.

Seed Bank

The seed bank consists of all viable seeds present in the soil or associated litter (Simpson et al. 1989). The spatial distribution and abundance of seeds present in the soil are important to the structure of plant communities (Reichman 1984; Roberts 1981). Revegetation of an area after disturbance is principally from the growth of seeds in the seed bank, which may lie dormant for many years (Moore and Wein 1977). Knowledge of the seed bank in an area may be helpful in understanding which species have the potential to germinate there in the future.

Studies of seed banks in deserts suggest that seeds are patchily distributed, and their distribution may be further affected by foraging ants, birds and rodents (Brown et al.

1979; Guo et al. 1998; Price and Reichman 1987; Reichman 1979, 1984). Seeds found in desert soils are mostly near the surface. Studies indicate from 80 to 90 percent of seeds found in desert soils are in the top two centimeters of soil (Childs and Goodall 1973; Kemp 1989; Reichman 1975), with most seeds in the litter or top few millimeters of soil (Dye 1969; Young and Evans 1975).

The technique generally used to investigate the seed bank is to take representative samples and then determine seed numbers either by germination or physical separation (Roberts 1981). Greenhouse germination allows for direct count of viable seeds, while physical separation must be followed by viability tests. Physical separation and viability testing were used in this study.

The grass "seed" is actually a fruit termed a caryopsis, with the ovary wall and seed coat fused together to form the fruit. The caryopsis contains the true seed, although it is common to refer to the caryopsis as the seed (Chapman 1996; Chapman and Peat 1992). Throughout this paper the term "seed" is used for consistency when referring to the grass caryopsis.

In the first field season, test soil samples were taken along one transect in each of the plots for the purpose of determining where in the seed bank buffelgrass seeds were located. The test samples were taken at three different levels (surface litter and 0-2.0 cm, 2.0-4.0 cm, and 4.0-6.0 cm) and initial results indicated that all of the buffelgrass seeds were either in the litter or top 2 cm of soil. In the second field season, only the litter and top 2 cm of soil were taken, this time keeping the litter separate from the soil. Each plot was divided into similar squares and numbers were randomly drawn to determine where to take the samples from each of the paired plots. Ten samples were taken from each plot, first carefully removing the litter, then the soil portion between 0-2 cm. Each soil sample measured about 20 x 20 x 2 cm (800 cm^3).

The organic component of the soil containing the seeds was separated following Malone (1967). This method uses a combination of hexametaphosphate (Calgon®) and sodium bicarbonate to break down the soil aggregates and to ensure efficient extraction of debris by flotation, which is accomplished by the addition of magnesium sulfate. First, the soil component over 2.0 mm and the component under 0.5 mm were separated from the sample using sieves. This step eliminates the portions that will not contain any buffelgrass seeds, which are usually at least 1 mm in size, or buffelgrass burs. After sieving, the portion containing particles between 0.5 mm and 2.0 mm in size was processed by separating the organic portion from the soil using the flotation method, a process which has been shown not to affect the viability of the seeds (Malone 1967). After drying, the organic portion of the sample was examined for the presence or absence of buffelgrass seeds under a dissecting microscope.

Seed Viability

Tetrazolium testing allows estimates of seed viability to be made and is an alternative to germination tests (Copeland 1981) that provides quick estimates of seed viability (Peters 2000). Tetrazolium (2,3,5-triphenyl tetrazolium chloride) is an oxidized, colorless, soluble salt that works by penetrating living tissue, where it is reduced to form a reddish compound (Peters 2000). Viable seeds stain red, while the non-viable seeds do not pick up any stain at all.

Buffelgrass seeds or burs were tested for viability using the tetrazolium staining method (Copeland 1981). In this method, seeds are treated with 2,3,5-triphenyl tetrazolium chloride, diluted to either a 1.0% solution for buffelgrass burs, or 0.1% solution for buffelgrass seeds (Peters 2000). Each buffelgrass bur usually contains 2 or 3 seeds at different stages of maturity, so whole burs were used for testing.

The seed units were prepared so that the tetrazolium could contact the embryo. Burs were soaked overnight to initiate germination and to soften the seeds or burs, so that a clean slice could be made through the embryo. Burs were then placed in a 1.0% tetrazolium solution and allowed to soak for a minimum of 24 hours. Those that stained red were considered viable and those that did not stain red were not considered viable. After the first field season, 200 burs were collected and tested for viability one year later. After the second field season, 200 burs were collected and tested for viability after three months.

Predictive Modeling

Between 1998 and 2005, over 7000 buffelgrass feature points were mapped in the park, all with geographic positioning system (GPS) units in the field, except in 1998, when the locations were mapped by hand onto topographic maps and then later digitized. These mapped data are vital to the project, as they represent the presence data for the species (Figure 13). The 1998 mapping was part of the park's Exotic Plant Management Plan and represents 381 buffelgrass sites. The 2001-2002 mapping was done by this author and represents 2485 buffelgrass sites. The 2003-2004 mapping was done by Patty Guertin and represents 4142 buffelgrass sites. The 2002-2005 mapping was done by park personnel and represents an additional 413 buffelgrass sites.

All buffelgrass points mapped as of May 2005 (n = 7401) were combined and used as an aid in characterizing the environmental conditions in which buffelgrass grows in the park and for building the predictive model. Estimations of "density" were not made for all of the 7401 buffelgrass feature points from the different databases, so any given data point could represent one plant or any number up to 200 plants. One point was eliminated because it fell out of the study area, in the Northern Rosillos Mountains and Persimmon Gap area, leaving a total of 7400 known buffelgrass locations for use in this study. The total area of the park for the predictive model is about 286,000 hectares.

Integrating all of the mapped data collected for buffelgrass into one file and then overlaying these data with the different types of environmental areas in which they occur in the park allowed correlations between occurrence and habitat to be determined. This information was used to build the predictive model, indicating where the species may already or could potentially occur.

Even without the predictive habitat map, a simple overlay of existing buffelgrass stands with the distribution of an endangered species such as the Chisos hedgehog cactus or a sensitive habitat can indicate areas of high management priority (Figure 14). These examples are possible only for buffelgrass that has already been mapped. With a predictive habitat map, potentially critical areas can be identified where buffelgrass has not yet been mapped. Appropriate management strategies for the conservation of a native or endangered species, or a threatened sensitive habitat, can then be determined based in part on this information.

ArcGIS Desktop software (version 9.0, published by ESRI, Redlands, CA) was employed to combine 7400 known buffelgrass locations and nine different environmental layers (elevation, slope, precipitation, geologic stratigraphy type, soil category, environmental subregion, vegetation form, general vegetation class, and Plumb's vegetation category) to build a baseline predictive habitat distribution model for the potential occurrence of buffelgrass in Big Bend National Park. ArcGIS makes use of numerous geoprocessing tools to define, manage, and analyze spatial information.

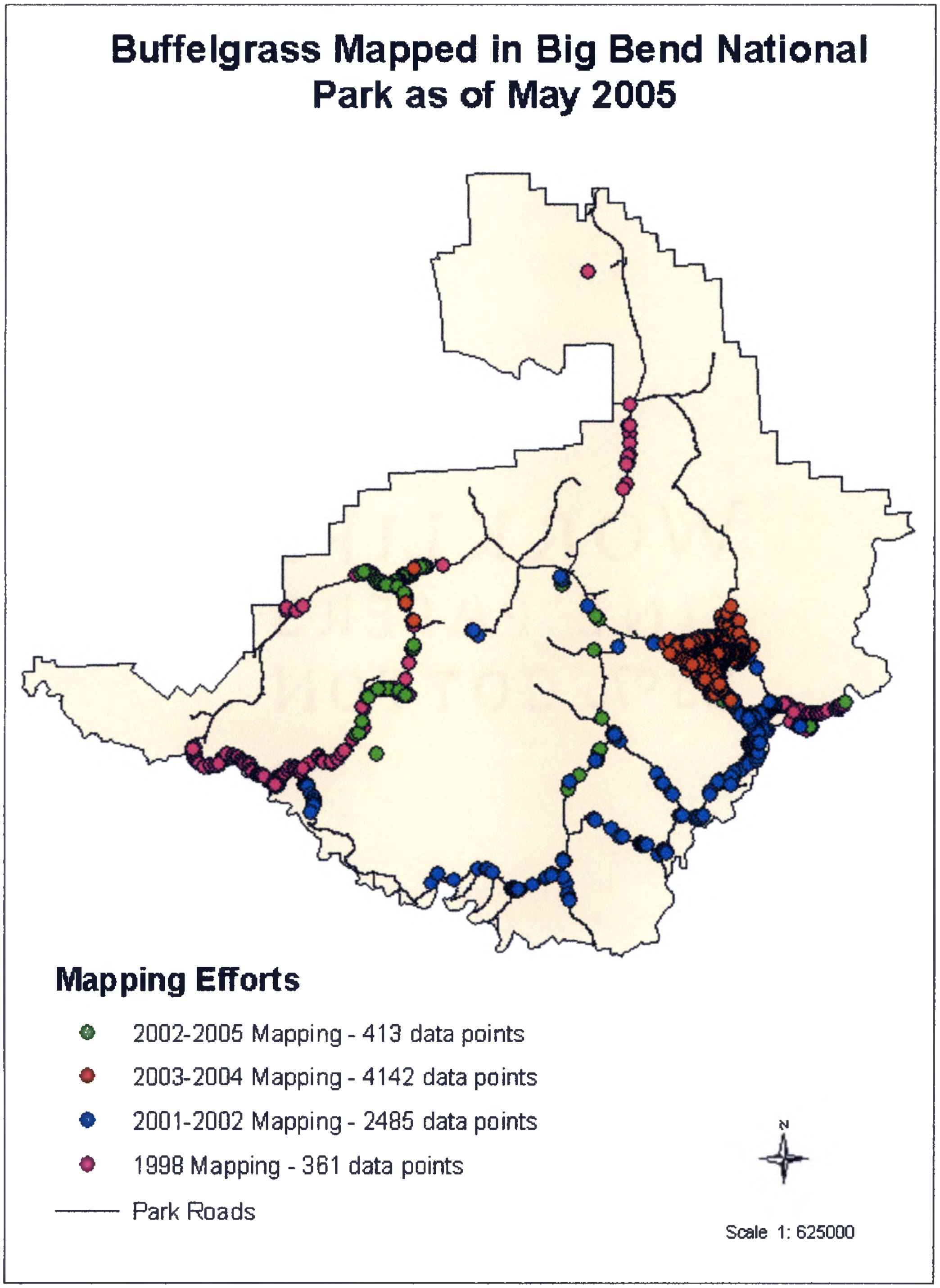

Figure 13: Buffelgrass mapped in Big Bend National Park as of May 2005. Mapping was accomplished in four discrete efforts between 1998 and 2005.

Mapping results were combined for this project into one file, totaling 7401 data points.

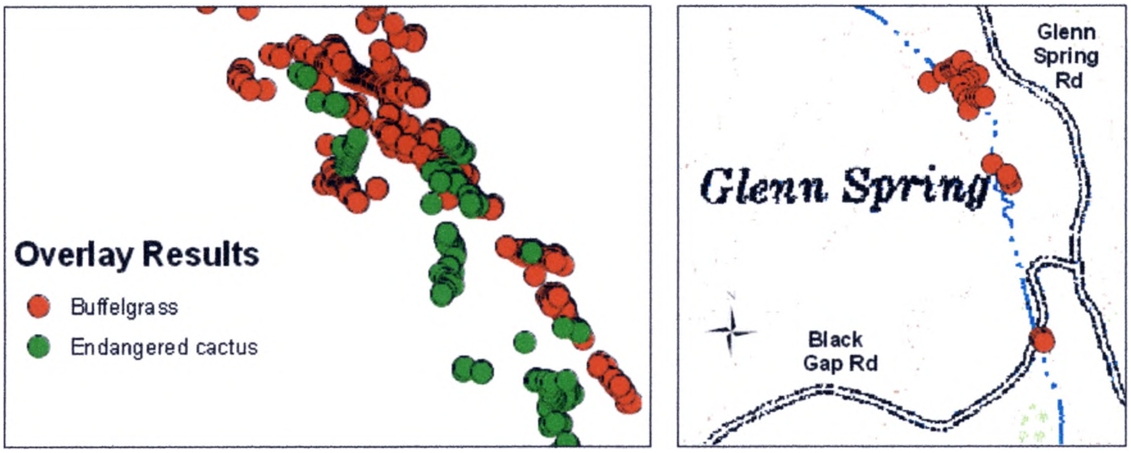

Figure 14. Examples of GIS overlay using mapped buffelgrass points. On the left, buffelgrass points have been overlayed in a GIS with an threatened cactus, and on the right, buffelgrass points have been overlayed with a USGS topographic quad showing Glenn Spring, a pristine water source in the park. Both areas indicate a high management priority for the eradication of the buffelgrass.

Absence data for buffelgrass in the park are incomplete at this time, so only presence data were used. All buffelgrass data available were collected, prepared, and appended into one file for this project (Table 1). All preparation and processing used on the buffelgrass data is described in the table.

Table 1. Buffelgrass files used in the predictive habitat model. Includes all buffelgrass mapped in Big Bend National Park as of May 2005.

Project Data File	File Creation	Data Processing
Buffelgrass Layer 1998 exotic survey File type: Vector point, line, and polygon files	Needed to derive buffelgrass file first, by extracting all buffelgrass from the 1998 exotic survey files, which included other species. Selected buffelgrass points from exotic file, creating buffelgrass only shapefile. Derived additional buffelgrass points where lines and polygons were used in original mapping, using edit tools, so that all buffelgrass mapped in 1998 would be represented by points. Merged these derived points together with the point feature shapefile.	Merged 1998 buffelgrass points with master buffelgrass file. One point was deleted from file as it fell out of study site (point was in Persimmon Gap). Used master buffelgrass file to query environmental layers.

Table 1-Continued. Buffelgrass files used in the predictive habitat model.		
Project Data File	**File Creation**	**Data Processing**
Buffelgrass Layer Buffelgrass mapped in 2001-2002 File type: Vector, point	Merged 2001 and 2002 files together into one shapefile.	Merged 2001-2002 points with master buffelgrass file. Used master buffelgrass file to query environmental layers.
Buffelgrass Layer Buffelgrass mapped in 2002-2005 File type: Vector, point	Separated out buffelgrass points in the Science Center database, creating buffelgrass only shapefile.	Merged 2002-2005 points with master buffelgrass file. Used master buffelgrass file to query environmental layers.
Buffelgrass Layer Buffelgrass mapped in 2003-2004 File type: Vector, point	Separated out the points that indicated location of no buffelgrass (absence data), creating buffelgrass presence only shapefile.	Merged 2003-2004 points with master buffelgrass file. Used master buffelgrass file to query environmental layers.

Environmental data were also vital for the project and most of the data used in this project was obtained from the Big Bend National Park Science and Research and Management Center, or derived from these data. Data available from the park for this project included soil, geology, several different vegetation layers, elevation, road, arroyo, springs and trail layers, and the files selected to use in the model are listed below (Table 2). The rainfall layer was obtained from the General Land Office GIS database.

The files used were selected based on their suitability for the project. Included in the table is the attribute used in each of the environmental files (e.g., the geology file uses the attribute stratigraphy). Also included are the number of classes found in the attribute (e.g., stratigraphy has 30 classes). The nine environmental layers include a total of 128 different classes. All preparation and processing used to prepare the data are also described in the table.

Table 2. Environmental layers used in the predictive habitat model. All data files were obtained from Big Bend National Park, Science and Research Management Center, unless noted otherwise. All data were projected to NAD 1983, Universal Transverse Mercator (UTM) Zone 13N as needed.

Project Data File	Data Attribute Classes	Data Processing
Geology Layer Park filename: Geolgy83.shp File type: Vector, polygon Classify by STRATIGRAPHY 30 different stratigraphy classes appear in this file.	1.Ipt 2.Kag 3.Kbd 4.Kbo 5.Kbse 6.Kdm 7.Kdt 8.Kgr 9.Kj 10.Kp 11.Ks-t 12.Kse 13.Ksu 14.O 15.Qal 16.Qalr 17.Qao 18.Qf 19.Ql 20.QTb 21.QTg 22.Tbp 23.Tc 24.Tcf 25.Tde 26.Tfi 27.Thh 28.Ti 29.Tmm 30.Tsr	Clip to study area. Dissolve on stratigraphy. Create separate layers for each stratigraphy class. Query class layers with buffelgrass points. Convert shapefile to raster based on stratigraphy. Reclassify raster based on buffelgrass presence. Use reclassified raster in weighted overlay process. Weight layer in ModelBuilder window.
Soil Layer Park filename: Soil-02.shp File type: Vector, polygon Classify by CATEGORY 27 different soil categories appear in this file.	1.BRG 2.CHC 3.CHD 4.CLC 5.CMD 6.ERF 7.GHA 8.HRD 9.HRF 10.LAE 11.LAF 12.LMF 13.LRF 14.LRG 15.MRE 16.PAA 17.PNA 18.PRF 19.RG 20.RVW 21.SCB 22.SRD 23.TAE 24.TLE 25.TOA 26.UNC 27.VBD	Clip to study area. Dissolve on soil category. Create separate layers for each soil category class. Query class layers with buffelgrass points. Convert shapefile to raster based on soil category. Reclassify raster based on buffelgrass presence. Use reclassified raster in weighted overlay process. Weight layer in Modelbuilder window.
Vegetation Layer Park filename: 83GenVeg.shp File type: Vector, polygon Classify by ENVSUBREG 7 different environmental subregion classes appear in this file.	1. Bare 2. Desert Plains 3. Igneous Mountains & Foothills 4. Limestone Mountains & Foothills 5. Montane 6. Riparian 7. Water	Clip to study area. Dissolve on environmental subregion. Create separate layers for each subregion class. Query class layers with buffelgrass points. Convert shapefile to raster based on environmental subregion. Reclassify raster based on buffelgrass presence. Use reclassified raster in weighted overlay process. Weight layer in ModelBuilder window.
Vegetation Layer Park filename: 83vegmap83.shp File type: Vector, polygon Classify by VEG_FORM 6 different vegetation form classes appear in this file.	1. Bare 2. Floodplain-Arroyo 3. Shrub Desert 4. Sotol-Grassland 5. Water 6. Woodland	Clip to study area. Dissolve. Create separate layers for each vegetation form class. Query class layers with buffelgrass points. Convert to raster grid based on vegetation form. Reclassify raster based on buffelgrass occurrence. Use reclassified raster in weighted overlay process. Weight layer in ModelBuilder window.

Table 2-Continued. Environmental layers used in the predictive habitat model.

Project Data File	Data Attribute Classes	Data Processing
Vegetation Layer Park filename: 83vegmap83.shp File type: Vector, polygon Classify by GEN_CLS 10 different general vegetation classes also appear in this file.	1. Bare 2. Closed Canopy Woodland 3. Creosote Scrub 4. High Desert Grassland 5. Lechuguilla Scrub 6. Open Canopy Woodland 7. Riverine Riparian 8. Scrub Woodland 9. Upland Riparian 10. Water	Create separate layers for each general vegetation class. Query class layers with buffelgrass points. Convert to raster grid based on vegetation layer. Reclassify raster based on buffelgrass occurrence. Use reclassified raster in weighted overlay process. Weight layer in ModelBuilder window.
Vegetation Layer Park filename: 83vegmap83.shp File type: Vector, polygon Classify by PLUMB_CAT 28 different Plumb's vegetation category classes also appear in this file.	1.Bare 2.Cottonwood Grove 3.Creosote Flats 4.Creosote Grass 5.Creosote-Lech-Prickly Pear 6.Creosote-Lechuguilla 7.Creosote-Tarbush 8.Creosote-Yucca-Grass 9.Desert Willow 10.Forest Meadow 11.Lechuguilla-Grass 12.Lechuguilla-Grass-Candelilla 13.Lechuguilla-Grass-Hechtia 14.Lechuguilla-Grass-Viguiera 15.Mesquite Thicket 16.Mixed Oak 17.Mixed Riparian 18.Mixed Scrub 19.Oak Scrub 20.Oak-Ponderosa Pine-Cypress 21.Pinyon-Juniper-Grass 22.Pinyon-Oak-Juniper 23.Pinyon-Talus 24.Reed Grass 25.Sotol-Lechuguilla-Grass 26.Sotol-Nolina-Grass 27.Water 28.Yucca-Sotol	Create separate layers for each Plumb's category class. Query class layers with buffelgrass points. Convert to raster grid based on Plumb's categories. Reclassify raster based on buffelgrass occurrence. Use reclassified raster in weighted overlay process. Weight layer in ModelBuilder window.
Rainfall Layer File source: General Land Office GIS files Filename: rainfall.shp File type: Vector, polygon 6 different rainfall range classes appear in this file.	1. 10-12 in (25.4-30.5 cm) 2. 12-14 in (30.6-35.6 cm) 3. 14-16 in (35.7-40.6 cm) 4. 16-18 in (40.7-45.7 cm) 5. 18-20 in (45.8-50.8 cm) 6. 20-22 in (50.9-55.9 cm) The original file used inches, which were converted to cm for use here.	Download from General Land Office. Project to UTM Zone 13N. Clip to study area. Dissolve on rainfall range. Create separate layers for each rainfall range class. Query class layers with buffelgrass points. Convert to raster grid based on rainfall range. Reclassify raster based on buffelgrass occurrence. Use reclassified raster in weighted overlay process. Weight layer in ModelBuilder window.

Table 2-Continued. Environmental layers used in the predictive habitat model.

Project Data File	Data Attribute Classes	Data Processing
Elevation Layer Park filename: gext2 File type: Raster 7 different elevation classes were derived using natural breaks (Jenks method). This is a park-wide DEM layer that has been previously converted to an elevation grid.	1. 521 to 751 m 2. 751.1 to 904 m 3. 904.1 to 1045 m 4. 1045.1 to 1209 m 5. 1209.1 to 1435 m 6. 1435.1 to 1764 m 7. 1764.1 to 2376 m	Convert raster to vector file. Derive elevation classes. Dissolve on elevation classes. Create separate layers for each elevation class. Query class layers with buffelgrass points. Reclassify original raster file based on the 7 derived classes. Reclassify this raster based on buffelgrass presence. Use this reclassified raster in weighted overlay process. Weight layer in ModelBuilder window.
Slope Layer Filename: Slope_gext2 File type: Raster 7 different slope classes were derived using natural breaks (Jenks method).	1. 0 to 4.3 degrees 2. 4.4 to 9.7 degrees 3. 9.8 to 16.1 degrees 4. 16.2 to 23.4 degrees 5. 23.5 to 31.6 degrees 6. 31.7 to 44.1 degrees 7. 44.2 to 77.8 degrees	Derive slope layer from elevation layer first, using Spatial Analyst tool. Convert raster to vector file. Derive slope classes. Dissolve on slope classes. Create separate layers for each slope class. Query class layers with buffelgrass points. Reclassify original raster file based on the 7 derived classes. Reclassify this raster based on buffelgrass presence. Use this reclassified raster in weighted overlay process. Weight layer in ModelBuilder window.

Before the predictive model could be built, the 7400 buffelgrass feature points had to be queried using the GIS to determine their frequency in each class of every environmental layer, including geologic stratigraphy (30 classes), soil type (27 classes), environmental subregion (7 classes), vegetation form (6 classes), vegetation general class (10 classes), Plumb's vegetation category (29 classes), rainfall range (6 classes), elevation range (7 classes), and slope range (7 classes).

The "Select by Attribute" tool was used to make individual shapefiles for each separate class to facilitate querying the buffelgrass points, which was done using the "Select by Location" tool, both done in ArcMap and outside of the ModelBuilder Window. This process required that the data all be in vector format (points, lines, or polygons). The relative frequencies for the 7400 mapped buffelgrass points occurring in each class of all layers can be seen in Table 3. These results were used to aid in reclassifying the environmental layers to a common scale for the model.

The "Weighted Overlay" process in ArcGIS requires all of the environmental layers to first be reclassified to a common evaluation scale, making it possible to perform arithmetic operations on the data. In this case, the common scale ranges from 1 to 5, with 1 associated with areas where buffelgrass is most likely to occur and 5 associated with areas where buffelgrass is least likely to grow.

Tables 3 through 11 include the class weight, or scale number, used in the reclassification process for each of the nine environmental layers. The classes within the layers were ranked strictly according to their relative frequencies. Each environmental layer lists all classes within the layer. The total number of buffelgrass points found in each layer class and their frequency of occurrence are included in the tables.

Table 3. Vegetation layer classified by general vegetation class.

Vegetation Layer Classified by General Vegetation Class	**Buffel Points**	**% of Total**	**Class Weight**
Creosote Scrub	4610	62.30	1
Lechuguilla Scrub	1065	14.39	2
Upland Riparian	835	11.28	2
High Desert Grassland	389	5.26	3
Bare	311	4.20	3
Closed Canopy Woodland	161	2.18	4
Scrub Woodland	29	0.39	5
Riverine Riparian	0	0.00	5
Open Canopy Woodland	0	0.00	5
Water	0	0.00	5
Total for all 10 classes	7400	100.00	

Table 4. Vegetation layer classified by environmental subregion.

Vegetation Layer Classified by Environmental Subregion	Buffel Points	% of Total	Class Weight
Igneous Mountains and Foothills	2612	35.30	1
Desert Plains	2252	30.43	1
Limestone Mountains and Foothills	1209	16.34	2
Riparian	921	12.45	2
Bare	309	4.18	3
Montane	97	1.31	4
Water	0	0.00	5
Total for all 7 classes	7400	100.00	

Table 5. Vegetation layer classified by Plumb's categories.

Vegetation Layer Classified by Plumb's Categories	Buffel Points	% of Total	Class Weight
Creosote-Lechuguilla-Prickly Pear	2367	31.99	1
Creosote-Lechuguilla	861	11.64	2
Creosote Grass	839	11.34	2
Lechuguilla-Grass-Hechtia	560	7.57	3
Desert Willow	538	7.27	3
Creosote Flats	528	7.14	3
Lechuguilla-Grass-Candelilla	505	6.82	3
Bare	311	4.20	3
Mesquite thicket	297	4.01	3
Lechuguilla-Grass-Viguiera	250	3.38	3
Pinyon-Oak-Juniper	94	1.27	4
Mixed Scrub	66	0.89	4
Creosote-Yucca-Grass	42	0.57	4
Sotol-Lechuguilla-Grass	39	0.53	4
Lechuguilla-Grass	34	0.46	4
Sotol-Nolina-Grass	22	0.30	4
Cottonwood Grove	18	0.24	4
Creosote-Tarbush	15	0.20	4
Mixed Riparian	11	0.15	4
Yucca-Sotol	2	0.03	5
Oak Scrub	1	0.01	5
Forest Meadow	0	0.00	5
Mixed Oak	0	0.00	5
Oak-Ponderosa Pine-Cypress	0	0.00	5
Pinyon-Juniper-Grass	0	0.00	5
Pinyon-Talus	0	0.00	5
Reed Grass	0	0.00	5
Water	0	0.00	5
Total for all 28 classes	7400	100.00	

Table 6. Vegetation layer classified by vegetation form.

Vegetation Layer Classified by Vegetation Form	Buffel Points	% of Total	Class Weight
Shrub Desert	5717	77.26	1
Floodplain-Arroyo	864	11.68	2
Sotol-Grassland	347	4.69	3
Bare	311	4.20	3
Woodland	161	2.18	4
Water	0	0.00	5
Total for all 6 classes	7400	100.00	

Table 7. Geology layer classified by geologic formation.

Geology Layer Classified by Stratigraphy		Buffel Points	% of Total	Class Weight
QTg	Pleist-Miocene terrace pediment & valley-fill gravels	1799	24.31	1
Qao	Pleistocene; alluvium, colluvium, caliche,un-partly consol	1513	20.45	1
Qf	Holocene, colluvium and fan deposits	1457	19.69	1
Qal	Holocene, non-Rio Grande floodplain & terraces	833	11.26	2
Kag	UpCret; Aguja;clay, sandst,lignite;marine2cont; fossils	674	9.11	2
Kbse	UpCret; Boquillas;SVicente,Ernst;marly limest,marinefossils	500	6.76	2
Kp	UpCret; Pen;=Aust.chlk;clay, yellow; marine fossils; 700'	296	4.00	3
Kbd	LwCret; Buda & DelRio Clay; massive/marly limest & clay/sandst	90	1.22	4
Kj	UpCret; Javelina; clay,sandst; 936'; bentonite; petrf. wood	64	0.86	4
Tde	Miocene; Delaho; up, sandst&conglom; lower, sandy siltstone 2200'	60	0.81	4
Tc	Oligocene; Chisos; TM,ME,BM,AS,AC; sandst, mudst, tuff, basalt	58	0.78	4
Tfi	Pleist; Fingers; conglom&sandst, poorly consol, angular, 700'	26	0.35	4
Kse	LwCret; SantaElena Limest; massive/interbed marl; 500-950'	18	0.24	4
Ti	Stocks, laccoliths, sills, dikes; basalt, trachyte, rhyolite, etc.	6	0.08	5
Thh	Eocene; HannoldHill; clay ,sandst, congl; 850'; lignite	3	0.04	5
Tbp	Paleocene; BlackPeaks; sandst, clay; 866'; concretions; fossils	2	0.03	5
Tsr	Oligocene; SouthRim; BM,LM,WS,BrRhy; rhyl, felsite; 30my;	1	0.01	5
Ipt	Pennslyvanian; Tesnus; sandst, shale; several thousand feet thick	0	0.00	5
Kbo	UpCret; Boquillas Flags; shale, limest, siltst; 450' (=42, Kbse)	0	0.00	5
Kdm	LwCret; Del Carmen Limest; massive; cherty; 350-800'	0	0.00	5
Kdt	LwCret; DelCarmen & Teleph.Canyon undivided; marly2massive	0	0.00	5
Kgr	LwCret; GlenRose; hard limest/soft marls; stairsteps; 335-733'	0	0.00	5
Ks-t	LwCret; SantaElena, SuePeaks, DelCarmen,Teleph.Cany, undivided	0	0.00	5
Ksu	LwCret; SuePeaks; limest&shale; marinefossils; 30-250'	0	0.00	5
O	Ord; PineMnt, Ordovicion undivided	0	0.00	5
Qalr	Holocene, RioGrande floodplain; silty sand; channel gravels	0	0.00	5
Ql	Holocene/Pleistocene; landslides (displaced bouldery rock masse)	0	0.00	5
QTb	Pleist-Miocene bolson (2000') clay, silt, sandstone, conglomerate	0	0.00	5
Tcf	Eocene;Canoe;sandst,slay,mudst,congl,tuff,basalt;1200'	0	0.00	5
Tmm	Oligocene;MitchellMesaWeldTuff;ashflow; 150'; 31.5my:Buckhill	0	0.00	5
Total for all 30 classes		7400	100.00	

Table 8. Elevation layer classified by elevation range.

Elevation Classified by Elevation Range Classified by Natural Breaks (Jenks) Method, 7 classes	Buffel Points	% of Total	Class Weight
521 to 751 meters	6720	90.81	1
751.1 to 904 meters	189	2.55	2
904.1 to 1045 meters	152	2.05	3
1045.1 to 1209 meters	177	2.39	2
1209.1 to 1435 meters	12	0.16	4
1435.1 to 1764 meters	150	2.03	3
1764.1 to 2376 meters	0	0.00	5
Total for all 7 classes	7400	100.00	

Table 9. Rainfall layer classified by rainfall range.

Rainfall Layer Classified by Rainfall Range	Buffel Points	% of Total	Class Weight
25.4 to 30.5 cm	5909	79.85	1
30.6 to 35.6 cm	1269	17.15	2
35.7 to 40.6 cm	72	0.97	4
40.7 to 45.7 cm	0	0.00	5
45.8 to 50.8 cm	150	2.03	3
50.9 to 55.9 cm	0	0.00	5
Total for all 6 classes	7400	100.00	

Table 10. Soil layer classified by soil category.

Soil Layer	Classified by Soil Category	Buffel Points	% of Total	Class Weight
CHC	Chamberino very gravelly loam, undulating	2141	28.93	1
CHD	Chamberino very gravelly loam, rolling	1052	14.22	1
UNC	Upton-Nickel association, undulating	993	13.42	1
PNA	Pantera very gravelly sandy loam, frequently flooded	651	8.80	2
PAA	Pajarito-Agustin association, gently sloping	584	7.89	2
TOA	Tornillo loam, occasionally flooded	502	6.78	2
SRD	Solis-Rock outcrop complex, rolling	331	4.47	3
VBD	Vieja-Badland complex, rolling	196	2.65	3
RVW	Riverwash	174	2.35	3
CMD	Chilicotal-Monterosa association, rolling	158	2.14	3
LMF	Liv-Mainstay-Rock outcrop complex, steep	150	2.03	3
MRE	Mariscal Rock outcrop complex, hilly	144	1.95	3
LRF	Lozier Rock outcrop complex, steep	102	1.38	4
LAE	Lajitas-Rock outcrop complex, hilly	75	1.01	4
CLC	Chilicotal very gravelly fine sandy loam, undulating	64	0.86	4
GHA	Glendale-Harkey association, occasionally flooded	37	0.50	4
LAF	Lajitas-Rock outcrop complex, steep	29	0.39	5
LRG	Lozier Rock outcrop complex, very steep	14	0.19	5
TLE	Terlingua-Rock outcrop complex, hilly	3	0.04	5
BRG	Brewster-Rock outcrop complex, very steep	0	0.00	5
ERF	Ector-Rock outcrop complex, steep	0	0.00	5
HRD	Hurds very gravelly sandy loam, rolling	0	0.00	5
HRF	Hurds very cobbly loam	0	0.00	5
PRF	Puerta-Madrone complex, steep	0	0.00	5
RG	Rio Grande	0	0.00	5
SCB	Solis-Chamberino association, gently undulating	0	0.00	5
TAE	Terlingua-Mariscal association, hilly	0	0.00	5
Total for all 27 classes		7400	100.00	

Table 11. Slope layer classified by slope range.

SlopeClassified by Slope Range Natural Breaks (Jenks) Method, 7 classes	Buffel Points	% of Total	Class Weight
0 to 4.3 degrees	6088	82.27	1
4.4 to 9.7 degrees	773	10.45	2
9.8 to 16.1 degrees	368	4.97	3
16.2 to 23.4 degrees	166	2.24	4
23.5 to 31.6 degrees	3	0.04	5
31.7 to 44.1 degrees	1	0.01	5
44.2 to 77.8 degrees	1	0.01	5
Total for all 7 classes	7400	100.00	

Finally, each environmental layer in the model was weighted according to its relative importance in determining habitat suitability. For example, elevation may be a more important factor for a species than soil type, so elevation can be given a higher weight than soil type in the model. The only requirement is that all of the weights total 100 percent, giving flexibility when one factor has more impact than another on a species. For this baseline model, all layers were weighted evenly (Table 12). This weighting process is the final stage of the model building preparation process.

Table 12. Weight of each environmental layer used in the model. The weight of each layer indicates its relative influence in the model (which must total 100 % for all of the layers).

Environmental Layer	Layer Weight in Model (%)
Geologic stratigraphy	11
Soil type	12
Environmental subregion	11
Vegetation form	11
Vegetation general class	11
Vegetation Plumb's category	11
Rainfall	11
Elevation	11
Slope	11
Total weight for all environmental layers	100 %

All processes included in the model are documented in a flow chart, preserving the model flow and facilitating any future adjustments. This is one of the advantages of using the ModelBuilder window. All of the processes of the model flow can be seen in Figure 15. The ArcGIS Modelbuilder window is not very user-friendly when trying to create a presentable flowchart of the model. This particular flow chart includes all of the model processes from beginning to end.

Figure 16 includes the last part of the model process only, highlighting one of the advantages of the ModelBuilder process. Once the original data have been processed

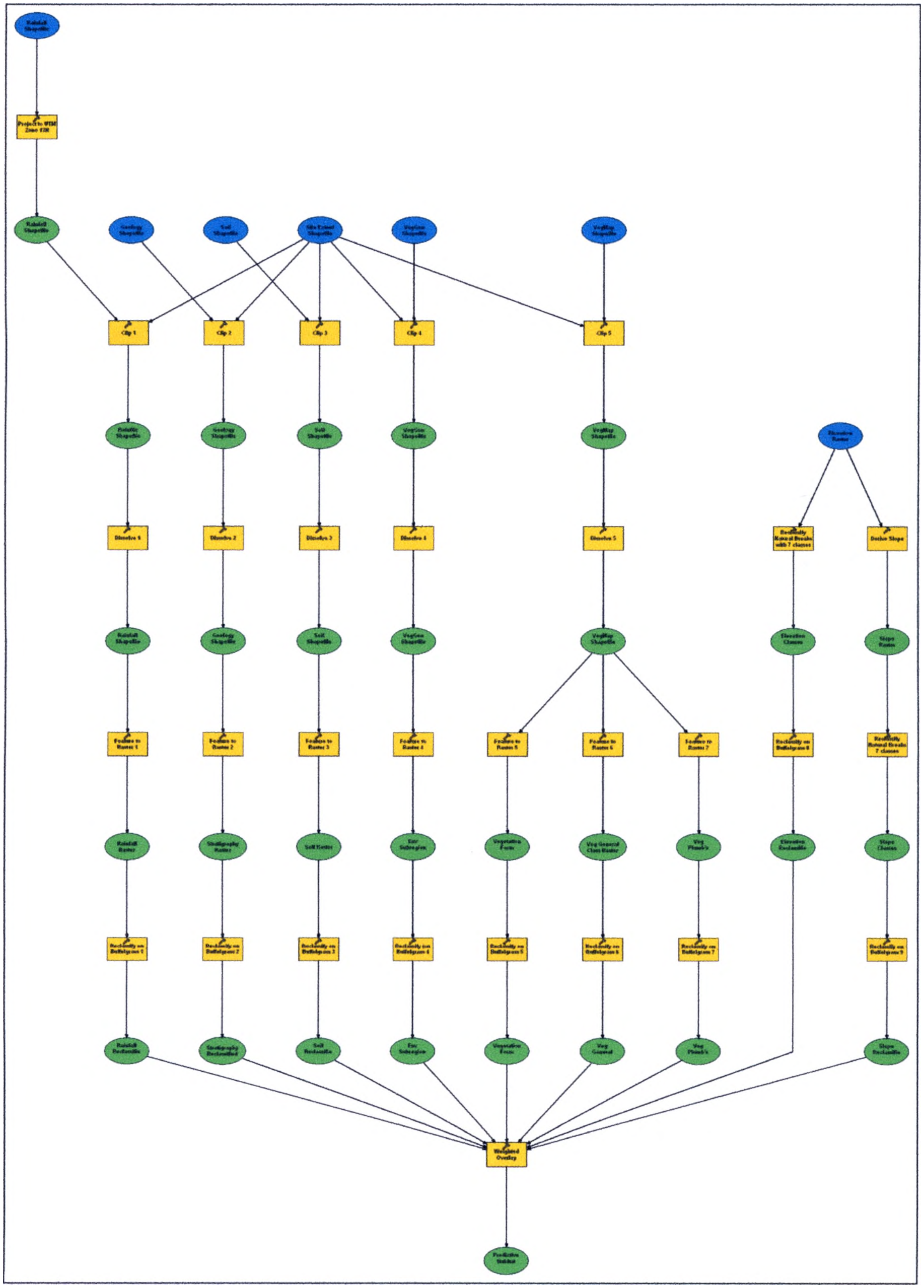

Figure 15. Flowchart of the modeling process. Flowchart includes all data processes in model, from each input environmental layer file to output predictive model file.

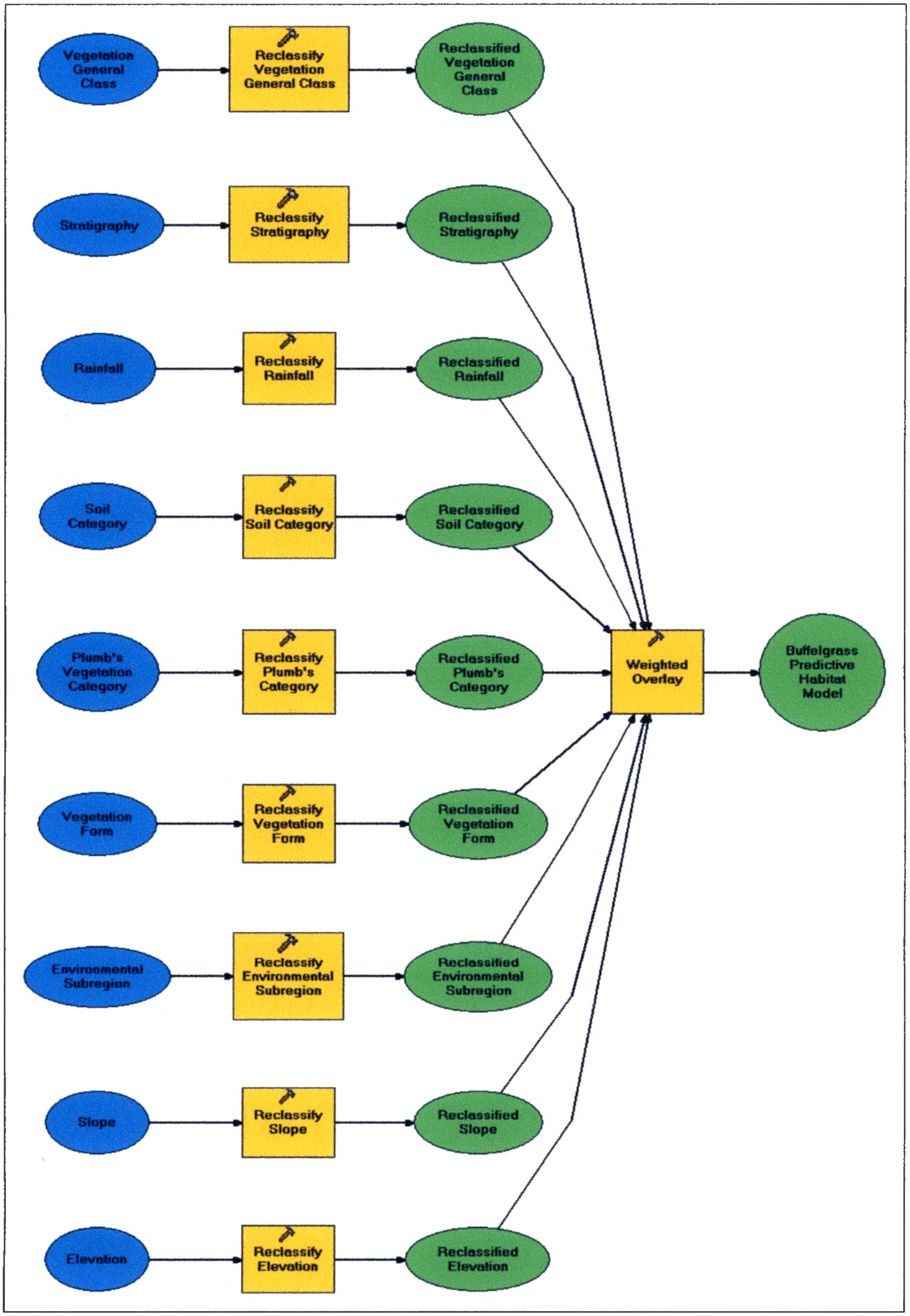

Figure 16. Highlight of the last part of the modeling process.

and the model built, it is a simple matter to remove a layer, add a new layer, reclassify a layer (blue oval), or re-weight a layer (green oval), as new information becomes available. The model can then be rerun, producing a new predictive habitat distribution map immediately, with the new data included.

The model was evaluated in the field in the spring of 2006. Validation in the field is recommended if at all possible, as it is the only way to determine with certainty if a target species occurs where it has been predicted (Anderson et al. 2003). Ten locations, where buffelgrass did not seem likely to occur due to familiarity with the park, yet where it was still predicted as likely to occur, were chosen for validation. At each validation site two parallel transect lines, each about 800 m long and at least 100 m apart were established. They were located in the field using the GPS at each site.

None of the transect sites were situated directly in the neighborhood of existing buffelgrass, and all of the validation transects were located fairly close to roads, for ease of access. Each transect was treated as a belt, with the entire area between the transect lines inspected for buffelgrass.

After the first model was validated in the field, the results were used to improve the model. The goal for improving the predictive habitat map was to lower the predicted values from 1 and 2 in the areas where the model transects contained no buffelgrass, while retaining or improving the predictability for the previously mapped buffelgrass points. Some environmental layers were eliminated from the model and the remaining layers re-weighted, producing a more accurate model.

CHAPTER III

RESULTS

Mapping

A total of 1992 buffelgrass points were mapped in the first field season (Fall 2001). What appeared to be nurse plants were associated with most of the buffelgrass mapped in the survey. Buffelgrass also grew in open unprotected sites, not associated with other plants. Fewer than 30 species of plants accounted for 99 percent of the "nurse plants" recorded in 2001 (Table 13).

Table 13. Summary of plants associated with buffelgrass in Big Bend National Park.

Common name	Scientific name	Family
Acacia	*Acacia* spp.	Fabaceae
Beebush, Whitebrush	*Aloysia* spp.	Verbenaceae
Burro brush	*Hymenoclea monogyra*	Asteraceae
Cactus	*Opuntia* spp.	Cactaceae
Creosotebush	*Larrea tridentata*	Zygophyllaceae
Desert willow	*Chilopsis linearis*	Bignoniaceae
Ephedra	*Ephedra* spp.	Ephedraceae
Four-winged saltbush	*Atriplex canescens*	Chenopodiaceae
Guayacan	*Guaiacum angustifolium*	Zygophyllaceae
Krameria	*Krameria* spp.	Krameriaceae
Leatherstem	*Jatropha dioica*	Euphorbiaceae
Lechuguilla	*Agave lechuguilla*	Liliaceae
Lotebush	*Ziziphus obtusifolia*	Rhamnaceae
Mesquite	*Prosopis glandulosa*	Fabaceae
Ocotillo	*Fouquieria splendens*	Fouquieriaceae
Purple sage, Ceniza	*Leucophyllum* spp.	Scrophulariaceae
Saltcedar	*Tamarix* spp.	Tamaricaceae
Shrubby poreleaf	*Porophyllum scoparium*	Asteraceae
Skeleton-leaf goldeneye	*Viguiera stenoloba*	Asteraceae
Yucca	*Yucca* spp.	Liliaceae

Mapping of new buffelgrass infestations continued in the fall of 2002. A total of 493 additional buffelgrass points were mapped in the field. During the 2002 field season, buffelgrass was noticed to occur next to quite a few different types of objects (Figure 17), so recording any "nurse plants" associated with buffelgrass while mapping with the GPS was discontinued.

Figure 17. Buffelgrass growing against different abiotic objects. Objects other than plants offer protection for buffelgrass establishment.

The compiling of the 7400 buffelgrass points into one database allowed the percentages of buffelgrass found in the nine different environmental layers to be calculated for all of the buffelgrass mapped in the park as of May 2005. In addition to elevation, geologic formation, and soil type, the percentage of buffelgrass found in the following layers was also determined: environmental subregion, vegetation form, general vegetation class, Plumb's vegetation categories, rainfall layer, and slope. These are the same nine environmental layers used in the modeling process.

As of May 2005, ninety-one percent of the buffelgrass points mapped in the park occurred between about 520 and 750 meters (Table 14).

Table 14: Elevation range of buffelgrass mapped in Big Bend National Park as of May 2005.

Elevation Range	Percentage of Buffelgrass Points
521 to 751 m	91 %
Other	9 %

Buffelgrass points occurred on 17 of the 30 different geologic formations found in the park (Table 15). Ninety-six percent of the buffelgrass occurred on only seven formation types with sixty-four percent of the points occurring on only three geologic formations (Pleistocene-Miocene terrace pediment and valley-fill gravels; Pleistocene alluvium, colluvium, and caliche; and Holocene colluvium and fan deposits).

Table 15. Geologic formations supporting buffelgrass mapped in Big Bend National Park as of May 2005.

Formation	Percentage of Buffelgrass Points
Pleist-Miocene; terrace pediment and valley-fill gravels (QTg)	24 %
Pleistocene; alluvium, colluvium, caliche (Qao)	20 %
Holocene; colluvium and fan deposits (Qf)	20 %
Holocene; non-Rio Grande floodplain and terraces (Qal)	11 %
Upper Cretaceous Aguja; clay, sandstone, lignite (Kag)	9 %
Upper Cretaceous Boquillas, San Vicente, Ernst (Kbse)	7 %
Upper Cretaceous Pen (Kp)	4 %
Other	5 %

Buffelgrass points occurred on 19 of the 26 different soil types found in the park. Eighty-five percent of the buffelgrass sites were found on seven different soil types (Table 16) with 43 percent of the points occurring on only two soil types (Chamberino very gravelly loam, undulating and rolling).

Table 16. Soil types supporting buffelgrass mapped in Big Bend National Park as of May 2005.

Soil Type	Percentage of Buffelgrass Points
Chamberino very gravelly loam, undulating (CHC)	29 %
Chamberino very gravelly loam, rolling (CHD)	14 %
Upton-Nickel association, undulating (UNC)	13 %
Pantera very gravelly sandy loam, frequently flooded (PNA)	9 %
Pajarito-Agustin association, gently sloping (PAA)	8 %
Tornillo loam, occasionally flooded (TOA)	8 %
Solis-Rock outcrop complex, rolling (SRD)	5 %
Other	15 %

Buffelgrass points occurred on 6 of the 7 different environmental subregions found in the park. Ninety-five percent of the buffelgrass sites were found in four of the environmental subregion classes (Table 17) with sixty-five percent of the points occurring in only two subregions (igneous mountains and foothills; and desert plains).

Table 17. Environmental subregions supporting buffelgrass mapped in Big Bend National Park as of May 2005.

Environmental Subregion	Percentage of Buffelgrass Points
Igneous mountains and foothills	35 %
Desert plains	30 %
Limestone mountains and foothills	16 %
Riparian	12 %
Other	7 %

Buffelgrass points occurred on 5 of the 6 different vegetation forms found in the park. Eighty-eight percent of the sites were found in only two of the vegetation form classes (Table 18), with seventy-seven percent of the points located in the shrub desert.

Table 18. Vegetation forms supporting buffelgrass mapped in Big Bend National Park as of May 2005.

Vegetation Form	Percentage of Buffelgrass Points
Shrub desert	77 %
Floodplain-arroyo	11 %
Other	12 %

Buffelgrass points occurred in 8 of the 11 general vegetation classes found in the park. Eighty-seven percent of the sites were found in only three of the general vegetation classes (Table 19) with sixty-two percent of the points located in the creosote scrub.

Table 19. General vegetation classes supporting buffelgrass mapped in Big Bend National Park as of May 2005.

General Vegetation Class	Percentage of Buffelgrass Points
Creosote scrub	62 %
Lechuguilla scrub	14 %
Upland riparian	11 %
Other	12 %

Buffelgrass points occurred in 21 of the 28 Plumb vegetation categories found in the park. Eighty-four percent of the sites were found in seven of the Plumb vegetation categories (Table 20) with thirty-two percent of the points found in only one category (creosote-lechuguilla-prickly pear).

Table 20. Plumb's vegetation categories supporting buffelgrass mapped in Big Bend National Park as of May 2005.

Plumb's Vegetation Category	Percentage of Buffelgrass Points
Creosote-lechuguilla-prickly pear	32 %
Creosote-lechuguilla	12 %
Creosote-grass	11 %
Lechuguilla-grass-hechtia	8 %
Desert willow	7 %
Creosote flats	7 %
Lechuguilla-grass-candelilla	7 %
Other	16 %

Eighty percent of the mapped buffelgrass points fell into the 25.4 to 30.5 cm class when overlayed and queried against the rainfall layer (Table 21). This is the only data layer not obtained from Big Bend National Park. It is not known whether these measurements include other types of precipitation than rain. An additional seventeen percent of the buffelgrass points fell in the 30.6 to 35.6 cm class.

Table 21. Rainfall ranges supporting buffelgrass mapped in Big Bend National Park as of May 2005.

Rainfall	Percentage of Buffelgrass Points
25.4 to 30.5 cm	80 %
30.6 to 35.6 cm	17 %
Other	3 %

Buffelgrass points occurred in all seven of the slope classes derived for the park (Table 22). Eighty-three percent of the sites were located in the lowest slope class (less than 4.3 degrees) with an additional 10 percent located between 4.4 and 9.7 degrees.

Table 22. Slope classes supporting buffelgrass mapped in Big Bend National Park as of May 2005.

Slope	Percentage of Buffelgrass Points
0 to 4.3 degrees	82 %
4.4 to 9.7 degrees	10 %
Other	8 %

Vegetation Transects

A total of 518.8 m of line transect length and 518.8 m^2 of belt transect area was established in the 24 monitoring plots. A complete list of all species occurring in the monitoring plots is presented in Table 23. Only 7 species occurred in all four monitoring units. The mapping was done in the fall and early winter months, representing plants growing during this time.

Table 23. Plant species occurring in the monitoring units.

Species	Common Name	Family	Monitoring Units Containing Species
Agave lechuguilla	Lechuguilla	Agavaceae (Liliaceae)	4
Allionia incarnata	Trailing windmills	Nyctaginaceae	4
Argythamnia neomexicana	New Mexico wild mercury	Euphorbiaceae	1, 2, 3, 4
Atriplex acanthocarpa	Armed saltbush	Chenopodiaceae	3
Bahia absinthifolia	Hairyseed bahia	Asteraceae	1, 2, 3, 4
Bouteloua gracilis	Blue grama	Poaceae	4
Bouteloua trifida	Red grama	Poaceae	3
Cenchrus ciliaris	Buffelgrass	Poaceae	1, 2, 3, 4
Cevallia sinuata	Stinging cevallia	Loasaceae	4
Chamaesyce spp.	Euphorbia	Euphorbiaceae	1, 2, 3, 4
Croton pottsii	Croton	Euphorbiaceae	1, 4
Echinocactus texensis	Horse crippler	Cactaceae	1
Echinocereus chloranthus	Green-flowered pitaya	Cactaceae	4
Euphorbia antisyphilitica	Candelilla	Euphorbiaceae	4
Forestiera angustifolia	Desert olive	Oleaceae	4
Guaiacum angustifolium	Guayacan	Zygophyllaceae	4
Gutierrezia sarothrae	Broom snakeweed	Asteraceae	1
Heliotropium confertifolium	Leafy heliotrope	Boraginaceae	4
Hilaria mutica	Tobosa	Poaceae	3
Isocoma pluriflora	Jimmyweed	Asteraceae	3
Jatropha dioica	Leatherstem	Euphorbiaceae	1, 4
Larrea tridentata	Creosotebush	Zygophyllaceae	1, 2, 3, 4
Leucophyllum frutescens	Cenizo	Scrophulariaceae	1
Leucophyllum minus	Big Bend silverleaf	Scrophulariaceae	4
Lippia graveolens	Scented lippia	Verbenaceae	4
Machaeranthera pinnatifida	Cutleaf goldenweed	Asteraceae	2, 3, 4
Menodora scabra	Rough menodora	Oleaceae	3
Nerisyrenia camporum	Bicolor greggia,	Brassicaceae	1, 2
Nicolletia edwardsii	Edwards nicolletia	Asteraceae	1, 4
Opuntia engelmannii	Engelmann pricklypear	Cactaceae	1, 4
Opuntia leptocaulis	Tasajillo	Cactaceae	1, 2, 3, 4
Opuntia macrocentra	Purple pricklypear	Cactaceae	1, 2
Opuntia schottii	Dog cholla	Cactaceae	1, 3, 4
Pappophorum bicolor	Pink pappusgrass	Poaceae	3
Pappophorum vaginatum	Whiplash pappusgrass	Poaceae	3

Table 23-Continued. Plant species occurring in the monitoring units.			
Species	**Common Name**	**Family**	**Monitoring Units Containing Species**
Parthenium confertum	Lyreleaf parthenium	Asteraceae	4
Pectis angustifolia	Lemonweed	Asteraceae	1
Physalis hederaefolia	Groundcherry	Solanaceae	4
Prosopis glandulosa	Honey mesquite	Fabaceae	2, 3, 4
Salsola kali	Russian thistle	Chenopodiaceae	3
Sarcostemma cyanchoides	Arroya twinevine	Asclepiadaceae	1
Senna durangensis	Durango senna	Fabaceae	1, 3, 4
Sphaeralcea angustifolia	Globemallow	Malvaceae	3
Sporobolus pyramidatus	Whorled dropseed	Poaceae	3
Suaeda suffrutescens	Desert seepweed	Chenopodiaceae	3
Thymophylla pentachaeta	Common dogweed	Asteraceae	1, 4
Tiquilia canescens	Shrubby coldenia	Boraginaceae	4
Tiquilia gossypina	Texas crinklemat	Boraginaceae	4

A summary of bare ground versus ground surface covered by vegetation in the monitoring units is presented in Table 24. In all cases, there was a considerable amount of bare ground found in the non-buffelgrasss plots versus the buffelgrass plots. Figure 18 depicts the average bare ground amount found in all plots.

Table 24. Bare ground versus ground surface covered in monitoring units. This table shows average bare ground for each plot type in each monitoring unit, bare ground totals, and percentages.

	Total Transect Length	**Average Bare Ground**	**Total Bare Ground**	**Percentage of Total Bare Ground**	**Percentage of Ground Surface Covered**
Monitoring Unit 1 Chamberino soil					
Buffelgrass plots	60.40 m	1.80 m	5.42 m	8.97 %	91.03 %
Non-buffelgrass plots	60.40 m	16.96 m	50.89 m	84.25 %	15.75 %
Monitoring Unit 2 Tornillo soil					
Buffelgrass plots	52.00 m	0.99 m	2.98 m	5.73 %	94.27 %
Non-buffelgrass plots	52.00 m	14.25 m	42.47 m	81.67 %	18.33 %
Monitoring Unit 3 Pantera soil					
Buffelgrass plots	65.00 m	1.55 m	4.65 m	7.15 %	92.85 %
Non-buffelgrass plots	65.00 m	12.92 m	38.75 m	59.62 %	40.38 %
Monitoring Unit 4 Upton-Nickel soil					
Buffelgrass plots	82.00 m	3.24 m	9.72 m	11.85 %	88.15 %
Non-buffelgrass plots	82.00 m	21.63 m	64.88 m	79.12 %	20.88 %
Overall Totals					
Buffelgrass plots	259.40 m		22.77 m	8.78 %	91.22 %
Non-buffelgrass plots	259.40 m		196.99 m	75.94 %	24.06 %

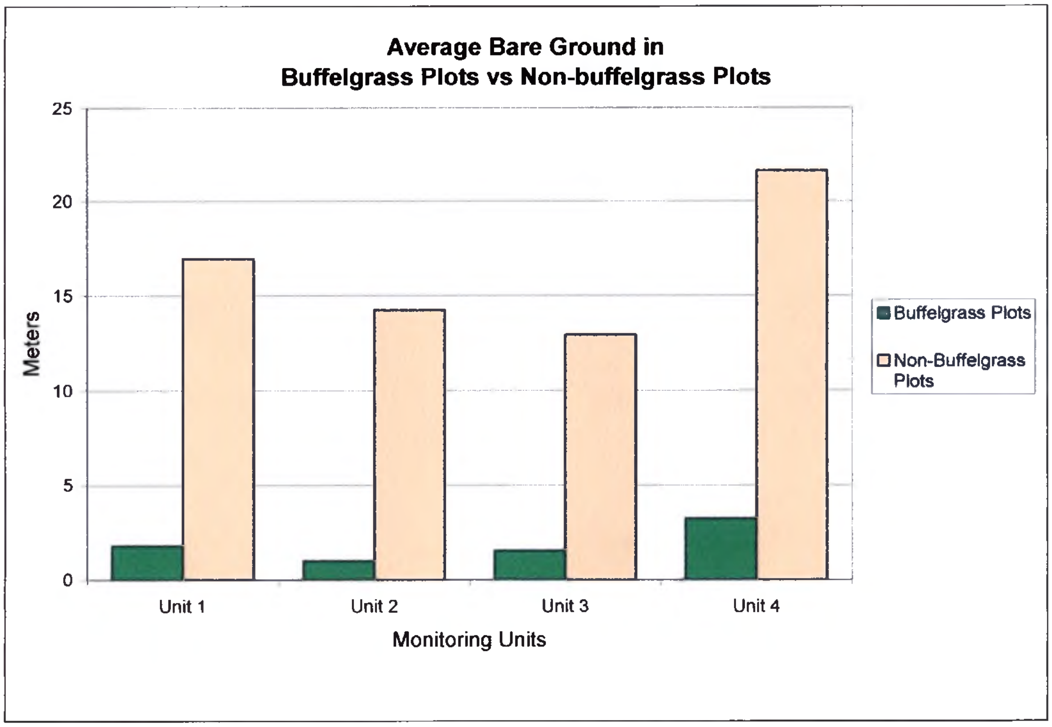

Figure 18. Graph of average bare ground amounts in all plots. The chart compares the amount of bare ground found in buffelgrass plots with that of non-buffelgrass plots.

An ANOVA test conducted on the mean values of bare ground showed a significant difference in the amount of bare ground in buffelgrass plots versus non-buffelgrass plots ($p < 0.001$; alpha = 0.05; d.f. = 6).

Figures 19 and 20 depict the relative frequencies of dominant species found in the buffelgrass and non-buffelgrass plots. Creosotebush was most abundant in monitoring units 1 and 2, supplemented by various herbaceous plants. Monitoring unit 3 appeared to be the most saline environment, supporting the halophytic species *Atriplex acanthocarpa*. Lechuguilla was most abundant in monitoring unit 4. Values calculated from vegetation measurements taken in the monitoring units are presented in Tables 25 through 40 with the raw data included in Appendix A.

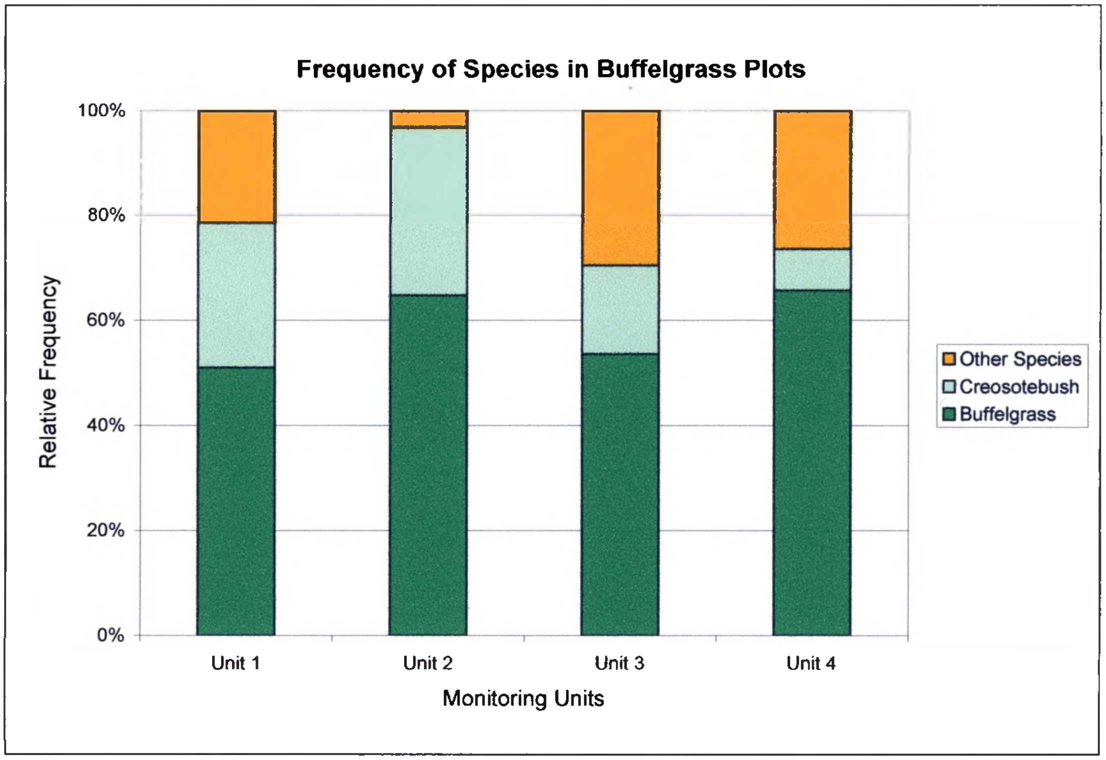

Figure 19. Frequency of species in buffelgrass plots. The relative frequencies of dominant species in the buffelgrass plots.

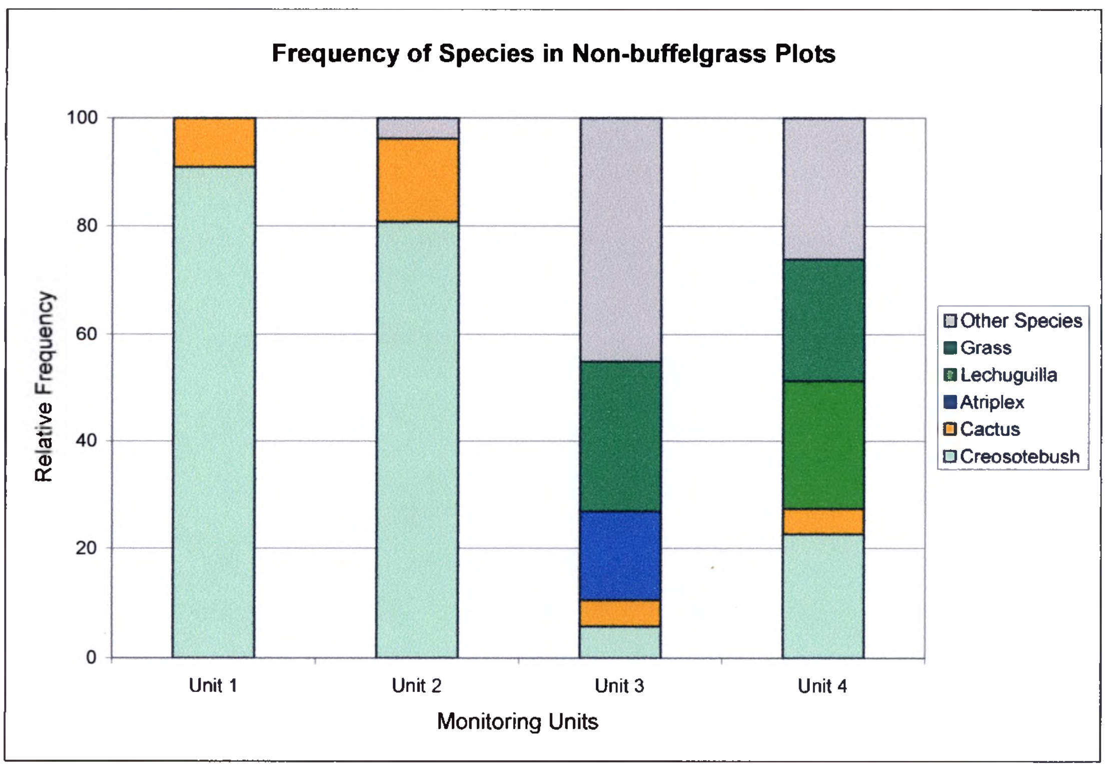

Figure 20. Frequency of species in non-buffelgrass plots. The relative frequencies of dominant species in the non-buffelgrass transects.

Table 25. Monitoring Unit 1, Buffelgrass Plots, Line Transects.

Plant Name	Cover (%)	Relative Cover (%)	Frequency (%)	Relative Frequency (%)	Importance Value
Argythamnia neomexicana	00.25	00.20	01.64	01.05	00.63
Bahia absinthifolia	08.82	06.97	18.85	12.11	09.54
Cenchrus ciliaris	78.51	62.02	79.51	51.05	56.54
Chamaesyce spp.	01.32	01.05	04.10	02.63	01.84
Larrea tridentata	32.55	25.71	42.62	27.37	26.54
Leucophyllum frutescens	00.35	00.27	00.82	00.53	00.40
Sarcostemma cyanchoides	03.97	03.14	05.74	03.68	03.41
Senna durangensis	00.81	00.64	02.46	01.58	01.11
Totals	126.59 %	100.00 %		100.00 %	

Table 26. Monitoring Unit 2, Buffelgrass Plots, Line Transects.

Plant Name	Cover (%)	Relative Cover (%)	Frequency (%)	Relative Frequency (%)	Importance Value
Argythamnia neomexicana	00.73	00.54	01.92	01.28	00.91
Cenchrus ciliaris	93.25	68.87	97.12	64.74	66.81
Larrea tridentata	39.08	28.86	48.08	32.05	30.46
Prosopis glandulosa	02.35	01.73	02.88	01.92	01.83
Totals:	135.40 %	100.00 %		100.00 %	

Table 27. Monitoring Unit 3, Buffelgrass Plots, Line Transects.

Plant Name	Cover (%)	Relative Cover (%)	Frequency (%)	Relative Frequency (%)	Importance Value
Argythamnia neomexicana	01.91	01.68	03.85	02.39	02.04
Atriplex acanthocarpa	3.51	03.08	06.92	04.31	03.69
Bouteloua trifida	00.80	00.70	02.31	01.44	01.07
Chamaesyce spp.	02.55	02.25	05.38	03.35	02.80
Cenchrus ciliaris	68.78	60.48	86.15	53.59	57.03
Hilaria mutica	00.62	00.54	01.54	00.96	00.75
Isocoma pluriflora	01.55	01.37	02.31	01.44	01.40
Larrea tridentata	20.75	18.25	26.92	16.75	17.50
Menodora scabra	03.34	02.94	05.38	03.35	03.14
Opuntia leptocaulis	03.69	03.25	06.15	03.83	03.54
Pappophorum bicolor	00.74	00.65	01.54	00.96	00.80
Prosopis glandulosa	02.40	02.11	04.62	02.87	02.49
Salsola kali	00.88	00.77	03.08	01.91	01.34
Senna durangensis	01.20	01.06	03.08	01.91	01.49
Suaeda suffrutescens	01.00	00.88	01.54	00.96	00.92
Totals:	113.72 %	100.00		100.00 %	

Table 28. Monitoring Unit 4, Buffelgrass Plots, Line Transects.

Plant Name	Cover (%)	Relative Cover (%)	Frequency (%)	Relative Frequency (%)	Importance Value
Argythamnia neomexicana	00.13	00.12	00.61	00.43	00.28
Bouteloua gracilis	00.59	00.54	00.61	00.43	00.49
Cenchrus ciliaris	82.23	75.33	92.07	65.65	70.49
Euphorbia antisyphilitica	03.52	03.23	05.49	03.91	03.57
Forestiera angustifolia	02.38	02.18	03.05	02.17	02.18
Larrea tridentata	04.65	04.26	10.98	07.83	06.04
Leucophyllum minus	02.61	02.39	03.05	02.17	02.28
Lippia graveolens	00.07	00.07	00.61	00.43	00.25
Machaeranthera pinnatifida	01.55	01.42	04.27	03.04	02.23
Opuntia engelmannii	03.09	02.83	04.27	03.04	02.94
Opuntia leptocaulis	03.20	02.93	04.27	03.04	02.99
Parthenium confertum	00.39	00.36	01.22	00.87	00.61
Prosopis glandulosa	03.84	03.52	06.10	04.35	03.93
Senna durangensis	00.91	00.84	03.66	02.61	01.72
Totals:	109.16 %	100.00 %		100.00 %	

Table 29. Monitoring Unit 1, Non-buffelgrass Plots, Line Transects.

Plant Name	Cover (%)	Relative Cover (%)	Frequency (%)	Relative Frequency (%)	Importance Value
Larrea tridentata	15.75	92.87	24.59	90.91	91.89
Opuntia leptocaulis	1.21	7.13	02.46	09.09	08.11
Totals:	16.95	100.00		100.00 %	

Table 30. Monitoring Unit 2, Non-buffelgrass Plots, Line Transects.

Plant Name	Cover (%)	Relative Cover (%)	Frequency (%)	Relative Frequency (%)	Importance Value
Bahia absinthifolia	00.38	02.16	00.96	03.85	03.00
Larrea tridentata	15.02	84.25	20.19	80.77	82.51
Opuntia leptocaulis	02.42	13.59	03.85	15.38	14.49
Totals:	17.83 %	100.00 %		100.00 %	

Table 31. Monitoring Unit 3, Non-buffelgrass Plots, Line Transects.

Plant Name	Cover (%)	Relative Cover (%)	Frequency (%)	Relative Frequency (%)	Importance Value
Argythamnia neomexicana	03.82	08.61	08.46	10.58	09.59
Atriplex acanthocarpa	06.63	14.95	13.08	16.35	15.65
Bouteloua trifida	01.66	03.75	03.08	03.85	03.80
Chamaesyce spp.	02.42	05.45	03.08	03.85	04.65

Table 31-Continued. Monitoring Unit 3, Non-buffelgrass Plots, Line Transects.					
Plant Name	**Cover (%)**	**Relative Cover (%)**	**Frequency (%)**	**Relative Frequency (%)**	**Importance Value**
Larrea tridentata	02.66	06.00	04.62	05.77	05.88
Menodora scabra	00.71	01.60	01.54	01.92	01.76
Opuntia leptocaulis	02.38	05.38	03.85	04.81	05.09
Prosopis glandulosa	06.72	15.16	07.69	09.62	12.39
Senna durangensis	00.83	01.87	03.85	04.81	03.34
Sphaeralcea angustifolia	03.15	07.11	06.15	07.69	07.40
Sporobolus pyramidatus	10.71	24.15	19.23	24.04	24.09
Suaeda suffrutescens	02.65	05.97	05.38	06.73	06.35
Totals:	44.34 %	100.00 %		100.00 %	

Table 32. Monitoring Unit 4, Non-buffelgrass Plots, Line Transects.

Plant Name	**Cover (%)**	**Relative Cover (%)**	**Frequency (%)**	**Relative Frequency (%)**	**Importance Value**
Agave lechuguilla	05.41	24.08	12.20	23.81	23.94
Allionia incarnata	00.21	00.92	01.22	02.38	01.65
Argythamnia neomexicana	00.67	02.98	02.44	04.76	03.87
Bahia absinthifolia	00.15	00.65	00.61	01.19	00.92
Bouteloua gracilis	04.98	22.13	11.59	22.62	22.37
Chamaesyce sp.	00.27	01.19	00.61	01.19	01.19
Euphorbia antisyphilitica	01.24	05.53	01.83	03.57	04.55
Jatropha dioica	00.35	01.57	00.61	01.19	01.38
Larrea tridentata	06.04	26.84	11.59	22.62	24.73
Opuntia engelmannii	01.04	04.61	01.22	02.38	03.50
Opuntia schottii	00.43	01.90	01.22	02.38	02.14
Senna durangensis	00.39	01.74	01.83	03.57	02.66
Tiquilia canescens	01.32	05.86	04.27	08.33	07.10
Totals	22.49 %	100.00 %			

Table 33. Monitoring Unit 1, Buffelgrass Plots, Belt Transects.

Plant Name	**Frequency (%)**	**Relative Frequency (%)**	**Density (plants per m^2)**	**Relative Density (%)**	**Importance Value**
Argythamnia neomexicana	33.33	5.00	0.20	04.35	04.68
Bahia absinthifolia	100.00	15.00	1.16	25.36	20.18
Cenchrus ciliaris	100.00	15.00	2.52	55.07	35.04
Chamaesyce spp.	33.33	5.00	0.05	01.09	03.05
Croton pottsii	33.33	5.00	0.03	00.72	02.86
Gutierrezia sarothrae	33.33	5.00	0.02	00.36	02.68
Jatropha dioica	33.33	5.00	0.03	00.72	02.86

Table 33-Continued. Monitoring Unit 1, Buffelgrass Plots, Belt Transects.					
Plant Name	**Frequency (%)**	**Relative Frequency (%)**	**Density (plants per m²)**	**Relative Density (%)**	**Importance Value**
Larrea tridentata	100.00	15.00	0.26	05.80	10.40
Leucophyllum frutescens	33.33	5.00	0.02	00.36	02.68
Pectis angustifolia	33.33	5.00	0.03	00.72	02.86
Sarcostemma cyanchoides	66.67	10.00	0.02	02.54	06.27
Senna durangensis	66.67	10.00	0.13	02.90	06.45
Totals:		100.00 %		100.00 %	

Table 34. Monitoring Unit 2, Buffelgrass Plots, Belt Transects.

Plant Name	Frequency (%)	Relative Frequency (%)	Density (plants per m²)	Relative Density (%)	Importance Value
Argythamnia neomexicana	33.33	09.09	00.04	01.74	05.42
Cenchrus ciliaris	100.00	27.27	01.94	87.83	57.55
Larrea tridentata	100.00	27.27	00.13	06.09	16.68
Machaeranthera pinnatifida	33.33	09.09	00.02	00.87	04.98
Opuntia leptocaulis	66.67	18.18	00.04	01.74	09.96
Prosopis glandulosa	33.33	09.09	00.04	01.74	05.42
Totals:		100.00 %		100.00 %	

Table 35. Monitoring Unit 3, Buffelgrass Plots, Belt Transects.

Plant Name	Frequency (%)	Relative Frequency (%)	Density (plants per m²)	Relative Density (%)	Importance Value
Argythamnia neomexicana	66.67	07.41	00.17	16.87	12.14
Atriplex acanthocarpa	33.33	3.70	00.02	01.61	02.66
Bouteloua trifida	100.00	11.11	00.02	02.01	06.56
Cenchrus ciliaris	100.00	11.11	00.57	57.43	34.27
Chamaesyce spp.	33.33	03.70	00.02	02.01	02.86
Hilaria mutica	33.33	03.70	0.004	00.40	02.05
Isocoma pluriflora	33.33	03.70	00.01	01.20	02.45
Larrea tridentata	100.00	11.11	00.03	03.21	07.16
Machaeranthera pinnatifida	33.33	03.70	0.004	00.40	02.05
Menodora scabra	33.33	03.70	00.06	06.02	04.86
Opuntia leptocaulis	100.00	11.11	00.03	02.81	06.96
Pappophorum bicolor	33.33	03.70	0.004	00.40	02.05
Pappophorum vaginatum	33.33	3.70	00.02	01.61	02.66
Prosopis glandulosa	66.67	07.41	00.01	00.80	04.11
Salsola kali	33.33	03.70	0.004	00.40	02.05
Senna durangensis	33.33	03.70	00.02	02.01	02.86
Suaeda suffrutescens	33.33	03.70	0.004	00.80	02.25
Totals:		100.00 %		100.00 %	

Table 36. Monitoring Unit 4, Buffelgrass Plots, Belt Transects.

Plant Name	Frequency (%)	Relative Frequency (%)	Density (plants per m^2)	Relative Density (%)	Importance Value
Agave lechuguilla	33.33	03.57	00.02	00.89	02.23
Argythamnia neomexicana	66.67	07.14	00.06	02.22	04.68
Bouteloua gracilis	33.33	03.57	00.01	00.44	02.01
Cenchrus ciliaris	100.00	10.71	01.99	72.44	41.58
Croton pottsii	33.33	03.57	00.01	00.44	02.01
Euphorbia antisyphilitica	33.33	03.57	00.05	01.78	02.68
Guaiacum angustifolium	33.33	03.57	00.01	00.44	02.01
Heliotropium confertifolium	33.33	03.57	00.01	00.44	02.01
Forestiera angustifolia	33.33	03.57	00.01	00.44	02.01
Larrea tridentata	100.00	10.71	00.12	04.44	07.58
Leucophyllum minus	33.33	03.57	00.05	01.78	02.68
Machaeranthera pinnatifida	100.00	10.71	00.06	02.22	06.47
Opuntia engelmannii	66.67	07.14	00.02	00.89	04.02
Opuntia leptocaulis	33.33	03.57	00.07	02.67	03.12
Parthenium confertum	33.33	03.57	00.05	01.78	02.68
Physalis hederaefolia	33.33	03.57	00.05	01.78	02.68
Prosopis glandulosa	66.67	07.14	00.02	00.89	04.02
Senna durangensis	66.67	07.14	00.11	04.00	05.57
Totals:		100.00 %		100.00 %	

Table 37. Monitoring Unit 1, Non-buffelgrass Plots, Belt Transects.

Plant Name	Frequency (%)	Relative Frequency (%)	Density (plants per m^2)	Relative Density (%)	Importance Value
Bahia absinthifolia	66.67	15.38	00.45	49.09	32.24
Echinocactus texensis	33.33	07.69	00.02	01.82	04.76
Larrea tridentata	100.00	23.08	00.25	27.27	25.18
Nerisyrenia camporum	33.33	07.69	00.05	05.45	06.57
Nicolletia edwardsii	33.33	07.69	00.05	05.45	06.57
Opuntia engelmannii	33.33	07.69	00.02	01.82	04.76
Opuntia leptocaulis	33.33	07.69	00.02	01.82	04.76
Opuntia macrocentra	33.33	07.69	00.02	01.82	04.76
Opuntia schottii	33.33	07.69	00.02	01.82	04.76
Thymophylla pentachaeta	33.33	07.69	00.03	03.64	05.67
Totals:		100.00		100.00	

Table 38. Monitoring Unit 2, Non-buffelgrass Plots, Belt Transects.

Plant Name	Frequency (%)	Relative Frequency (%)	Density (plants per m^2)	Relative Density (%)	Importance Value
Argythamnia neomexicana	33.33	08.33	00.15	20.51	14.42
Bahia absinthifolia	100.00	25.00	00.23	30.77	27.89
Chamaesyce spp.	33.33	08.33	00.04	05.13	06.73
Larrea tridentata	100.00	25.00	00.21	28.21	26.61
Nerisyrenia camporum	33.33	08.33	00.02	02.56	05.45
Opuntia leptocaulis	33.33	08.33	00.06	07.69	08.01
Opuntia macrocentra	66.67	16.67	00.04	05.13	10.90
Totals		100.00 %		100.00%	

Table 39. Monitoring Unit 3, Non-buffelgrass Plots, Belt Transects.

Plant Name	Frequency (%)	Relative Frequency (%)	Density (plants per m^2)	Relative Density (%)	Importance Value
Argythamnia neomexicana	66.67	11.76	00.63	15.89	13.83
Atriplex acanthocarpa	33.33	05.88	00.40	10.08	07.98
Bahia absinthifolia	33.33	05.88	00.05	01.16	03.52
Bouteloua trifida	33.33	05.88	00.08	01.94	03.91
Chamaesyce spp.	33.33	05.88	00.20	05.04	05.46
Larrea tridentata	66.67	11.76	00.05	01.16	06.46
Menodora scabra	33.33	05.88	00.02	00.39	03.14
Opuntia leptocaulis	33.33	05.88	00.02	00.39	03.14
Opuntia schottii	33.33	05.88	00.03	00.78	03.33
Prosopis glandulosa	33.33	05.88	00.02	00.39	03.14
Salsola kali	33.33	05.88	00.03	00.78	03.33
Senna durangensis	33.33	05.88	00.63	15.89	10.89
Sphaeralcea angustifolia	33.33	05.88	00.32	08.14	07.01
Sporobolus pyramidatus	33.33	05.88	01.34	33.72	19.80
Suaeda suffrutescens	33.33	05.88	00.17	04.26	05.07
Totals:		100.00 %		100.00 %	

Table 40. Monitoring Unit 4, Non-buffelgrass Plots, Belt Transects.

Plant Name	Frequency (%)	Relative Frequency (%)	Density (plants per m^2)	Relative Density (%)	Importance Value
Agave lechuguilla	100.00	07.89	00.27	12.50	10.20
Allionia incarnata	33.33	02.63	00.01	00.57	01.60
Argythamnia neomexicana	66.67	05.26	00.06	02.84	04.05
Bahia absinthifolia	100.00	07.89	00.09	03.98	05.94
Bouteloua gracilis	66.67	05.26	00.46	21.59	13.43

Table 40-Continued. Monitoring Unit 4, Non-buffelgrass Plots, Belt Transects.					
Plant Name	**Frequency (%)**	**Relative Frequency (%)**	**Density (plants per m^2)**	**Relative Density (%)**	**Importance Value**
Cevallia sinuata	66.67	05.26	00.02	01.14	03.20
Chamaesyce spp.	100.00	07.89	00.13	06.25	07.07
Echinocereus chloranthus	33.33	02.63	00.01	00.57	01.60
Euphorbia antisyphilitica	33.33	02.63	00.15	06.82	04.73
Heliotropium confertifolium	66.67	05.26	00.05	02.27	03.77
Jatropha dioica	33.33	02.63	00.01	00.57	01.60
Larrea tridentata	100.00	07.89	00.22	10.23	09.06
Machaeranthera pinnatifida	66.67	05.26	00.05	02.27	03.77
Nicolletia edwardsii	33.33	02.63	00.01	00.57	01.60
Opuntia engelmannii	33.33	02.63	00.01	00.57	01.60
Opuntia leptocaulis	33.33	02.63	00.02	01.14	01.89
Opuntia schottii	33.33	02.63	00.04	01.70	02.17
Physalis hederaefolia	66.67	05.26	00.13	06.25	05.76
Senna durangensis	100.00	07.89	00.06	02.84	05.37
Thymophylla pentachaeta	33.33	02.63	00.24	11.36	07.00
Tiquilia canescens	33.33	02.63	00.07	03.41	03.02
Tiquilia gossypina	33.33	02.63	00.01	00.57	01.60
Totals:		100.00 %		100.00 %	

In all cases, the results of calculating the diversity indices tests, including the Shannon index, Evenness, and the Simpson's index, the numbers were higher in non-buffelgrass plots than in buffelgrass plots, while the species richness in the four units varied. The results of the diversity indices are summarized in Table 41.

A two-tailed paired t-test was conducted on the diversity indices to see if there was a statistically significant difference between the diversity in the buffelgrass and non-buffelgrass plots. In all cases, even though the diversity calculations appear higher for the non-buffelgrass plots, they are not statistically significant. The results are reported in Table 41. A comparison of the Shannon Index results for buffelgrass versus non-buffelgrass plots is graphed in Figure 21.

Table 41. Results of the diversity indices tests in the belt transects. The indices are not statistically significant. There is no difference.

Plots	Species Richness	Evenness	Shannon Index	Simpson's Index
Unit 1				
Buffelgrass	12	0.5516	1.371	0.6253
Non-buffelgrass	10	0.6539	1.506	0.6757
Unit 2				
Buffelgrass	6	0.2997	0.537	0.2240
Non-buffelgrass	7	0.8430	1.640	0.7719
Unit 3				
Buffelgrass	17	0.5549	1.572	0.6313
Non-buffelgrass	15	0.7354	1.992	0.8138
Unit 4				
Buffelgrass	18	0.4495	1.299	0.4683
Non-buffelgrass	22	0.8302	2.566	0.8958
Paired t-test				
p-value	0.87289	0.96018	0.94807	0.94607
alpha	0.05	0.05	0.05	0.05
d.f.	2	2	2	2

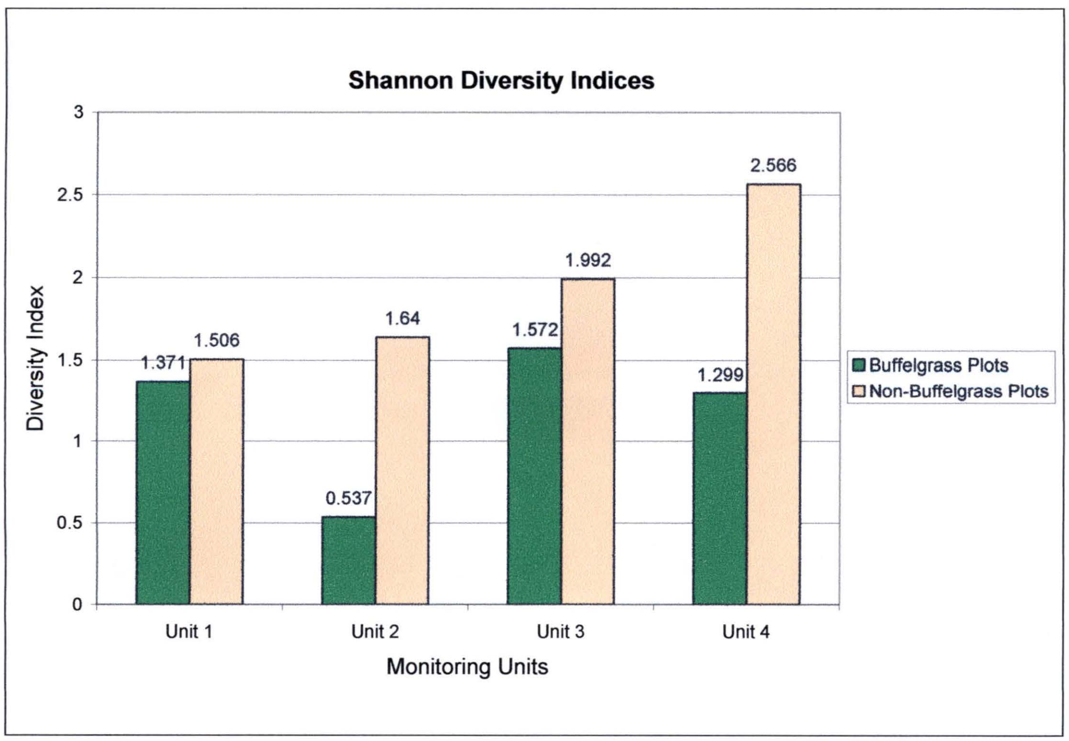

Figure 21. Graph of Shannon diversity indices. Comparison of buffelgrass and non-buffelgrass plots. Shannon diversity is not statistically significant.

Seed Bank

The seed bank results included the presence or absence of seeds in the litter layer and the soil layer from 0-2 cm, in both the buffelgrass plots and the non-buffelgrass plots in all 4 monitoring units. Litter was present in almost all of the buffelgrass plot samples, but not in all of the non-buffelgrass plot samples (about 40250 cm^3 in the buffelgrass plots versus roughly 1425 cm^3 in the non-buffelgrass plots).

The presence results for buffelgrass burs and/or seeds in the soil and litter samples are summarized in Table 42. Since none of the non-buffelgrass samples contained any buffelgrass seeds, they were not analyzed further.

Table 42. Summary of samples containing buffelgrass seeds. Total number of samples containing seeds is shown.

Location	**Buffelgrass Samples - Litter**	**Buffelgrass Samples - Soil**	**Non-buffelgrass Samples - Litter**	**Non-buffelgrass Samples - Soil**
Monitoring Unit 1	30	8	0	0
Monitoring Unit 2	30	5	0	0
Monitoring Unit 3	28	5	0	0
Monitoring Unit 4	27	6	0	0
Actual Total	115	24	0	0
Number of Samples Collected	120	120	120	120

A 2 X 2 Contingency table was constructed and analyzed to determine if the proportion of buffelgrass seeds found in the litter of buffelgrass samples was statistically different from the proportion of seeds found in the buffelgrass soil samples. Soil type was considered similar in each unit for this test. The table was set up for the test as follows:

Sample	Seeds Present	Seeds Absent	Marginal Totals
BG Litter	115	5	120
BG Soil	24	96	120
Marginal Totals	139	101	240

The results ($p < 0.001$; alpha = 0.05; d.f. = 3) are statistically significant and indicate that the proportion of seeds present in buffelgrass litter samples is dissimilar from the proportion found in buffelgrass soil samples. More seeds tend to be found in the litter than the soil.

Seed Viability

The buffelgrass burs collected for viability testing came from all of the monitoring units, with no attempt to keep the units separate. The important consideration was to collect ripe or mature seed heads for testing.

In the 2001 field season, the burs were stored at room temperature for almost one year before testing. The tetrazolium tests showed 83 percent viability in the burs. In the 2002 field season, the burs were stored at room temperature for three months before testing. The tetrazolium tests showed 64 percent viability in the burs. In all burs, the actual number of seeds viable varied from one to all three, though it was usually one or two of the seeds. The results are presented in Table 43.

Table 43. Tetrazolium test results for buffelgrass seed viability. Burs collected during the 2001 and 2002 field seasons.

Year Collected	Storage Time	Total Bur Number	Viable	Non-Viable
2001	12 months	200	166 (83%)	34 (17%)
2002	3 months	200	128 (64%)	72 (36%)

Predictive Modeling

Guisan and Zimmerman (2000) recommend that all environmental layers used in a model be included in the report as maps. This allows for visual examination by the user, exposing potential problems with the layer. The maps created for this model can be seen in Figures 22 through 30 and show both the original value and the values reclassified to the common scale of 1 to 5.

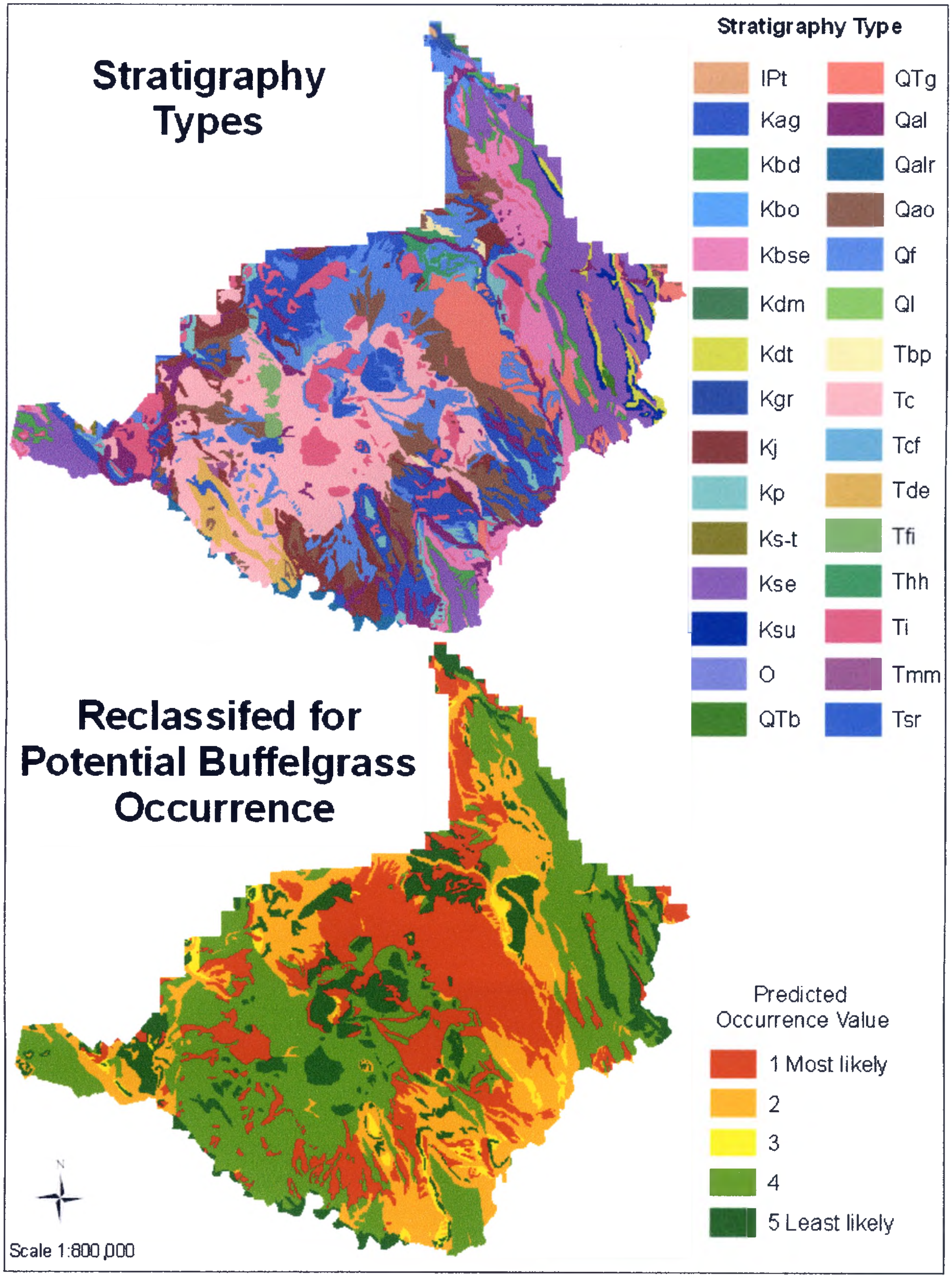

Figure 22. Stratigraphy types found in Big Bend National Park. The upper map shows the distribution of the 30 stratigraphy types found in the park. The lower map shows the stratigraphy types reclassified on a scale ranging from 1 to 5, based on the likeliness of buffelgrass occurrence.

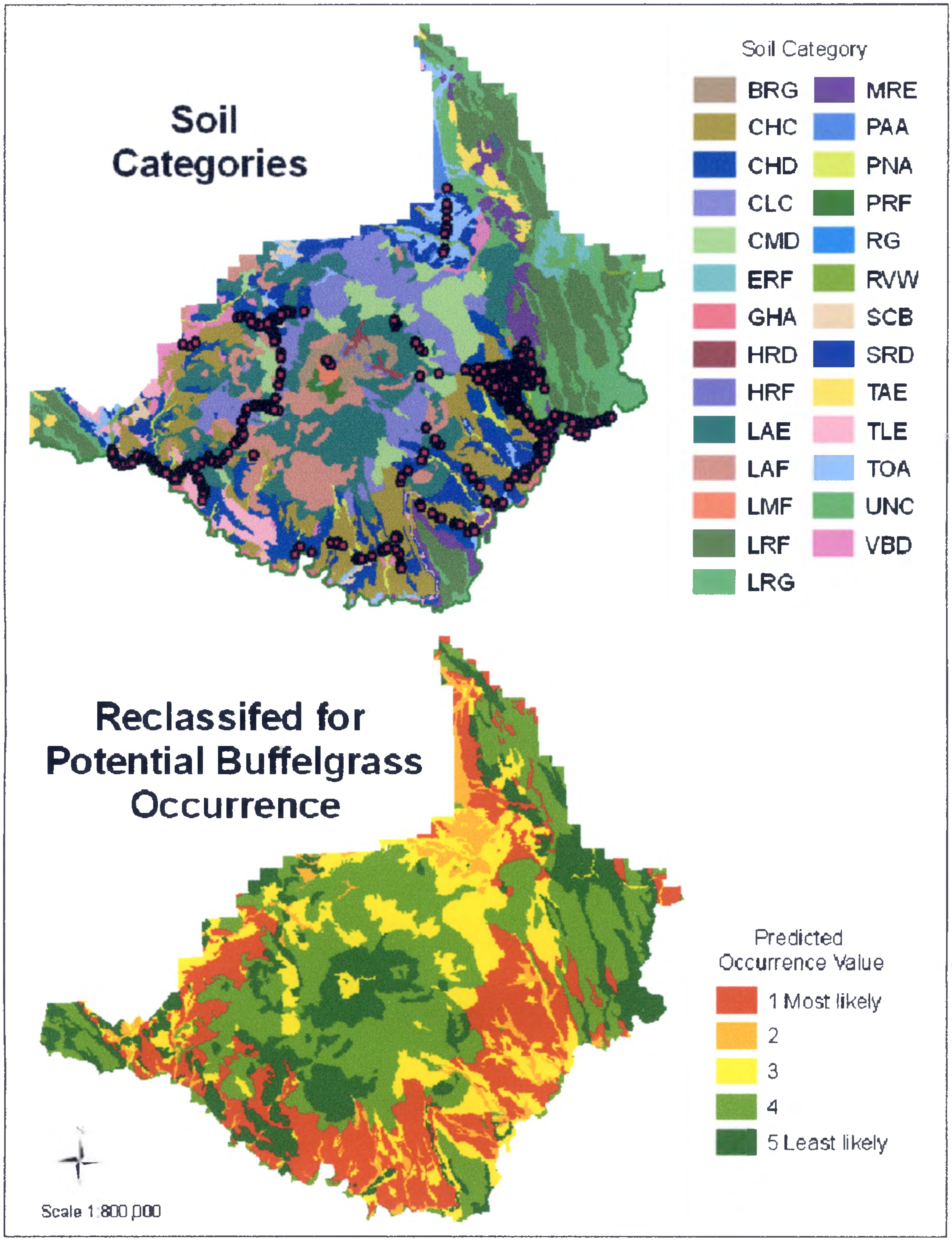

Figure 23. Soil types found in Big Bend National Park. The upper map shows the distribution of the 27 soil categories found in the park. The lower map shows the soil categories reclassified on a scale ranging from 1 to 5, based on the likeliness of buffelgrass occurrence.

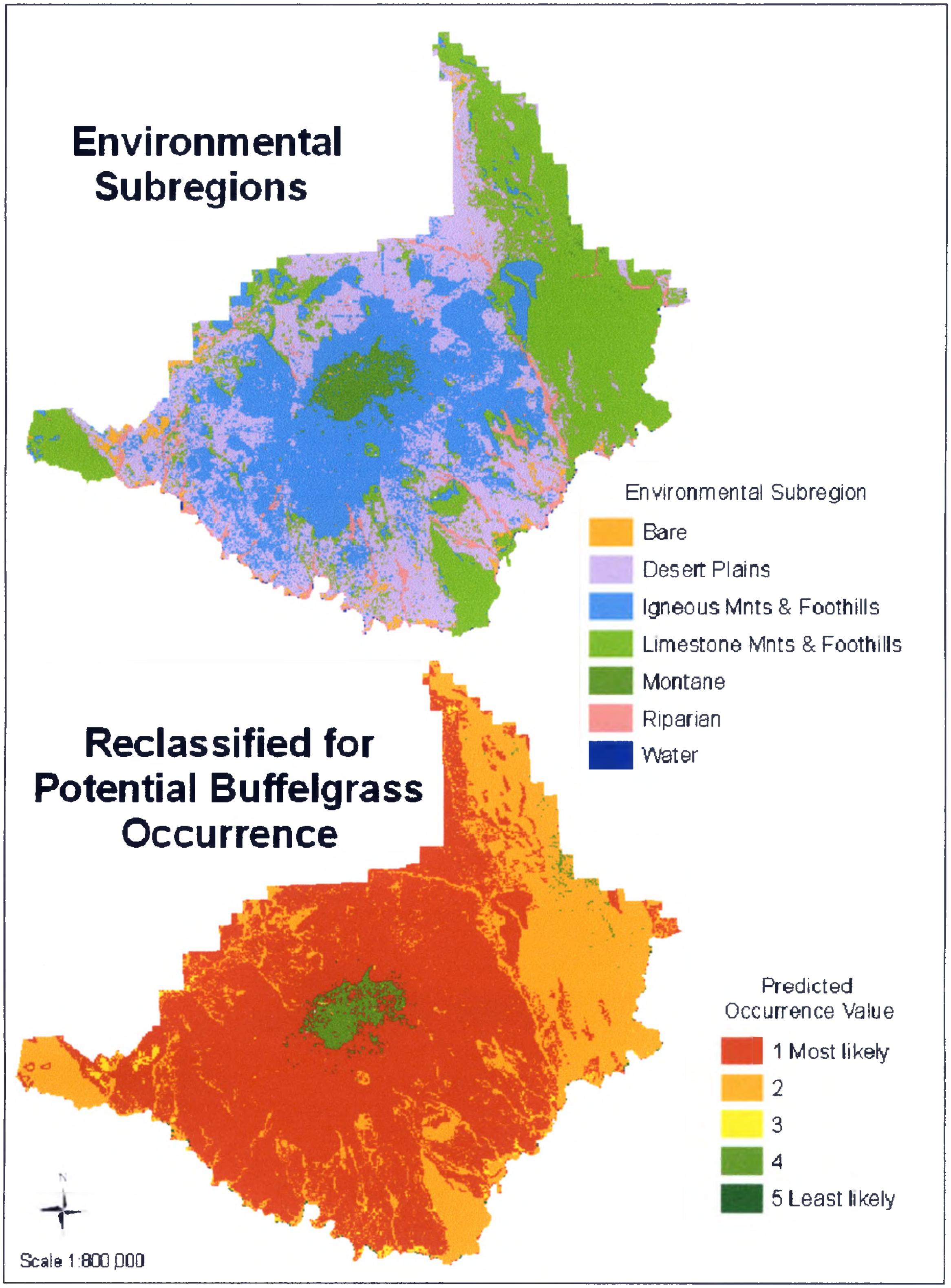

Figure 24. Environmental subregions found in Big Bend National Park. The upper map shows the distribution of the 7 environmental subregion classes found in the park. The lower map shows the environmental subregions reclassified on a scale ranging from 1 to 5, based on the likeliness of buffelgrass occurrence.

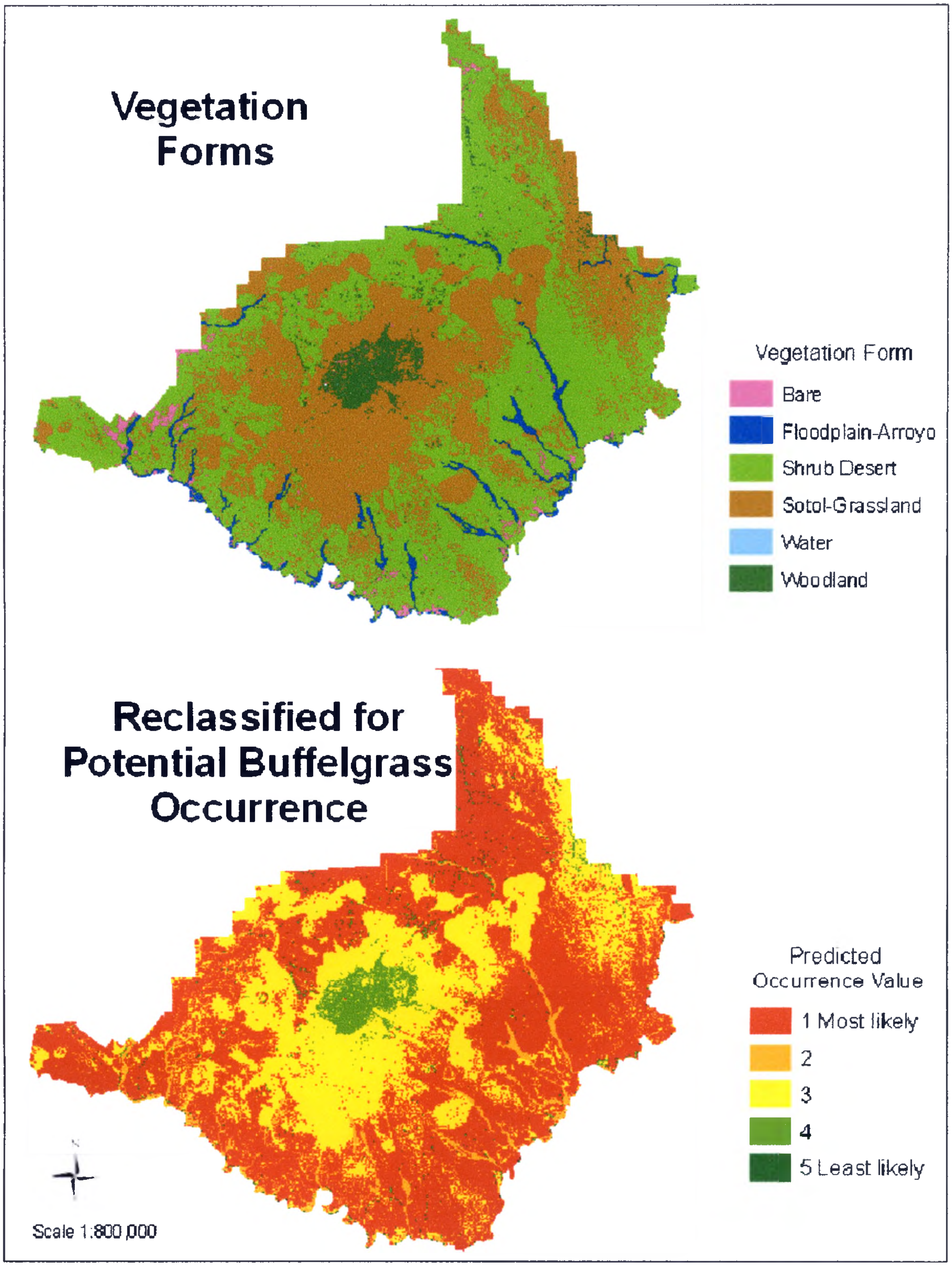

Figure 25. Vegetation forms found in Big Bend National Park. The upper map shows the distribution of the 6 vegetation form classes found in the park. The lower map shows the vegetation forms reclassified on a scale ranging from 1 to 5, based on the likeliness of buffelgrass occurrence.

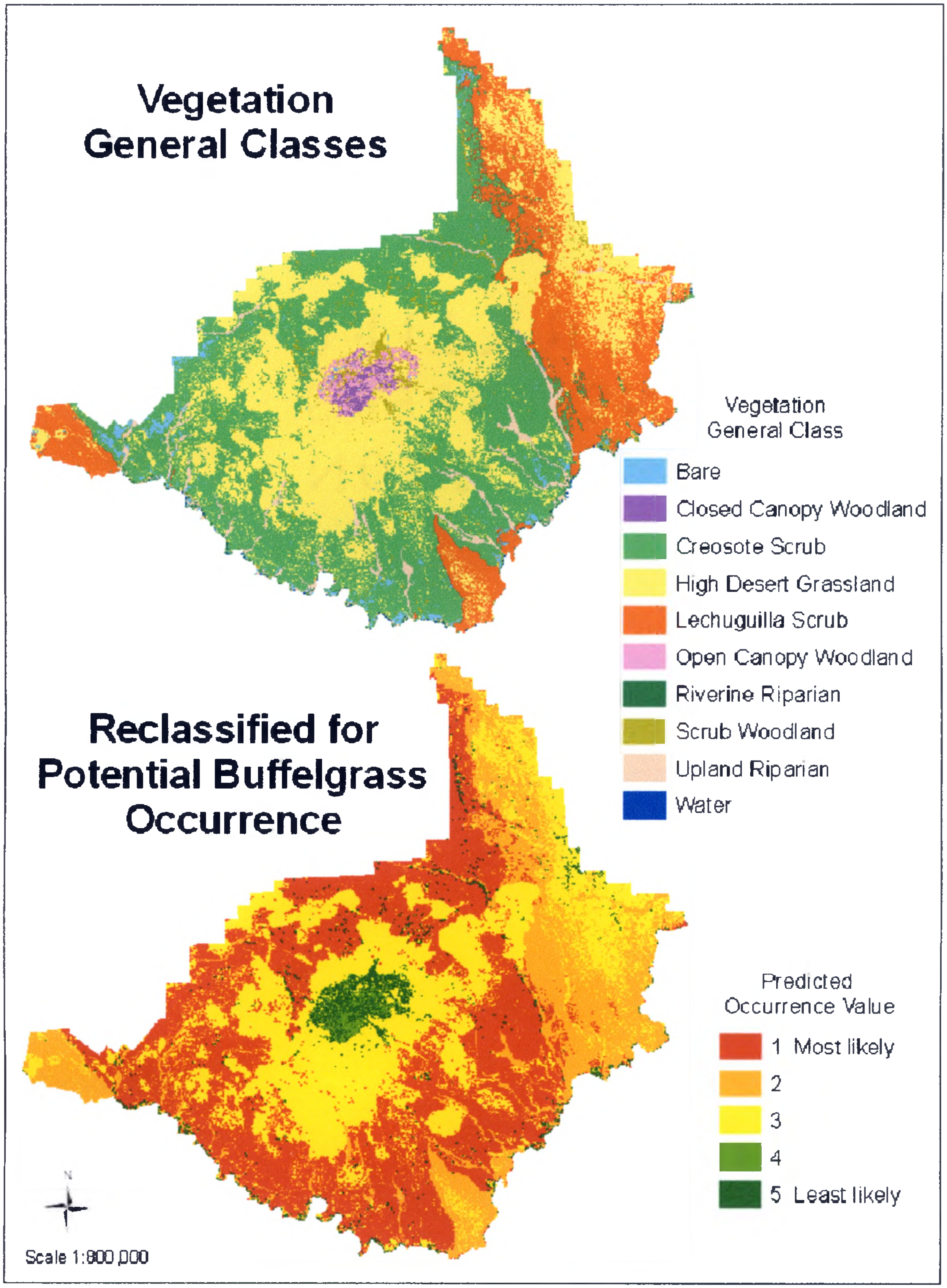

Figure 26. General vegetation classes found in Big Bend National Park. The upper map shows the distribution of the 10 general vegetation classes found in the park. The lower map shows the general vegetation classes reclassified on a scale ranging from 1 to 5, based on the likeliness of buffelgrass occurrence.

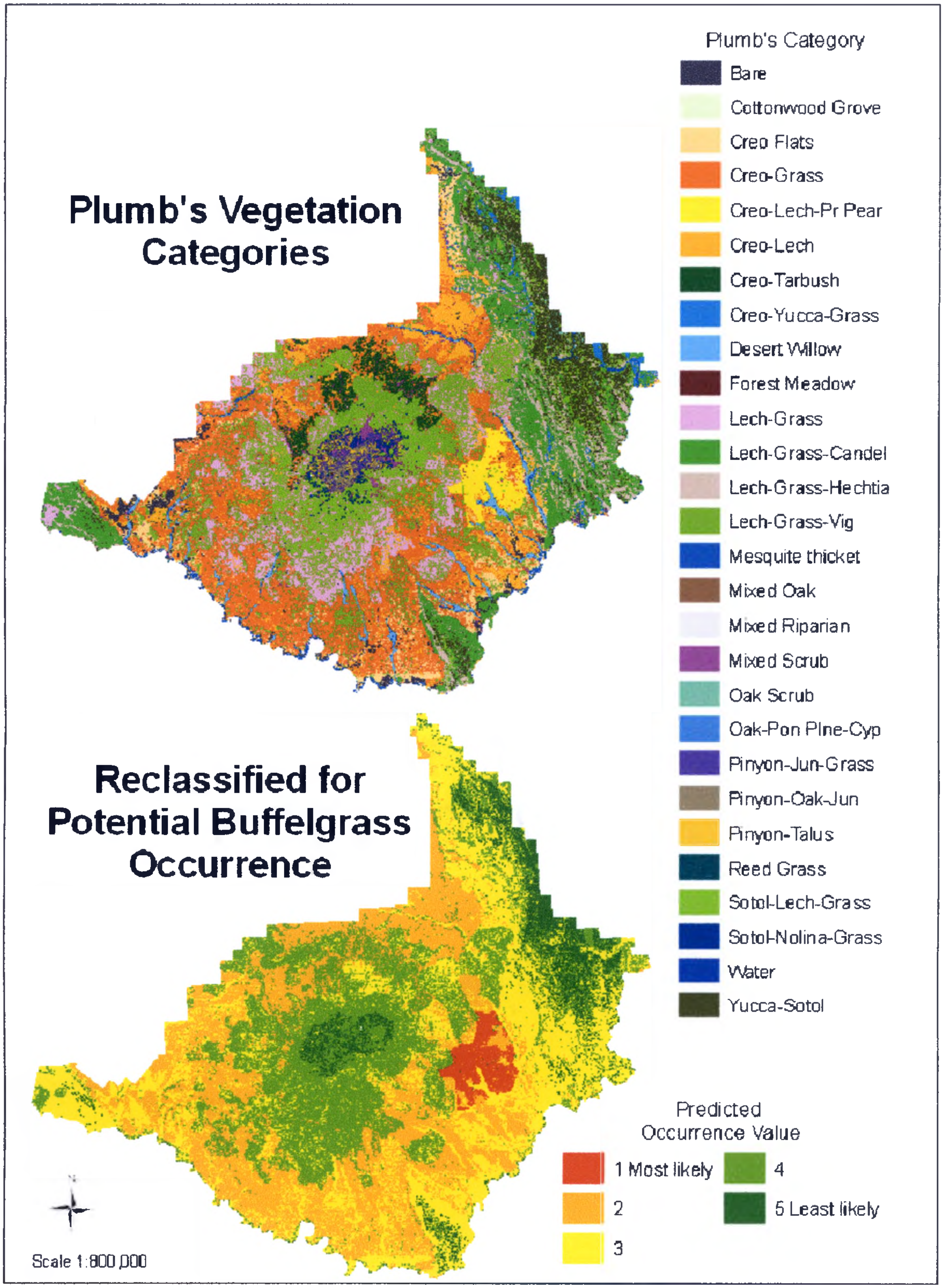

Figure 27. Plumb's vegetation categories for Big Bend National Park. The upper map shows the distribution of the 28 Plumb's vegetation classes found in the park. The lower map shows the Plumb categories reclassified on a scale ranging from 1 to 5, based on the likeliness of buffelgrass occurrence.

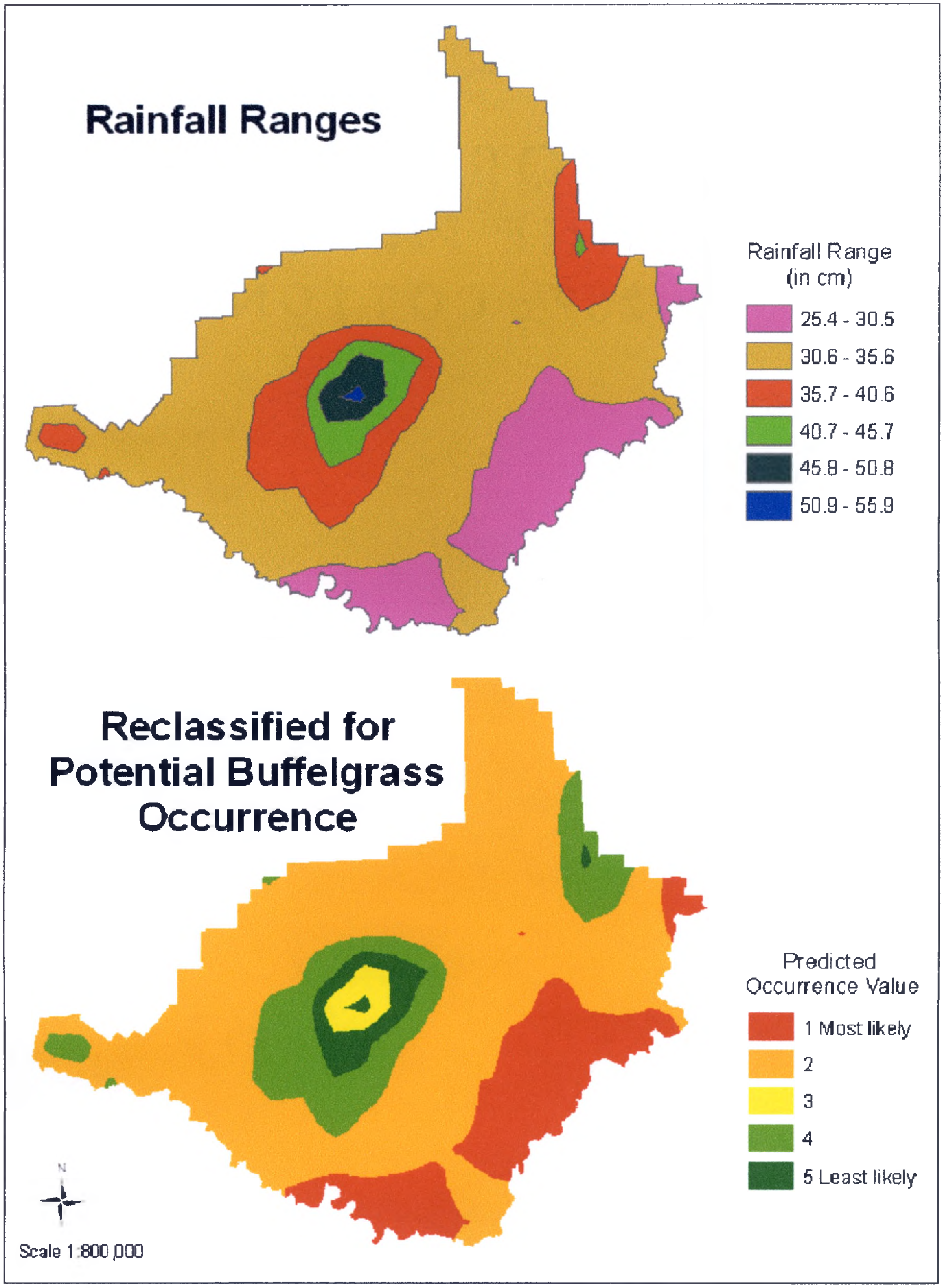

Figure 28. Rainfall ranges in Big Bend National Park. The upper map shows a rough distribution of the rainfall in the park (layer from General Land Office). The lower map shows the rainfall ranges reclassified on a scale ranging from 1 to 5, based on the likeliness of buffelgrass occurrence.

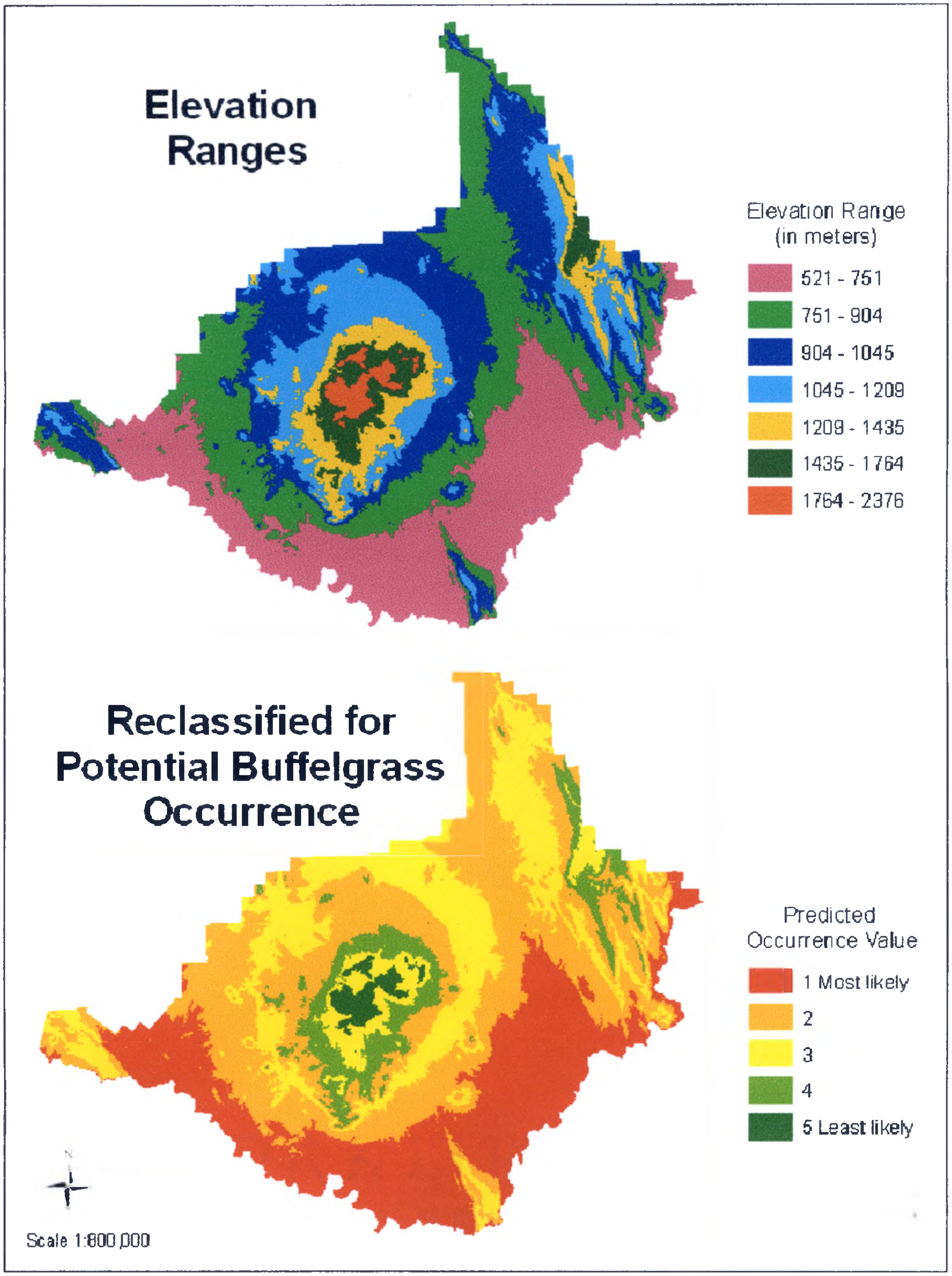

Figure 29. Elevation ranges in Big Bend National Park. The upper map shows 7 elevation ranges, classified using the Natural Breaks (Jenks) method, in the park. The lower map shows the elevation ranges reclassified on a scale ranging from 1 to 5, based on the likeliness of buffelgrass occurrence.

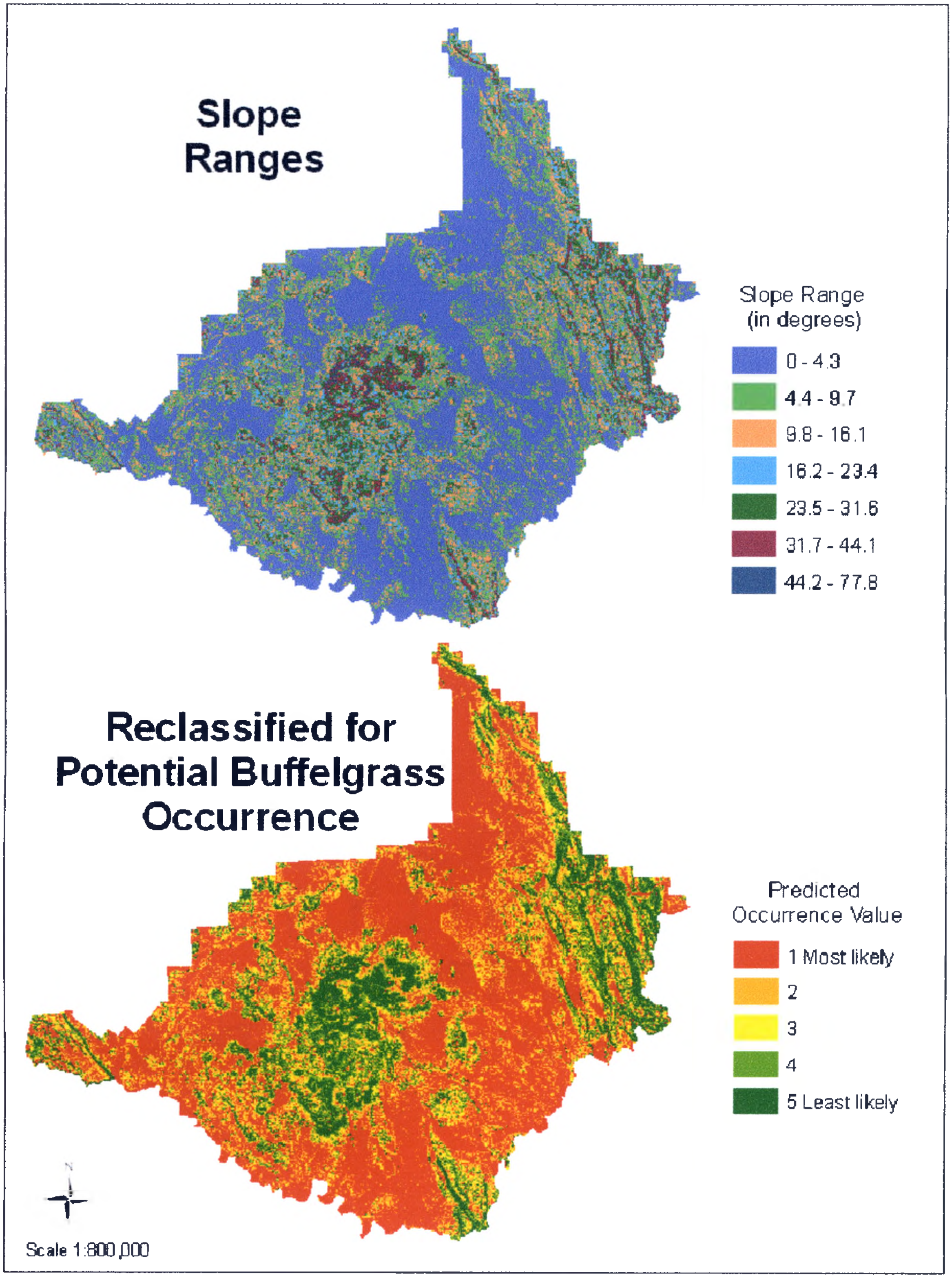

Figure 30. Slope ranges in Big Bend National Park. The upper map shows 7 slope ranges, classified using the Natural Breaks (Jenks) method, in the park. The lower map shows the slope ranges reclassified on a scale ranging from 1 to 5, based on the likeliness of buffelgrass occurrence.

The output of the baseline predictive model is presented in Figure 31. All 7400 buffelgrass points were used to define suitable buffelgrass habitat in the baseline model.

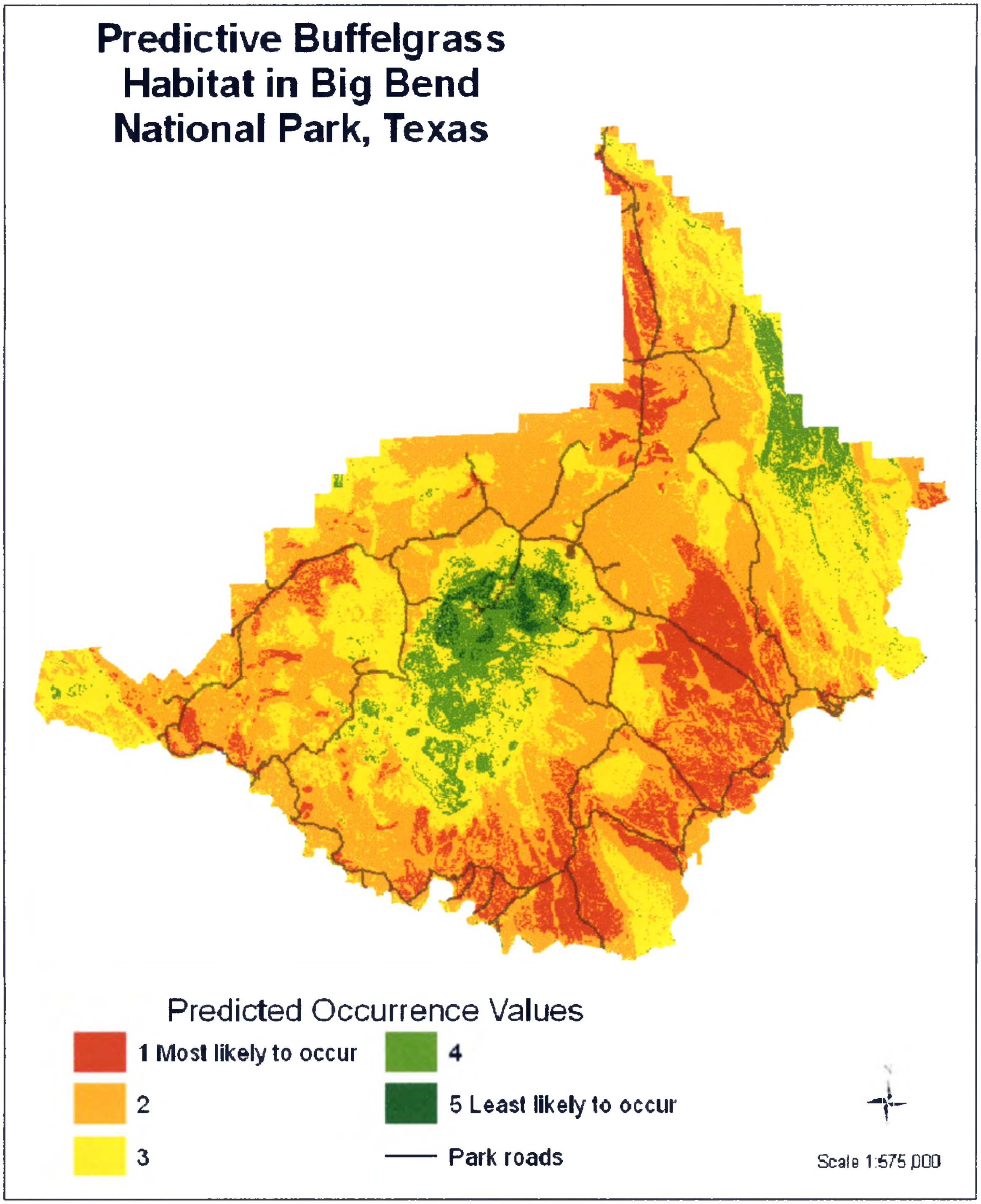

Figure 31. Predictive habitat for buffelgrass in Big Bend National Park. This map shows the results of the weighted overlay process, which combined the nine weighted environmental layers, producing a baseline map with values ranging from 1 to 5.

Table 44 shows how the initial habitat model correlated the occurrence of the mapped buffelgrass in each of the 5 values. Of the 7400 known point locations, 57.61 percent (4263) appeared in value 1 of the predictive model. Value 2 was correlated with 2852 of the buffelgrass points (38.54 percent). The buffelgrass points associated with value 3 of the predictive map decreased considerably, down to 284 points, or less than 4 percent. Value 4 was correlated with 1 point (0.01 percent), and there were no points in value 5.

Table 44. Results from querying the baseline predictive habitat map with the mapped buffelgrass points. The percentage of total point points in each value is shown.

Value	Buffelgrass Points Located in Value	Percentage of Total
1	4263	57.61
2	2852	38.54
3	284	3.84
4	1	0.01
5	0	0.00
Totals	7400	100.00

Value 1, where buffelgrass is predicted most likely to occur, represents desert plains or shrub desert areas where elevation is below about 750 meters, slope is less than about 4.5 degrees, and annual precipitation is less than 30 cm. The vegetation is mostly creosote scrub with lechuguilla and prickly pear, the soil is gravelly loam, and the geologic stratigraphy includes Pleistocene to Holocene terrace pediments, alluvium, colluvium, caliche, and fan deposits. Value five is at the highest elevations, with montane vegetation, and higher annual precipitation.

Validation transects selected for the model are presented in Figure 32. The transects were established by mapping the transect lines with UTM Easting and Northing values (Figure 33) and using the GPS to locate these values in the field. Waypoints were set for the start and finish of each transect line, and the GPS was used for direction along the transect line.

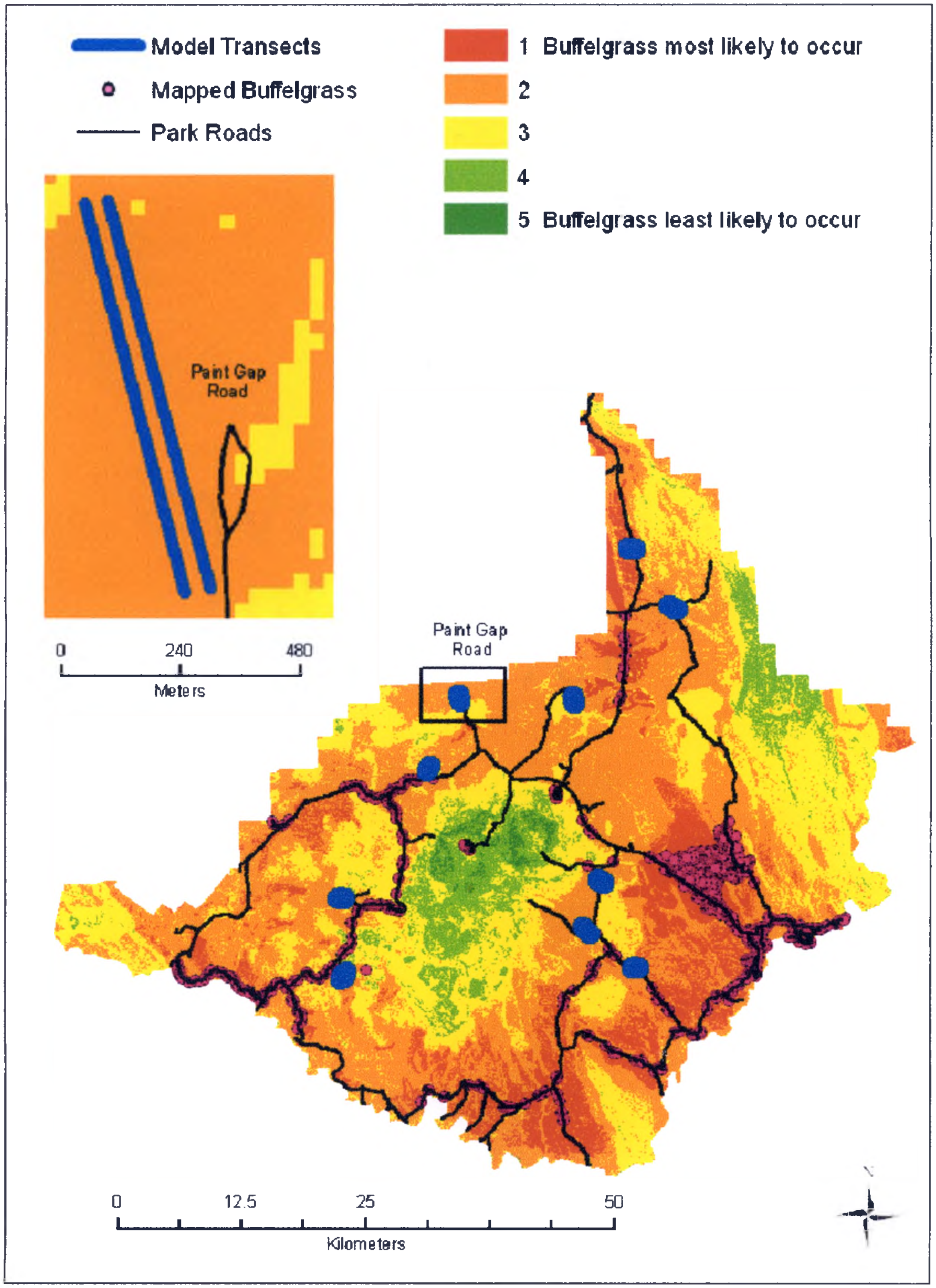

Figure 32. Model validation transects. The blue lines show the location of the model transects used for validation.

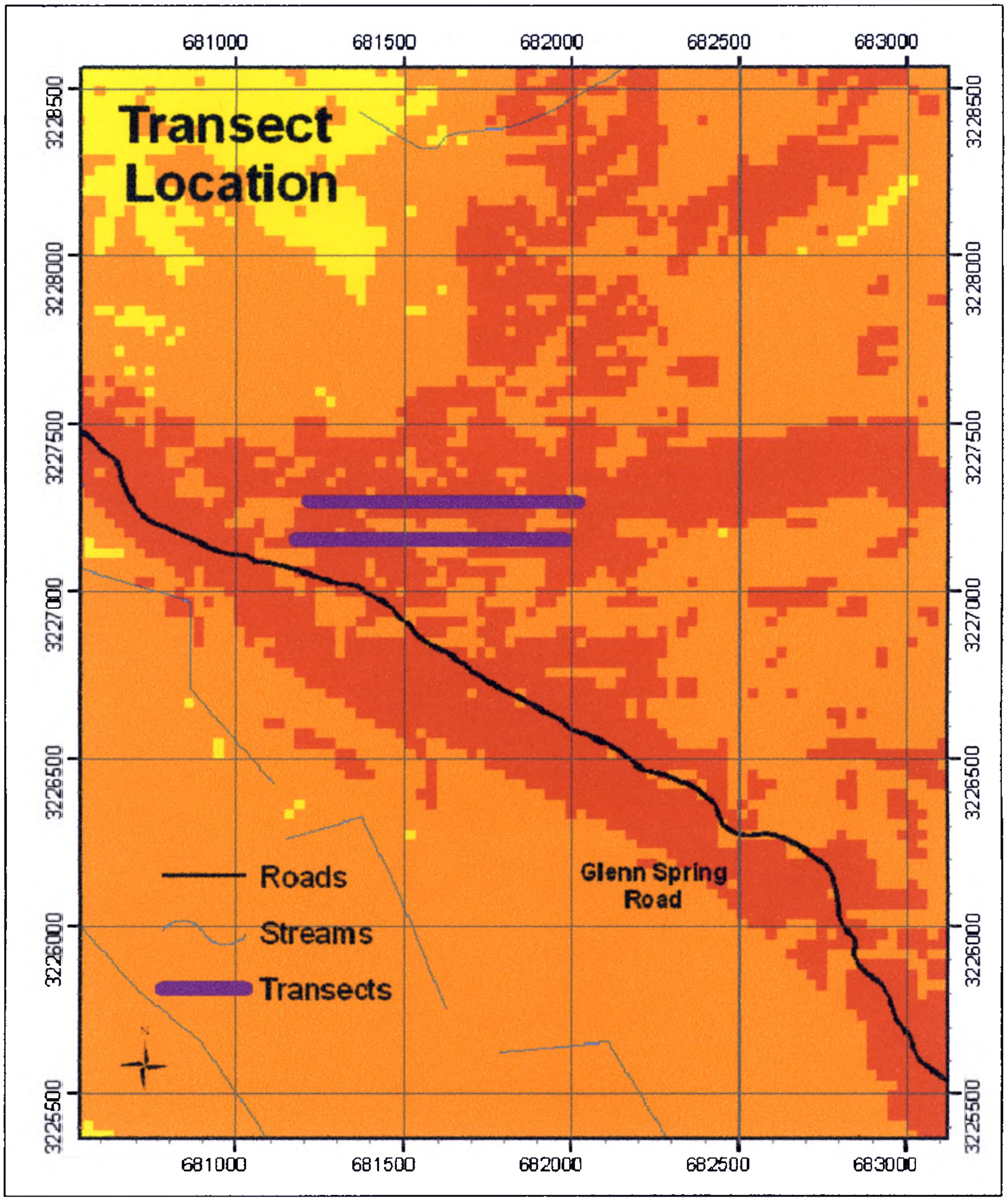

Figure 33. Transect location example. The numbers along the edges are UTM Easting and Northing values used for location with the GPS. Waypoints are programmed into the GIS for the transect lines, used to located yourself at the start of a transect line. The coordinates of the transect show a path along the transect line in the GPS.

Although no buffelgrass was found along the validation transects, two new occurrences were noticed along the road and mapped and, when compared to the model, they both end up in high predicted values of 1 and 2 (Figure 34). These two areas were located along Persimmon Gap Road, just north of Dagger Flat Road, and along Glenn Spring Road, just south of Black Gap Road.

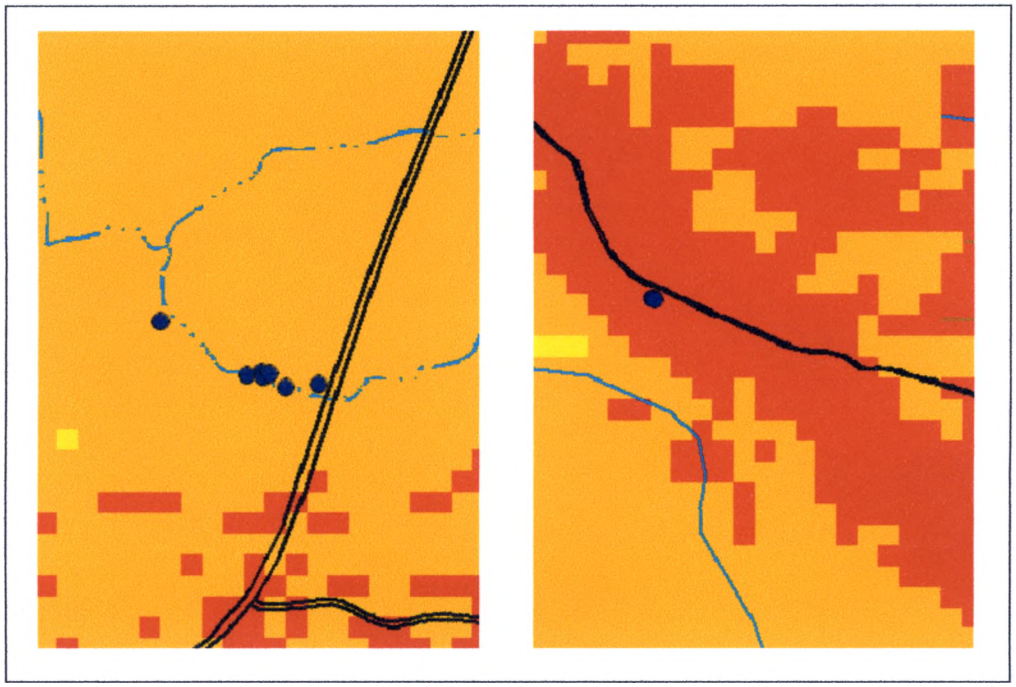

Figure 34. New buffelgrass infestations mapped in 2006. Points in blue were mapped while validating the model. The figure on the left is along Persimmon Gap Road, just north of Dagger Flat Road. The figure on the right is along Glenn Springs Road, just south of Black Gap Road. Notice how the points line up with the road in the right figure and an ephemeral arroyo in the left figure.

To improve the predicted model, subjective elimination of some environmental layers and re-weighting of the remaining layers was required. The model was rerun over 40 times, with a methodical removal and re-weighting of the layers. The improved model used six of the original nine layers. The environmental layers used in the final model and their respective weights are presented in Figure 35. The flowchart presents how the final part of the model can be re-run, with the environmental layers included in the model shown and the adjusted weighting for each layer shown. This produced a new model, based on the new input. The final, improved predictive model is presented in Figure 36.

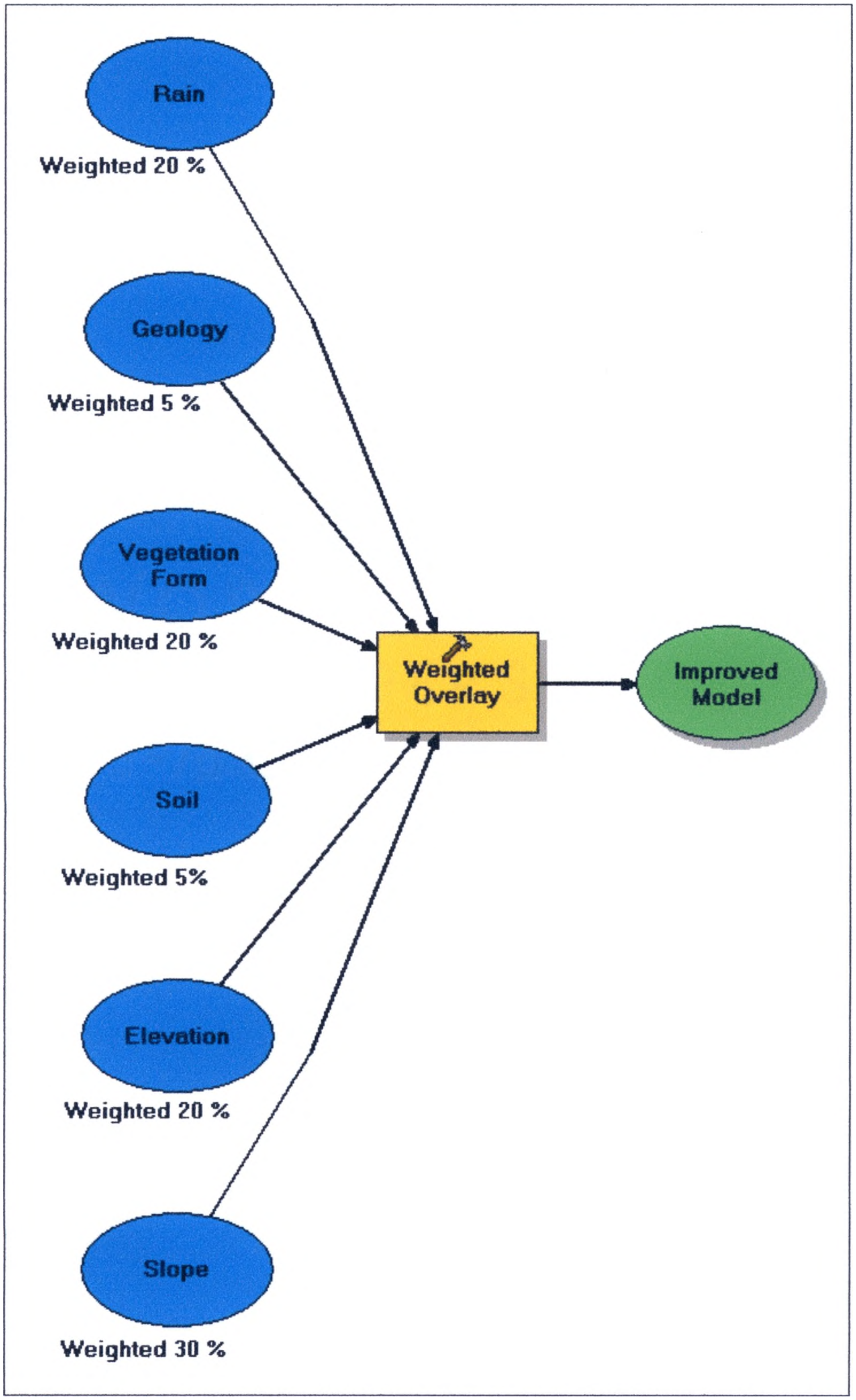

Figure 35. Flowchart showing layers used in final model. Some of the layers in the original model have been removed, and the remaining layers have been re-weighted, producing the new model.

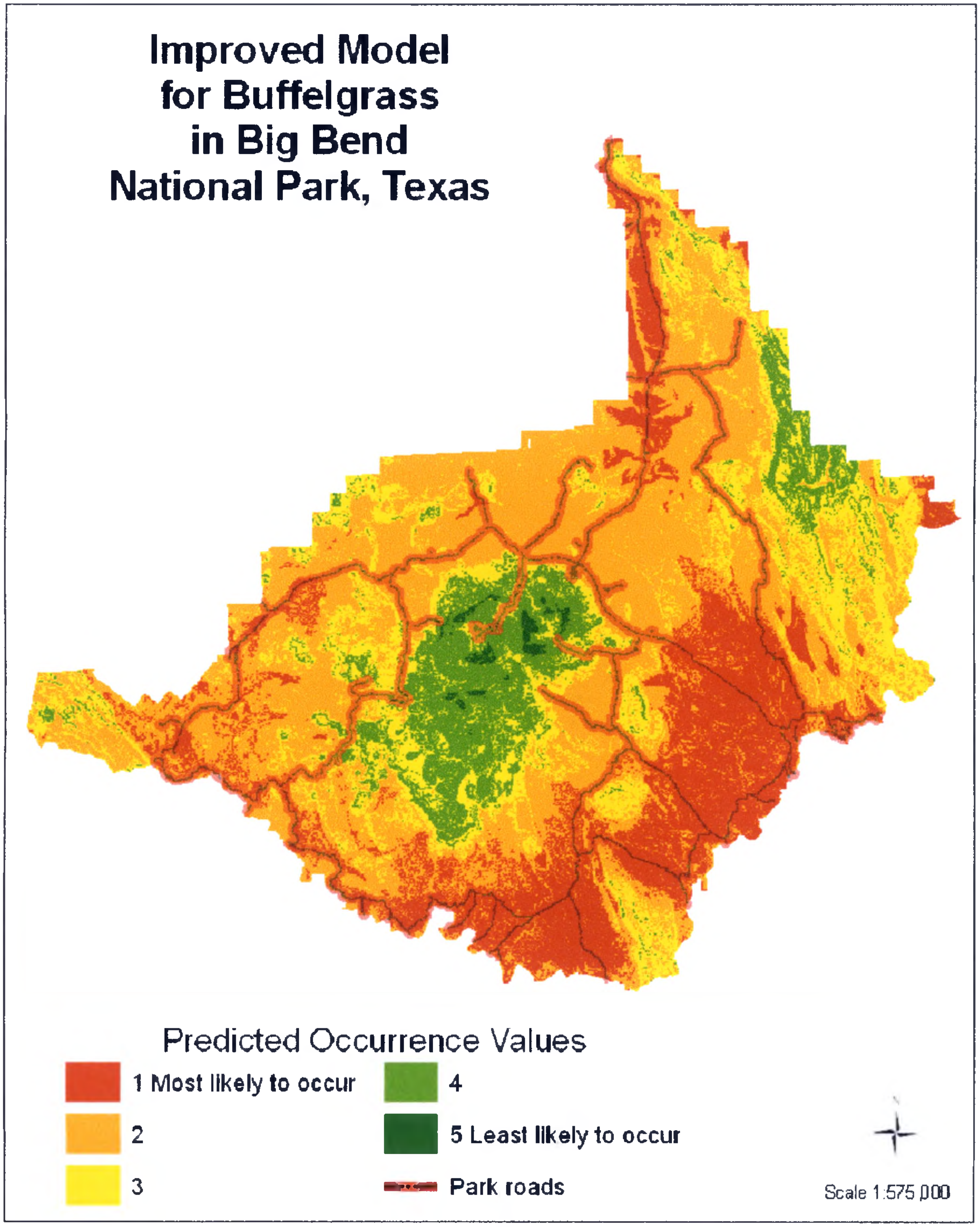

Figure 36. Improved predictive habitat model for buffelgrass in Big Bend National Park.

Table 45 shows how the improved, final habitat model correlated the occurrence of the mapped buffelgrass with each of the 5 values. Of the 7400 known point locations, 80.07 percent (5925) appeared in value 1 of the predictive model, as opposed to 57.61 percent in the baseline model. Value 2 was correlated with 1243 of the buffelgrass points (16.80 percent). The buffelgrass points associated with value 3 of the predictive map decreased to 225 points (3.04 percent). Value 4 was correlated with 7 points (0.09 percent), and there were no points correlated with value 5. The values from both predictive habitat maps are shown for comparison.

Table 45. Results from querying both predictive habitat maps with the mapped buffelgrass points for comparison. Shown are the results from the original baseline map and the results from the final, improved map.

Value	Buffelgrass Points Located in Value in Baseline Model	Percentage of Total	Buffelgrass Points Located in Value in Improved Model	Percentage of Total
1	4263	57.61	5925	80.07
2	2852	38.54	1243	16.80
3	284	3.84	225	3.04
4	1	0.01	7	0.09
5	0	0.00	0	0.00
Totals	7400	100.00	7400	100.00

Again, value 1, where buffelgrass is predicted most likely to occur, represents desert plains or shrub desert areas where elevation is below about 750 meters, slope is less than about 4.5 degrees, and annual precipitation is less than 30 cm. The vegetation is mostly creosote scrub with lechuguilla and prickly pear, the soil is gravelly loam, and the geologic stratigraphy includes Pleistocene to Holocene terrace pediments, alluvium, colluvium, caliche, and fan deposits. Value five is at the highest elevations, with montane vegetation, and higher annual precipitation.

While the baseline model weighted each of the environmental layers equally, the improved model placed more emphasis on slope (30 %), equal emphasis on elevation, rain, and vegetation form (20 %), and the least emphasis on soil types and geologic formations (5%).

CHAPTER IV

DISCUSSION

Mapping

None of the mapping efforts in the park were random. All mapping efforts were done with a specific purpose rather than with a random sampling plan. The 1998 effort was done to assess the exotics along the paved roads in the park. This author mapped the unpaved roads in the southwest area of the park in the 2001-2003 mapping effort, concentrating on the River Road area. In 2003-2004, one spot in the park was intensively mapped near mile marker 14 along Park Route 12 where a large culvert had been recently installed, and the remaining mapping was done by personnel in targeted areas of the park. This is a limitation to the data set, and the relationship between buffelgrass presence and the environment could be biased by the selection of mapping areas.

Buffelgrass infestations in Big Bend National Park occur along both primary (paved) and secondary (unpaved) roads. Infestations are not restricted to the roadsides, but spread into the outlying areas, both by traveling overland and by traveling through the many washes (arroyos, draws, etc.) that intersect the roads. The roadside introductions more than likely have resulted from accidental transport of buffelgrass seeds by vehicles (Clifford 1959; Schmidt 1989; Trombulak and Frissell 2000).

Anthropogenic activities, such as roadside construction, and other disturbances such as heavy rains that cause ephemeral flooding may enhance the speed and extent of buffelgrass invasion (Hodkinson and Thompson 1997; Spellerberg 1998). However, the results suggest that dispersal from road corridors into adjacent natural areas can occur even if levels of disturbance are low and perhaps even if disturbance is absent.

Only about a quarter of the buffelgrass mapped in the 2001 survey occurred within two meters of roadsides, paved or unpaved. The majority was located further away from the roadside. This would suggest that the buffelgrass, once established, is able to spread into outlying areas without disturbance. The majority of buffelgrass mapped occurred off of unpaved roads, with a preference for locating in a drainage. Once buffelgrass is established in a drainage, it appears to be able to spread both up and down the drainage. It can spread down-drainage whenever water rushes through the drainage, and can move up-drainage perhaps due to wind currents or herbivores spreading the seeds upstream. The results indicate that buffelgrass has the ability to spread into remote, undisturbed areas of the park, especially along drainages.

The mapping of new infestations indicates that buffelgrass is spreading into the backcountry, forming large patches and filling in open spaces between existing shrubs and trees. Figures 14 through 17, depicting the four monitoring units established in 2002, use digital orthophoto-quarter-quads (DOQQs) as a background. The DOQQs appear to be an excellent tool for determining where buffelgrass is likely to spread into the backcountry. Mapped buffelgrass consistently lines up with the vegetation presently on the ground as revealed by the DOQQs.

At first glance, buffelgrass does appear to predominate on certain soil types in Big Bend National Park. The soils where buffelgrass occurred in the 2001 mapping were all gravelly or sandy loams. Buffelgrass seems to become established on soils with a minimum of fine-textured components (Hanselka 1988; Mutz and Scifres 1975). A 1995 study in Mexico (Ibarra-F et al. 1995) showed that where buffelgrass spreads, the soils are generally coarse textured. The widespread occurrence of buffelgrass in the park appears to indicate that soil type, although important, is fairly general for buffelgrass establishment. The same appears to hold true for geologic stratigraphy. Buffelgrass appears to tolerate a wide range of geologic environments.

Historically, elevation has been a limiting factor for the spread of buffelgrass. All infestations mapped in the 2001 survey occurred below 900 meters. Lack of winter hardiness in buffelgrass has limited its adaptation to south of about 29° N latitude in Texas (Hussey 1985; Ibarra-F. et al. 1995). Buffelgrass in Big Bend appears to have a fairly strict thermal tolerance limit and was absent from the upper elevations of the park until recently. About 850 plants were mapped in the Chisos Mountains in the fall of 2002 along the Window Trail and in the Group Campground area. This buffelgrass was completely eradicated in the spring of 2003 by park personnel, and the Chisos will be monitored for re-growth and removal. Due to the economic importance of buffelgrass as livestock forage, researchers are currently trying to improve the winter hardiness of buffelgrass germplasm (Hussey and Bashaw 1996), perhaps allowing future varieties to permanently invade higher elevations.

It is interesting to note that buffelgrass appeared at the Science and Research Center in Panther Junction in the Fall 2002 season, in the area where park personnel and researchers park their vehicles after being in the field. This is a painfully obvious example of how easily buffelgrass can be spread by human activity. In the Basin area, all of the buffelgrass was noted in areas of heavy visitor activity, and these areas will have to be consistently monitored and the buffelgrass removed.

Vegetation Transects

A preliminary look at the transect data supports the tendency toward a buffelgrass monoculture. Where buffelgrass is established, it appears to have the ability to eventually outcompete and replace the native vegetation. The diversity indices had no statistically significant difference, although the numbers indicate that buffelgrass does appear to potentially have an impact on species diversity and thus biodiversity in the park. While it may be a slow process, it is occurring. An Australian study (Jackson 2005) compared the herbaceous species composition of sites with and without buffelgrass present, finding the species richness to be lower in the buffelgrass dominated sites. The situation with buffelgrass in Australia is much the same as it is here; it is both a highly-valued forage grass and a noxious, invasive species.

An extremely important aspect of the vegetation transects was the percentage of bare ground in the buffelgrass plots versus non-buffelgrass plots. This brings out one of the most noxious aspects of the presence of buffelgrass, which is alteration of the fire regime. Buffelgrass fills in the spaces between other vegetation, creating fuel for fire in places where fire has never occurred before, or not for a long time. This is a major problem in the Sonoran Desert (Búrquez-Montijo et al. 2002) and could potentially be a problem in Big Bend where large patches of buffelgrass already occur (Figure 37).

Buffelgrass does not appear to require any particular plant species such as creosotebush as a nurse plant. Nurse plant relationships are positive biotic interactions, with the nurse plant providing such things as shade, a buffered microenvironment, and protection from prey for the plants growing beneath it (Tewksbury and Lloyd 2001).

Figure 37. Large buffelgrass patches in the park. The left picture shows a large stand of buffelgrass near Mile Marker 16 on Park Route 12. The right picture shows two discrete stands in Ernst Tinaja. Buffelgrass will tend to fill in the bare ground unless removed. These two sites have been treated by park personnel.

Buffelgrass seems much more general in its location for establishment, appearing to germinate against whatever obstacle it lands next to, providing environmental conditions are favorable. Once established against an obstacle, it will spread tenaciously into areas that are bare of vegetation.

Seed Bank and Viability

Studies have indicated that about 80 to 90 percent of all seeds in the seed bank of desert soils occur in the top 2 cm, and most of those are in the litter or top few millimeters of soil (Kemp 1989; Roberts 1981), but no studies have been done on the buffelgrass seed bank in Big Bend National Park.

The seed bank studies done in the park were difficult to analyze. The seed heads often fall in one piece from the plant, with the burs still intact. It is more often the bur that travels, and not the individual seeds. Experience has shown that it takes some effort to remove a seed from the bur. Strong winds and especially water will move the burs or seeds to new locations, until the seed hits a new obstacle and stops.

Rabbits and other animals use the buffelgrass patches for shelter, and may aid in transporting the seeds to new locations. Ants were seen carrying buffelgrass burs by the hundreds away from the source (Figure 38).

According to the literature, buffelgrass seeds have longevity of about two years, and the longer they sit, the more viable they become, breaking dormancy after six months (Silcock and Smith 1990). The results of the tetrazolium tests may support this. Though collected in different years, more of the one-year old seeds were viable than those tested after three months. Buffelgrass seeds appear to have a good chance of germinating, given a protective location, time on the ground, and a little water, allowing for the establishment and spread of more buffelgrass in the park.

Figure 38. Ants transporting buffelgrass burs. Photos by Fern Daniels.

Predictive Model

One drawback of any predictive map is that even though the map may show areas where a species is likely to become established or spread, it probably does not predict where it can be found at any given time (Higgins and Richardson 1996). An area that is suitable for buffelgrass may or may not actually support it at any given point in time. Though an area may not presently contain buffelgrass, it certainly could occur there in the future. This is one reason why absence data can be very difficult to collect or predict (Guisan and Zimmerman 2000). The validation transects were chosen in the more remote areas, and though buffelgrass did not currently appear along the transects, it is hard to say it will never occur there in the future.

There are possible ways the model can be improved. For example, there are monitoring stations in the park for both precipitation and temperature data, and it could be possible to interpolate spatial layers for these two variables using the data from these monitoring stations. Both moisture and temperature are very important to buffelgrass development, and since these new layers would both be continuous data (as opposed to discrete), it might be possible to integrate some kind of logistic regression for at least some of the variables included in the model (precipitation, temperature, elevation, and slope).

Until then, the precipitation or rainfall layer is the only layer which does not come from the park. A park shapefile should be used in the model, based on data from the monitoring stations in the park, when it becomes available. This will maintain consistency in the data, as it will all be generated by park personnel, and the model then reflects the accuracy of the park's data only.

One improvement was to split the model into smaller sections, as in a pre-processing model and a final "Weighted Overlay" model, so that the flowcharts are easier to read and the model does not require as much time to run from start to finish. Once the initial, time-consuming data preparation has been done, it does not have to be done again. The final part of the model can then be easily rerun as needed. The model flowcharts could also be annotated (see Figure 35), so that the processes can be more easily identified and replicated.

Park road and hydrology layers are insufficient for the model at this point. It is widely reported in the literature that invasive weeds will follow the roadways and available water sources during dispersion, and buffelgrass is no exception (Chambers and MacMahon 1994; Hansen and Clevenger 2005; Hodkinson and Thompson 1997; Howe and Smallwood 1982; Schmidt 1989; Trombulak and Frissell 2000). Most of the buffelgrass mapping has been done relatively close to roads. But when the mapped buffelgrass points are queried in the GIS, most of the buffelgrass is found to be located away from the park road and arroyo layers.

It is possible to buffer the roads or arroyos (increase their width), either by 50 or 100 meters for overlay purposes. The model requires the use of raster instead of vector layers. Converting the park road and arroyo layers from vector to raster format does not work with the current park shapefiles. The conversion results in non-continuous roads or arroyos, rendering it unsuitable for model input (Figure 39). Roads and arroyos are both very important factors in the transport and spread of buffelgrass in the park.

If you buffer the current park arroyo layer, the model picks up less than one-third of the buffelgrass points. Yet if you overlay mapped buffelgrass points with a USGS topographic map (Figure 40), you can see how closely the buffelgrass follows the blue lines (intermittent arroyos) found on the topographic maps. The green ribbon is the park arroyo layer which has been buffered by 50 meters, and it does pick up some of the points. Notice though, how precisely the buffelgrass follows the blue lines on the topographic map.

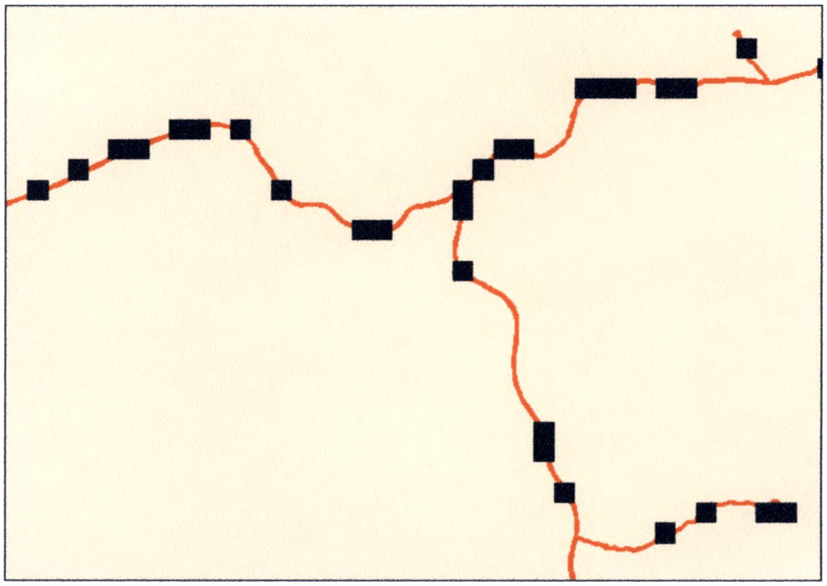

Figure 39. Results from converting road file from vector to raster format. This makes it unsuitable for the model.

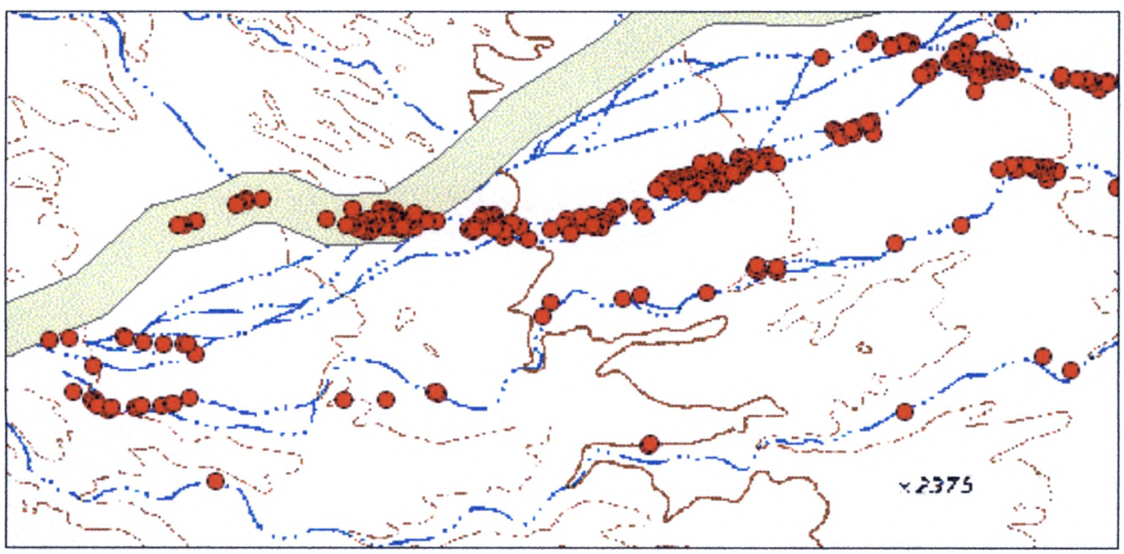

Figure 40. Part of USGS topographic map showing intermittent waterways that do not appear in the park hydrology shapefile. Hydrology from the park shapefile is indicated by the green ribbon (a buffer). Notice how the mapped buffelgrass follows the waterways on the USGS topographic map almost perfectly.

It was possible to extract the arroyo layer from a mosaic of the 31 park topographic maps, and this can be used to overlay potential problematic areas, even though it is not part of the actual model. The USGS water layer could be overlayed with high priority areas in helping to determine future areas for validation (Figure 41).

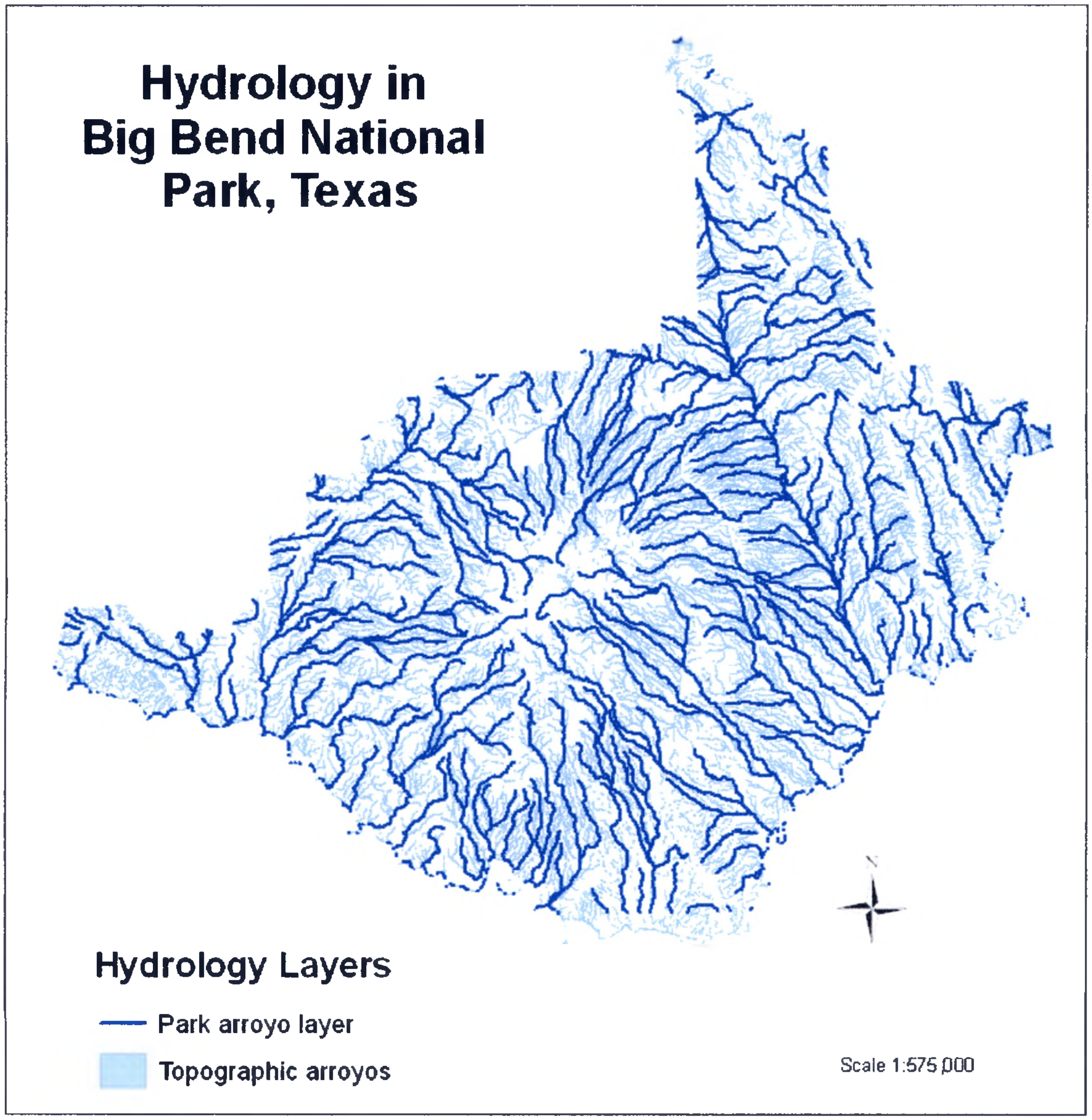

Figure 41. Hydrology layers for Big Bend National Park. The dark blue lines are from the park arroyo layer, while the light blue lines are from the USGS topographic maps.

One last consideration on possible improvements to the model would be to figure out a way to use aerial photographs (DOQQs) in the model, or at least in the validation process as an overlay. Buffelgrass has a very strong tendency to grow first around existing vegetation, of apparently any type, before spreading into open areas (Figure 42). The buffelgrass points in this figure were mapped before ever seeing the DOQQ and it was amazing to see how consistently the buffelgrass followed the existing vegetation once the two layers were overlayed.

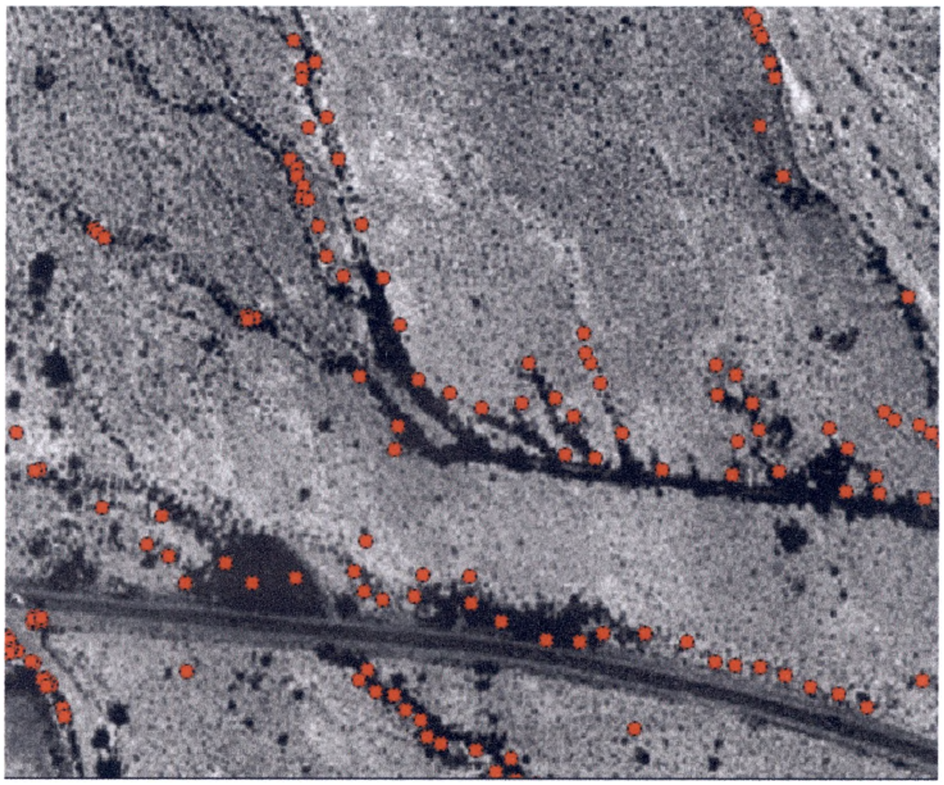

Figure 42. Part of a digital orthophotoquarterquad showing vegetation in the park. Notice how the mapped buffelgrass follows the fingers of vegetation almost perfectly.

The more knowledge or expertise that can be incorporated into the model, the more accurate the results will be and the more useful the map will be. In the future, it is recommended that all mapping in the park include absence data points as well as presence data points. This reduces some of the limits on future spatial modeling methods.

The literature agrees though, that even a baseline predictive model is better than no model at all (Griffiths et al. 1999, Salem 2003). Hopefully, the map will aid in management decisions as far as buffelgrass is concerned. It also shows a methodology by which a predictive map can be created with any other species of concern in the park.

There is some consideration that as the methodology for modeling species habitat has evolved in recent years, the gap between the scientists who develop the models and the managers that actually use them has widened (Stauffer 2002; Wiens 2002). GIS is the option most likely available to those involved in the day-to-day responsibility of conservation management, especially in protected areas, such as a national park or wildlife reserve, and the option that appears most suited to producing a reliable, baseline map in a timely and cost-effective manner. There is still much progress to be made, but the advancements are rapid, and the results can potentially be quite beneficial to many different types of organizations, including national parks.

As technology improves, there will be easier ways to create predictive habitat distribution models, and software to aid in the process is currently being developed and offered as freeware. Biomapper, a GIS-toolkit to model ecological niche and habitat suitability, is available online at < http://www.unil.ch/biomapper>. This will allow easier access for resource and conservation managers. Most national and state parks, heritage sites, and other conservation areas are usually limited by the tools (GPS and GIS) and data they have on hand to build their predictive models, whatever the species. This project has shown that a feasible and accurate predictive habitat map can be built and displayed totally within the GIS framework and be a practical and acceptable tool for the conservation goals of a resource management team. GPS can be helpful in the data collection.

Hopefully, GIS will prove to be a valuable tool in helping to meet conservation goals. All ecological systems are subject to many variables, and as GIS can often provide spatial layers to represent at least some of these variables, and the ability to manipulate spatial data, it has the potential to offer an extremely useful framework for ecological analyses of many types, not just plant invasions.

Appendix A

Monitoring Units Raw Data

Monitoring Unit 1, Buffelgrass Plots, Line Transects.

Plant Name	**Plot 1a**	**Plot 2a**	**Plot 3a**	**Total Intercept Length**	**Intervals Containing Species**
Bare ground	00.65	04.77	-	05.42 m	
Argythamnia neomexicana	-	00.15	-	00.15	2
Bahia absinthifolia	00.40	04.73	00.20	05.33	23
Cenchrus ciliaris	19.81	08.27	19.34	47.42	97
Chamaesyce spp.	-	00.80	-	00.80	5
Larrea tridentata	04.30	08.63	06.73	19.66	52
Leucophyllum frutescens	-	-	00.21	00.21	1
Sarcostemma cyanchoides	00.71	01.69	-	02.40	7
Senna durangensis	-	00.05	00.44	00.49	3
Total length covered by all species (not including bare ground)	25.22 m	24.32 m	26.92 m	76.46 m	
Transect length	21.00 m	22.40 m	17.00 m	60.40 m	
Total intervals					190

Monitoring Unit 2, Buffelgrass Plots, Line Transects.

Plant Name	**Plot 4a**	**Plot 5a**	**Plot 6a**	**Total Intercept Length**	**Intervals Containing Species**
Bare ground	01.68	00.00	01.30	02.98	
Argythamnia neomexicana	00.38	-	-	00.38	2
Cenchrus ciliaris	19.79	12.00	16.70	48.49	101
Larrea tridentata	11.61	03.94	04.77	20.32	50
Prosopis glandulosa	-	-	01.22	01.22	3
Total length covered by all species (not including bare ground)	31.78 m	15.94 m	22.69 m	70.41 m	
Transect length	22.00 m	12.00 m	18.00 m	52.00 m	
Total intervals					156

Monitoring Unit 3, Buffelgrass Plots, Line Transects.

Plant Name	Plot 7a	Plot 8a	Plot 9a	Total Intercept Length	Intervals Containing Species
Bare ground	00.33	00.66	3.66	4.65	
Argythamnia neomexicana	00.70	00.54	-	01.24	5
Atriplex acanthocarpa	-	-	02.28	02.28	9
Bouteloua trifida	00.11	00.19	00.22	00.52	3
Chamaesyce spp.	-	01.66	-	01.66	7
Cenchrus ciliaris	14.82	12.52	17.37	44.71	112
Hilaria mutica	-	-	00.40	00.40	2
Isocoma pluriflora	-	-	01.01	01.01	3
Larrea tridentata	07.34	04.60	01.55	13.49	35
Menodora scabra	02.17	-	-	02.17	7
Opuntia leptocaulis	01.02	-	01.38	02.40	8
Pappophorum bicolor	-	00.48	-	00.48	2
Prosopis glandulosa	-	00.58	00.98	01.56	6
Salsola kali	00.34	00.23	-	00.57	4
Senna durangensis	00.35	00.43	-	00.78	4
Suaeda suffrutescens	-	-	00.65	00.65	2
Total length covered by all species (not including bare ground)	26.85 m	21.23 m	25.84 m	73.92 m	
Transect length	22.00 m	19.00 m	24.00 m	65.00 m	
Total intervals					209

Monitoring Unit 4, Buffelgrass Plots, Line Transects.

Plant Name	Plot 10a	Plot 11a	Plot 12a	Total Intercept Length	Intervals Containing Species
Bare ground	00.99	05.85	02.88	09.72	
Argythamnia neomexicana	00.11	-	-	00.11	1
Bouteloua gracilis	-	00.48	-	00.48	1
Cenchrus ciliaris	21.24	20.16	26.03	67.43	151
Euphorbia antisyphilitica	02.89	-	-	02.89	9
Forestiera angustifolia	-	-	01.95	01.95	5
Larrea tridentata	01.37	01.47	00.97	03.81	18
Leucophyllum minus	-	-	02.14	02.14	5
Lippia graveolens	00.06	-	-	00.06	1
Machaeranthera pinnatifida	00.84	-	00.43	01.27	7
Opuntia engelmannii	01.24	01.29	-	02.53	7
Opuntia leptocaulis	02.62	-	-	02.62	7
Parthenium confertum	00.32	-	-	00.32	2
Prosopis glandulosa	01.54	-	01.61	03.15	10
Senna durangensis	00.71	00.04	-	00.75	6
Total length covered by all species (not including bare ground)	32.94 m	23.44 m	33.13 m	89.51 m	
Transect length	27.00 m	25.00 m	30.00 m	82.00 m	
Total intervals					230

Monitoring Unit 1, Non-Buffelgrass Plots, Line Transects.

Plant Name	Plot 1b	Plot 2b	Plot 3b	Total Intercept Length	Intervals Containing Species
Bare ground	18.41	20.19	12.29	50.89	
Larrea tridentata	02.59	02.21	04.71	09.51	30
Opuntia leptocaulis	-	00.73	-	00.73	3
Total length covered by all species (not including bare ground)	02.59 m	02.94 m	04.71 m	10.24 m	
Transect length	21.00 m	22.40 m	17.00 m	60.40 m	
Total intervals					33

Monitoring Unit 2, Non-Buffelgrass Plots, Line Transects.

Plant Name	Plot 4b	Plot 5b	Plot 6b	Total Intercept Length	Intervals Containing Species
Bare ground	21.12	11.80	09.82	42.74	
Bahia absinthifolia	-	00.20	-	00.20	1
Larrea tridentata	00.88	-	06.93	07.81	21
Opuntia leptocaulis	-	-	01.26	01.26	4
Total length covered by all species (not including bare ground)	00.88 m	00.20 m	08.19 m	09.27 m	
Transect length	22.00 m	12.00 m	18.00 m	52.00 m	
Total intervals					26

Monitoring Unit 3, Non-Buffelgrass Plots, Line Transects.

Plant Name	Plot 7b	Plot 8b	Plot 9b	Total Intercept Length	Intervals Containing Species
Bare ground	18.84	06.37	13.54	38.75	
Argythamnia neomexicana	00.64	01.84	-	02.48	11
Atriplex acanthocarpa	-	-	04.31	04.31	17
Bouteloua trifida	01.08	-	-	01.08	4
Chamaesyce spp.	-	01.57	-	01.57	4
Larrea tridentata	00.91	00.82	-	01.73	6
Menodora scabra	00.46	-	-	00.46	2
Opuntia leptocaulis	-	-	01.55	01.55	5
Prosopis glandulosa	-	-	04.37	04.37	10
Senna durangensis	00.54	-	-	00.54	5
Sphaeralcea angustifolia	-	02.05	-	02.05	8
Sporobolus pyramidatus	-	06.96	-	06.96	25
Suaeda suffrutescens	-	-	01.72	01.72	7
Total length covered by all species (not including bare ground)	03.63 m	13.24 m	11.95 m	28.82 m	
Transect length	22.00 m	19.00 m	24.00 m	65.00 m	
Total intervals					104

Monitoring Unit 4, Non-Buffelgrass Plots, Line Transects.

Plant Name	Plot 10b	Plot 11b	Plot 12b	Total Intercept Length	Intervals Containing Species
Bare ground	20.14	20.70	24.04	64.88	
Agave lechuguilla	02.62	00.12	01.70	04.44	20
Allionia incarnata	00.06	00.11	-	00.17	2
Argythamnia neomexicana	-	00.55	-	00.55	4
Bahia absinthifolia	-	00.12	-	00.12	1
Bouteloua gracilis	-	00.87	03.21	04.08	19
Chamaesyce sp.	00.22	-	-	00.22	1
Euphorbia antisyphilitica	-	01.02	-	01.02	3
Jatropha dioica	-	-	00.29	00.29	1
Larrea tridentata	02.05	01.62	01.28	04.95	19
Opuntia engelmannii	00.85	-	-	00.85	2
Opuntia schottii	00.35	-	-	00.35	2
Senna durangensis	-	00.32	-	00.32	3
Tiquilia canescens	01.08	-	-	01.08	7
Total length covered by all species (not including bare ground)	07.23 m	04.73 m	06.48 m	18.44 m	
Transect length	27.00 m	25.00 m	30.00 m	82.00 m	
Total intervals					84

Monitoring Unit 1, Buffelgrass Plots, Belt Transects.

Plant Name	Plot 1a	Plot 2a	Plot 3a	Total Plants	Intervals Containing Species
Argythamnia neomexicana	-	12	-	12	1
Bahia absinthifolia	23	44	3	70	3
Cenchrus ciliaris	59	44	49	152	3
Chamaesyce spp.	-	3	-	3	1
Croton pottsii	-	2	-	2	1
Gutierrezia sarothrae	1	-	-	1	1
Jatropha dioica	2	-	-	2	1
Larrea tridentata	3	5	8	16	3
Leucophyllum frutescens	-	-	1	1	1
Pectis angustifolia	-	2	-	2	1
Sarcostemma cyanchoides	2	5	-	7	2
Senna durangensis	-	6	2	8	2
Total plant number	90	123	63	276	
Belt area	21.00 m^2	22.40 m^2	17.00 m^2	60.40 m^2	
Total belts					20

Monitoring Unit 2, Buffelgrass Plots, Belt Transects.

Plant Name	Plot 4a	Plot 5a	Plot 6a	Total Plants	Intervals Containing Species
Argythamnia neomexicana	2	-	-	2	1
Cenchrus ciliaris	33	28	40	101	3
Larrea tridentata	3	2	2	7	3

Machaeranthera pinnatifida	1	-	-	1	1
Opuntia leptocaulis	1	-	1	2	2
Prosopis glandulosa	-	-	2	2	1
Total plant number	40	30	45	115	
Belt area	22.00 m^2	12.00 m^2	18.00 m^2	52.00 m^2	
Total belts					11

Monitoring Unit 3, Buffelgrass Plots, Belt Transects.

Plant Name	Plot 7a	Plot 8a	Plot 9a	Total Plants	Intervals Containing Species
Argythamnia neomexicana	28	14	-	42	2
Atriplex acanthocarpa	-	-	4	4	1
Bouteloua trifida	3	1	1	5	3
Cenchrus ciliaris	41	47	55	143	3
Chamaesyce spp.	-	5	-	5	1
Hilaria mutica	-	-	1	1	1
Isocoma pluriflora	-	-	3	3	1
Larrea tridentata	4	2	2	8	3
Machaeranthera pinnatifida	-	-	1	1	1
Menodora scabra	15	-	-	15	1
Opuntia leptocaulis	3	1	3	7	3
Pappophorum bicolor	-	1	-	1	1
Pappophorum vaginatum	-	-	4	4	1
Prosopis glandulosa	-	1	1	2	2
Salsola kali	-	1	-	1	1
Senna durangensis	5	-	-	5	1
Suaeda suffrutescens	-	-	1	1	1
Total plant number	99	73	77	248	
Belt area	22.00 m^2	19.00 m^2	24.00 m^2	65.00 m^2	
Total belts					27

Monitoring Unit 4, Buffelgrass Plots, Belt Transects.

Plant Name	Plot 10a	Plot 11a	Plot 12a	Total Plants	Intervals Containing Species
Agave lechuguilla	2	-	-	2	1
Argythamnia neomexicana	2	3	-	5	2
Bouteloua gracilis	-	1	-	1	1
Cenchrus ciliaris	52	52	59	163	3
Croton pottsii	1	-	-	1	1
Euphorbia antisyphilitica	4	-	-	4	1
Forestiera angustifolia	-	-	1	1	1
Guaiacum angustifolium	-	-	1	1	1
Heliotropium confertifolium	-	1	-	1	1
Larrea tridentata	5	3	2	10	3
Leucophyllum minus	-	-	4	4	1

Machaeranthera pinnatifida	3	1	1	5	3
Opuntia engelmannii	1	1	-	2	2
Opuntia leptocaulis	6	-	-	6	1
Parthenium confertum	4	-	-	4	1
Physalis hederaefolia	-	4	-	4	1
Prosopis glandulosa	1	-	1	2	2
Senna durangensis	8	1	-	9	2
Total plant number	89	67	69	225	
Belt area	27.00 m^2	25.00 m^2	30.00 m^2	82.00 m^2	
Total belts					28

Monitoring Unit 1, Non-Buffelgrass Plots, Belt Transects.

Plant Name	Plot 1b	Plot 2b	Plot 3b	Total Plants	Intervals Containing Species
Bahia absinthifolia	16	11	-	27	2
Echinocactus texensis	1	-	-	1	1
Larrea tridentata	3	1	11	15	3
Nerisyrenia camporum	-	3	-	3	1
Nicolletia edwardsii	-	3	-	3	1
Opuntia engelmannii	-	-	1	1	1
Opuntia leptocaulis	-	1	-	1	1
Opuntia macrocentra	1	-	-	1	1
Opuntia schottii	-	-	1	1	1
Thymophylla pentachaeta	-	2	-	2	1
Total plant number	21	21	13	55	
Belt area	21.00 m^2	22.40 m^2	17.00 m^2	60.40 m^2	
Total belts					13

Monitoring Unit 2, Non-Buffelgrass Plots, Belt Transects.

Plant Name	Plot 4b	Plot 5b	Plot 6b	Total Plants	Intervals Containing Species
Argythamnia neomexicana	-	8	-	8	1
Bahia absinthifolia	1	7	4	12	3
Chamaesyce spp.	-	2	-	2	1
Larrea tridentata	2	2	7	11	3
Nerisyrenia camporum	-	-	1	1	1
Opuntia leptocaulis	-	-	3	3	1
Opuntia macrocentra	1	-	1	2	2
Total plant number	4	19	16	39	
Belt area	22.00 m^2	12.00 m^2	09.00 m^2	26.00 m^2	
Total belts					12

Monitoring Unit 3, Non-Buffelgrass Plots, Belt Transects.

Plant Name	Plot 7b	Plot 8b	Plot 9b	Total Plants	Intervals Containing Species
Argythamnia neomexicana	19	22	-	41	2
Atriplex acanthocarpa	-	-	26	26	1

Bahia absinthifolia	3	-	-	3	1
Bouteloua trifida	5	-	-	5	1
Chamaesyce spp.	-	13	-	13	1
Larrea tridentata	1	2	-	3	2
Menodora scabra	1	-	-	1	1
Opuntia leptocaulis	-	-	1	1	1
Opuntia schottii	-	-	2	2	1
Prosopis glandulosa	-	-	1	1	1
Salsola kali	-	2	-	2	1
Senna durangensis	41	-	-	41	1
Sphaeralcea angustifolia	-	21	-	21	1
Sporobolus pyramidatus	-	87	-	87	1
Suaeda suffrutescens	-	-	11	11	1
Total plant number	70	147	41	258	
Belt area	22.00 m^2	19.00 m^2	24.00 m^2	65.00 m^2	
Total belts					17

Monitoring Unit 4, Non-Buffelgrass Plots, Belt Transects.

Plant Name	**Plot 10b**	**Plot 11b**	**Plot 12b**	**Total Plants**	**Intervals Containing Species**
Agave lechuguilla	13	2	7	22	3
Allionia incarnata	1	-	-	1	1
Argythamnia neomexicana	-	3	2	5	2
Bahia absinthifolia	3	2	2	7	3
Bouteloua gracilis	-	13	25	38	2
Cevallia sinuata	-	1	1	2	2
Chamaesyce spp.	4	6	1	11	3
Echinocereus chloranthus	-	-	1	1	1
Euphorbia antisyphilitica	-	12	-	12	1
Heliotropium confertifolium	3	-	1	4	2
Jatropha dioica	-	-	1	1	1
Larrea tridentata	6	5	7	18	3
Machaeranthera pinnatifida	-	1	3	4	2
Nicolletia edwardsii	-	-	1	1	1
Opuntia engelmannii	1	-	-	1	1
Opuntia leptocaulis	2	-	-	2	1
Opuntia schottii	3	-	-	3	1
Physalis hederaefolia	-	9	2	11	2
Senna durangensis	1	4	-	5	3
Thymophylla pentachaeta	-	20	-	20	1
Tiquilia canescens	6	-	-	6	1
Tiquilia gossypina	-	1	-	1	1
Total plant number	43	79	54	176	
Belt area	27.00 m^2	25.00 m^2	30.00 m^2	82.00 m^2	
Total belts					38

Appendix B

Soil Samples and Seed Raw Data

Data reflects presence (P) or absence (A) of seeds in soil samples, and approximate amount of each litter layer.

Plot	Sampl e	Litter Amount (cm^2)	Seeds P/A	Soil 0-2 cm Seeds P/A	Plot	Samp le	Litter Amount (cm^2)	Seeds P/A	Soil 0-2 cm Seeds P/A
1A	A1	300	P	P	**1B**	A1	50	A	A
1A	A3	350	P	A	**1B**	A3	none	A	A
1A	B1	325	P	A	**1B**	B1	none	A	A
1A	B2	225	P	A	**1B**	B2	none	A	A
1A	B3	175	P	A	**1B**	B3	none	A	A
1A	B4	350	P	A	**1B**	B4	none	A	A
1A	C2	125	P	A	**1B**	C2	none	A	A
1A	C5	350	P	P	**1B**	C5	none	A	A
1A	C6	600	P	P	**1B**	C6	none	A	A
1A	D1	200	P	A	**1B**	D1	none	A	A
2A	A2	550	P	A	**2B**	A2	none	A	A
2A	A3	250	P	A	**2B**	A3	none	A	A
2A	A6	350	P	A	**2B**	A6	none	A	A
2A	B2	500	P	P	**2B**	B2	none	A	A
2A	B4	400	P	A	**2B**	B4	none	A	A
2A	C3	400	P	A	**2B**	C3	75	A	A
2A	C6	450	P	A	**2B**	C6	none	A	A
2A	D1	450	P	P	**2B**	D1	none	A	A
2A	D2	800	P	P	**2B**	D2	none	A	A
2A	D3	300	P	A	**2B**	D3	50	A	A
3A	A2	300	P	A	**3B**	A2	none	A	A
3A	A3	675	P	P	**3B**	A3	none	A	A
3A	A6	700	P	A	**3B**	A6	none	A	A
3A	B3	350	P	P	**3B**	B3	none	A	A
3A	B4	425	P	A	**3B**	B4	none	A	A
3A	C1	450	P	A	**3B**	C1	125	A	A
3A	C4	350	P	A	**3B**	C4	100	A	A
3A	C5	500	P	A	**3B**	C5	none	A	A
3A	C6	425	P	A	**3B**	C6	10	A	A
3A	D3	350	P	A	**3B**	D3	75	A	A
4A	A3	300	P	A	**4B**	A3	none	A	A

4A	A6	150	P	A	**4B**	A6	none	A	A
4A	B3	350	P	A	**4B**	B3	none	A	A
4A	B5	75	P	A	**4B**	B5	50	A	A
4A	C5	300	P	A	**4B**	C5	none	A	A
4A	C6	550	P	P	**4B**	C6	none	A	A
4A	D1	350	P	A	**4B**	D1	none	A	A
4A	D2	250	P	A	**4B**	D2	none	A	A
4A	D3	400	P	P	**4B**	D3	none	A	A
4A	D4	325	P	P	**4B**	D4	none	A	A
5A	A1	200	P	A	**5B**	A1	none	A	A
5A	A3	400	P	A	**5B**	A3	none	A	A
5A	A4	400	P	A	**5B**	A4	none	A	A
5A	A5	350	P	A	**5B**	A5	none	A	A
5A	A6	200	P	A	**5B**	A6	none	A	A
5A	B2	250	P	A	**5B**	B2	none	A	A
5A	B6	300	P	A	**5B**	B6	none	A	A
5A	C2	450	P	A	**5B**	C2	none	A	A
5A	D1	400	P	P	**5B**	D1	none	A	A
5A	D4	300	P	A	**5B**	D4	10	A	A
6A	A1	250	P	A	**6B**	A1	none	A	A
6A	A4	450	P	A	**6B**	A4	none	A	A
6A	B4	300	P	A	**6B**	B4	none	A	A
6A	B6	400	P	A	**6B**	B6	none	A	A
6A	C2	400	P	A	**6B**	C2	50	A	A
6A	C5	350	P	P	**6B**	C5	75	A	A
6A	C6	600	P	A	**6B**	C6	none	A	A
6A	D2	325	P	A	**6B**	D2	none	A	A
6A	D4	350	P	A	**6B**	D4	25	A	A
6A	D6	600	P	A	**6B**	D6	none	A	A
7A	A1	300	P	A	**7B**	A1	50	A	A
7A	A3	700	P	P	**7B**	A3	none	A	A
7A	A4	250	P	A	**7B**	A4	10	A	A
7A	A5	200	P	A	**7B**	A5	25	A	A
7A	B1	300	P	A	**7B**	B1	25	A	A
7A	B3	525	P	P	**7B**	B3	15	A	A
7A	B4	400	P	P	**7B**	B4	10	A	A
7A	B5	500	P	A	**7B**	B5	25	A	A
7A	C2	500	P	P	**7B**	C2	25	A	A
7A	C3	575	P	A	**7B**	C3	25	A	A
8A	A2	225	P	A	**8B**	A2	25	A	A
8A	A4	250	P	A	**8B**	A4	25	A	A
8A	A6	250	P	A	**8B**	A6	15	A	A
8A	B1	325	P	A	**8B**	B1	10	A	A
8A	B2	400	P	A	**8B**	B2	25	A	A
8A	B3	125	A	A	**8B**	B3	50	A	A
8A	B5	150	P	A	**8B**	B5	25	A	A
8A	C3	175	A	A	**8B**	C3	50	A	A
8A	D1	200	P	A	**8B**	D1	10	A	A
8A	D5	300	P	A	**8B**	D5	25	A	A
9A	A3	250	P	A	**9B**	A3	5	A	A
9A	B2	450	P	A	**9B**	B2	none	A	A
9A	B3	250	P	A	**9B**	B3	none	A	A
9A	B5	150	P	A	**9B**	B5	none	A	A

9A	B6	100	P	A	**9B**	B6	15	A	A
9A	C1	275	P	A	**9B**	C1	10	A	A
9A	C3	350	P	A	**9B**	C3	5	A	A
9A	D1	400	P	A	**9B**	D1	none	A	A
9A	D2	325	P	A	**9B**	D2	none	A	A
9A	D4	325	P	A	**9B**	D4	none	A	A
10A	A3	400	P	A	**10A**	A3	none	A	A
10A	A6	325	P	A	**10A**	A6	none	A	A
10A	B3	350	P	A	**10A**	B3	none	A	A
10A	B5	200	P	P	**10A**	B5	none	A	A
10A	C5	300	P	P	**10A**	C5	none	A	A
10A	C6	300	P	A	**10A**	C6	none	A	A
10A	D1	250	P	A	**10A**	D1	none	A	A
10A	D2	500	P	P	**10A**	D2	none	A	A
10A	D3	400	P	A	**10A**	D3	none	A	A
10A	D4	200	P	A	**10A**	D4	none	A	A
11A	A2	175	P	A	**11B**	A2	15	A	A
11A	A4	350	P	A	**11B**	A4	none	A	A
11A	B3	200	P	A	**11B**	B3	50	A	A
11A	B4	250	P	A	**11B**	B4	none	A	A
11A	B5	75	A	A	**11B**	B5	none	A	A
11A	B6	500	P	A	**11B**	B6	25	A	A
11A	C1	275	P	A	**11B**	C1	none	A	A
11A	C6	400	P	P	**11B**	C6	none	A	A
11A	D2	325	P	A	**11B**	D2	25	A	A
11A	D5	425	P	P	**11B**	D5	none	A	A
12A	A1	750	P	P	**12B**	A1	15	A	A
12A	A2	400	P	P	**12B**	A2	15	A	A
12A	A3	100	P	A	**12B**	A3	10	A	A
12A	B2	250	P	A	**12B**	B2	10	A	A
12A	B3	125	P	A	**12B**	B3	none	A	A
12A	B4	75	A	A	**12B**	B4	50	A	A
12A	C3	100	P	A	**12B**	C3	none	A	A
12A	C4	125	P	A	**12B**	C4	none	A	A
12A	C5	75	A	A	**12B**	C5	none	A	A
12A	D3	225	P	A	**12B**	D3	10	A	A
	Totals	**~ 40250 cm^2**	**P=115 A=5**	**P=24 A=96**			**~ 1425 cm^3**	**P=0 A=120**	**P=0 A=120**

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VITA

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