RESPONSE TO DISTURBANCE AND HABITAT CHARACTERIZATION OF *ABRONIA MACROCARPA* (NYCTAGINACEAE)

THESIS

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Population demography, community composition and similarity, and habitat requirements of *Abronia macrocarpa*, an endangered Texas endemic were examined to aid in monitoring changes in populations over time, assist in determining possible reintroduction sites and help in restoring populations subjected to disturbances.

I examined population density and structure, and community composition of existing populations. Density varied significantly ($p<0.005$, $F=8.387$, $df=6$) among seven populations. Sites with highest density of *A. macrocarpa* have greater than 50% bare ground. Population structure varied, with significant differences between number of

seedlings and vegetative plants ($p = 0.007$, $df = 2$). Coefficient of Community Index indicates that communities supporting populations of *A. macrocarpa* are similar, with coefficient values ranging from 0.67 to 0.99. The majority of sites have a pH ranging from 5.3 to 6.6, with one strongly acidic at pH 4.8.

I also collected data to compare disturbed and undisturbed areas of one population that was disturbed in 1992 by construction of an oil well. Soil pH is 6.6 in the undisturbed portion and 7.2 in the disturbed area. Significant differences ($p=0.01$, $df=38$) in *A. macrocarpa* density were found. Density in the undisturbed area was 5.2 individuals per m^2, whereas density in the disturbed portion was 0.2 individuals per m^2. There is a significant difference in the amount of bare ground and vegetative cover ($p<0.001$, $df=2,38$, $F=33.46$ bare ground, $F=37.113$ vegetation). The undisturbed area, which has a higher density of *A. macrocarpa*, has 66.75% bare ground. *Abronia macrocarpa* has not recolonized more than 60% of the total disturbed area.

Recovery criteria require the existence of 20 populations. Obtaining the goal of recovery may entail creating populations by reintroduction. This study has revealed specific habitat requirements that should be considered when selecting potential sites for the reintroduction. Soil chemistry should fall within similar ranges of the known *A. macrocarpa* sites. The community should support commonly associated species with a community similarity index of at least 0.65. Because the sites with high *A. macrocarpa* densities have a higher percentage of bare ground, this should also be taken into consideration in selecting reintroduction sites.

CHAPTER I

INTRODUCTION

The conservation of rare species is dependent on an understanding of many aspects of an organism's biology. Over the past two decades two approaches to conservation have developed. One approach emphasizes the understanding of genetic data, whereas the other emphasizes an ecological approach. The use of genetics might help to understand gene flow and the degree of migration between populations (Lacy, 1988). An ecological approach can help elucidate the natural history and habitat requirements of rare species (Brussard, 1991).

Knowledge of ecology, including habitat requirements and community structure, is vital in developing management strategies to conserve rare taxa. Although protecting the habitats of endangered species is a goal of conservation, the Endangered Species Act does not provide protection for plant species on non-federal lands unless the landowner is receiving federal funding. In Texas, nearly 95% of the land is privately owned (Berger, 1973) and the state is home to 91 threatened and endangered species, 28 of which are plants (Texas Parks and Wildlife Department, 2005). Therefore, the majority of habitat for these endangered species is on private properties, which are used for a variety of purposes. In studying biological diversity on U.S. Forest Service lands, Wilcove (1989) pointed out that rare species must be able to persist on lands that have multiple purposes.

The same is true of species inhabiting private lands, and in a state such as Texas, rare plants must be able to persist on privately owned lands that have multiple uses.

Texas ranks fourth in the number of threatened and endangered plants, with *Abronia macrocarpa* (Nyctaginaceae) among those federally and state listed (U.S. Fish and Wildlife Service, 1992; 1988). When first described and when listed as endangered, only one population of *A. macrocarpa* was known; now there are eight known populations in existence (Williamson and Werth, 1999), all located on private property. Texas is home to 16 species of *Abronia*, two of which are endemic. *Abronia macrocarpa,* one of these endemics, is known to exist only in Leon, Freestone, and Robertson Counties (Figure 1). The species commonly called Large-fruited Sand Verbena, was first described in 1972 by Leo Galloway and named for its thin walled anthocarps (Figure 2) that are larger and more papery than those of other species of *Abronia* (Galloway, 1972). The type locality of *A. macrocarpa* is in the resort community of Hilltop Lakes, Texas (Figure 1, Population 4). *Abronia macrocarpa* is associated with deep, sandy soils of the Post Oak Savannah Woodlands of East Texas (Galloway, 1972). Although little was known about the taxon at the time of listing, today we know a considerable amount about the biology of the species.

Abronia macrocarpa is an herbaceous perennial that produces a large tap root (Figure 3). The plant emerges in October as a small basal rosette (Figure 4) and blooms (Figure 5) between late February and early May. During the summer the upper portions of the plant die back, but the taproot persists. Like other members of the Nyctaginaceae, *A macrocarpa* lacks petals. The sepals are fused and nectar is secreted at the base of the

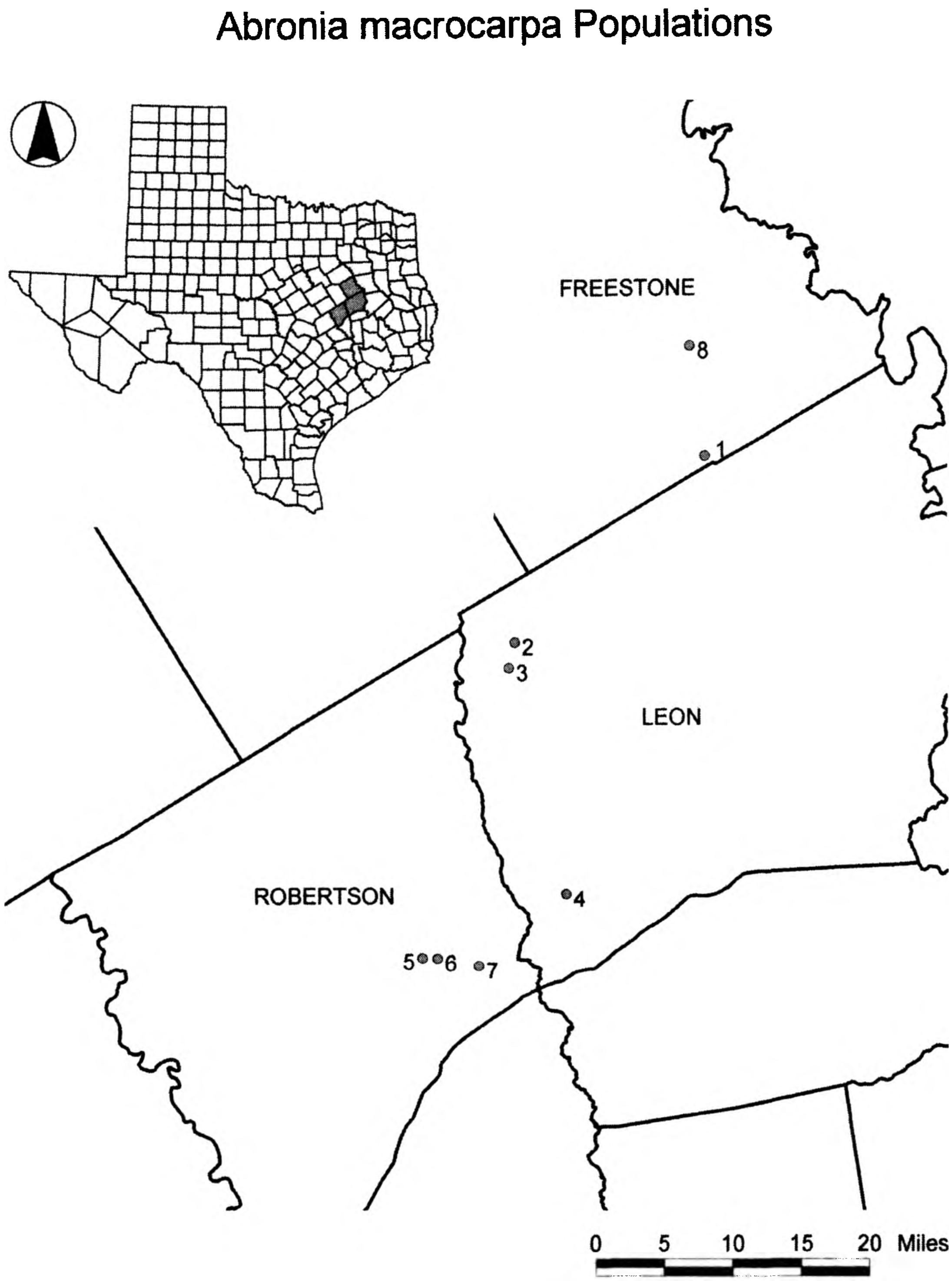

Figure 1. Map of Texas showing the location of the eight known *Abronia macrocarpa* populations in Leon, Freestone, and Robertson Counties.

Figure 2. *Abronia macrocarpa* anthocarps.

Figure 3. *Abronia macrocarpa* roots.

Figure 4. *Abronia macrocarpa* basal rosettes.

Figure 5. *Abronia macrocarpa* in bloom.

floral tube (Williamson et al., 1994). The papery anthocarp develops from an enlarged calyx and, when pollinated and fertilized, a single achene develops.

Abronia macrocarpa is an obligate outcrosser (Williamson and Bazeer, 1997), pollinated by noctuid and sphingid moths (Williamson et al., 1994). A study of the level of genetic variation across populations indicates high levels of genetic variability, though the variation is not spread evenly within or among populations (Williamson and Werth, 1999). Although much is known about the biology of *A. macrocarpa*, more information is needed to develop strategies for conservation of this endangered species.

Since the majority of habitat in Texas is privately owned with multiple uses, endangered species are often affected by a variety of anthropogenic disturbances. Monitoring the response of an organism to disturbance and documenting successional patterns might identify effective management strategies that would prevent further decline of a rare species and might even lead to species recovery. Like many rare species (Ellstrand and Elam, 1993) *A. macrocarpa* is found in isolated populations (Williamson and Werth, 1999). These populations are prone to disturbance and have little protection. Disturbances can have positive or negative impacts. In a study of a tall-grass prairie, Collins (1987) determined that disturbance could increase species diversity. Disturbance can also provide opportunity for invasive species to enter into an area which could result in a population decrease in certain target species (Burke and Grime, 1996). Soil fertility can influence community structure between dominant and target species (Baer et al., 2004). Endangered or threatened species might not be able to compete with more dominant species following changes in soil fertility.

A portion of the population at Hilltop Lakes, Texas was disturbed with the development of an oil well and associated ponds in August 1992. All plants (ca. 2,500) occurring within this area were eradicated. The ponds were found to be in violation of the Migratory Bird Act and had to be removed. The ponds were filled in December 1992 using the soil excavated during their development, and monitoring of the area occurred between 1993 and 1998 (Couch, 1996; Williamson, unpublished data). Re-examining the population 15 years after the initial disturbance will aid in determining the species' ability to re-colonize following a disturbance. Examining the natural revegetation of the disturbed portion of the Hilltop Lakes population might elucidate factors that will affect recovery of this endangered species.

The ability to manage existing properties, aiding populations in recovery from disturbance, and the creation of new populations is essential to the survival of *A. macrocarpa*. In recent years the development of reintroduction programs has gained momentum (Lofflin and Kephart, 2005; Friar et al., 2001). In *Cirsium pitcheri,* studies determined the planting protocols that might maximize survivorship (Rowland and Maun, 2001). Other species of *Abronia* have been successfully reintroduced in Oregon. Introduced populations of *A. umbellata* subsp. *breviflora* are shown to retain 90% of their genetic variation when the populations contained more than 1,000 individuals (McGlaughlin et al., 2002). Reintroduction within the historic range is accomplished by creating new populations in suitable habitat. The development of reintroduction programs is dependent on understanding a plant's population biology (Friar et al., 2001).

Two important aspects of population biology are population density and structure. Population structure is determined by assessing age, reproductive status, and size.

Population structure and density could have different implications for annual species than for perennial species. Annual species might decline quickly, whereas longer lived species might decline slowly in response to environmental changes (Schmeske et al., 1994). Population structure can also help determine recruitment within a population. In a study of *Scorzonera humilis* it was determined that recruitment by seeds occurred in young, regenerating populations, but not in aged populations (Colling et al., 2002).

In addition to collecting demographic data and determining life history stages that affect population growth, Schmeske et al. (1994) cited the examination of biotic and abiotic factors that impact population size as essential for developing recovery plans. Abiotic and biotic factors that can influence populations include edaphic features of the habitat and the associated plant species that compose the community.

Plant community development and diversity can be influenced by edaphic features such as interactions between nutrient availability and soil biota (De Deyn et al., 2004). Growth of *Howellia aquatilis*, an endangered aquatic annual, was affected by the amount of organic matter and minerals in the substrate (Lesica, 1992). Soil composition might also affect the types of plants growing in a given community.

Community composition could also contribute to delineating habitat critical to supporting a taxon. In a study of *Panax quinquefolium,* Anderson et al. (1993) found that the species was associated with communities that had heavy shrub coverage and high tree density. Dzwonko and Loster (1998) determined that species composition in restored grasslands was dependent on initial site conditions. If the site had a closed canopy dominated by trees before disturbances, the communities had increased species richness following the disturbance. Community composition can give insight into species commonly associated with *A. macrocarpa*.

Understanding population demography, community composition and similarity, and edaphic features of existing *A. macrocarpa* populations will aid in monitoring changes in populations over time, assist in identifying possible reintroduction sites, and help in restoring populations subjected to disturbances.

The goals of this study are:

1. Quantify population structure and density of *A. macrocarpa* at all existing populations;
2. Measure and record community composition and similarity of communities containing populations of *A. macrocarpa*;
3. Examine the edaphic features of *A. macrocarpa* habitat;
4. Evaluate the recolonization of *A. macrocarpa* following a disturbance.

CHAPTER II

MATERIALS AND METHODS

Study Sites

Populations of *A. macrocarpa* occur in the region of Texas classified by Diamond et al. (1987) as Oak Woods and Prairie. The eight known populations are included in different aspects of this study. All of the populations occur on private property, and study sites are located in Freestone, Leon, and Robertson Counties. Average annual rainfall is 97.5 centimeters, with an average growing season of 267 days. The elevation in these counties ranges from 150 feet (46 meters) in Leon County up to 900 feet (274 meters) above sea level in Freestone County. *Abronia macrocarpa* populations are known to occur between elevations of 360-450 feet (110-137 meters) (U.S. Fish and Wildlife Service, 1992).

Abronia macrocarpa occurs in the sandy openings between mottes of oaks, yaupon, and hickory. Using soil maps for Leon (Neitsch, 1998) and Freestone Counties (Janeck and Griffin, 2002), soils determined to be associated with *A macrocarpa* sites include Arenosa fine soils in Leon County and Pinkton loamy fine soil in Freestone County. The Silsted-Padina soil association was reported as associated with *A. macrocarpa* in Robertson County (U.S. Fish and Wildlife Service, 1992).

Population Parameters

Seven populations of *A. macrocarpa* were included in this section of the study. I placed 20 1 m^2 quadrats (Krebs, 1999) randomly throughout each of seven population sites of *A. macrocarpa*. Population 6 (Figure 1) was not included due to recent clearing of the land which greatly reduced population size. Data were recorded between March and April 2005. I recorded the number of *A. macrocarpa* seedlings, vegetative plants, and flowering plants for each quadrat. Seedlings were characterized as those plants with one or two leaves, the other plants were classified as vegetative or at anthesis (flowering). These data were compiled and analyzed to determine the number of individual plants per structure class. *Abronia macrocarpa* density was calculated using the following formula:

$$\text{Density} = \frac{\text{Number of plants}}{\text{Number of 1 } m^2 \text{ quadrats sampled}}$$

Population density was compared among the populations using a one way analysis of variance ($p<0.05$) using SPSS 9.0 for Windows.

Three age groups were identified: seedlings, vegetative, and plants at anthesis. Percent composition for each age group was calculated at each site. Percent composition was analyzed using a single-factor ANOVA ($p< 0.05$). Tukey's Multiple Comparison was performed to determine where differences occur. Normality and homoscedasticity were checked before analysis. Data were analyzed using S-Plus 7.0 Student Statistics package.

Community Composition and Similarity

I divided each quadrat into four sections, to ease counting and estimation, and recorded the number and type of associated plant species. Associated species were recorded during the blooming season of *A. macrocarpa,* in 2005. Species identification followed the *Manual of Vascular Plants of Texas* (Correll and Johnston, 1979). The percent bare ground, vegetative cover, and litter were also estimated. I calculated the relative density of plant species occurring within the quadrats to determine community composition using the following formula:

$$\text{Relative Density} = \frac{\text{Number of plants of a given species}}{\text{Total number of plants}} \times 100$$

I used principal component analysis (PCA) to determine if there were major trends in the species composition found among the sites sampled. The PCA identifies linear patterns of correlated change among several variables and arranges each sample unit along the trend represented by the principal component (PC) (Anderson et al., 1993). Data were analyzed using S-Plus 7.0 Student Statistics package.

I used the presence and absence of individual species and their density to determine community similarity. A Coefficient of Community Index (Cheetham and Hazel, 1969) was used to compare communities with populations of *A. macrocarpa* for similarity. This index uses 0 to represent those communities that have no species in common to 1 for communities that have all species in common.

$$\text{Coefficient of Community} = \frac{2C}{N_1+N_2}$$

C = Sum of lower of the two values for shared species

N_1 = Sum of values for community 1

N_2 = Sum of values for community 2

Edaphic Features

Soil samples were collected at each population site. Composite samples were collected by taking soil from 8 to 10 random sites throughout the population. The samples were then sent to the Texas Cooperative Extension Soil, Water, and Forage Testing Laboratory to determine pH, levels of nitrates, phosphorus, potassium, calcium, magnesium, sulfur, sodium, iron, zinc, manganese, copper, salinity and conductivity. Data for seven chemical parameters were collected for each of eight sites. Four of these parameters, (nitrogen, phosphorous, potassium, and pH) were analyzed to determine if there was a correlation between chemistry and relative density of *A. macrocarpa* documented at seven of the eight sites. Data were analyzed by testing for multicoliniarity and using multiple regression analysis. Data were analyzed using S-Plus 7.0 Student Statistics package.

Response to Disturbance

At Hilltop Lakes, Texas the disturbed portion of the population is an area approximately 45 x 85 meters. The ponds were found to be in violation of the Migratory Bird Act. The ponds were filled with the soil excavated during their construction. I examined the undisturbed and disturbed (Figures 6 to 11) areas of the population. I examined the recolonization of the disturbed area by dividing the area into $5m^2$ quadrats and mapping *A. macrocarpa* within these quadrats. Using the same methods described above, I compared population density and structure, community composition, and edaphic features between the disturbed and undisturbed areas. Population density was compared among the disturbed and undisturbed areas of the population using a t-test $p<0.05$) and population structure was compared using a one way ANOVA ($p<0.05$) using SPSS 9.0 for Windows.

Figure 6. Hilltop Lakes, Texas population site in October 1990, prior to disturbance.

Figure 7. Hilltop Lakes, Texas location during the disturbance, showing a pond present in early 1992.

Figure 8. Hilltop Lakes, Texas location during the disturbance, showing oil well present in early 1992.

Figure 9. Hilltop Lakes, Texas location after the pond was filled in 1992.

Figure 10. Hilltop Lakes, Texas location after the disturbance. Plants are revegetating the area.

Figure 11. Hilltop Lakes, Texas disturbed portion of the population in March 2006.

CHAPTER III

RESULTS

Population Density

Population density of *A. macrocarpa* varied significantly ($p<0.005$, $F=8.387$, $df=6$) among the seven sites supporting populations of the taxon. There was more variation among the sites than within each individual site. Site 8 was significantly different from other populations, with the exception of site 3. Density ranged from approximately 1.0 plant per m^2 at sites 2 and 5 to 12.45 plants per m^2 at site 8 (Figure 12).

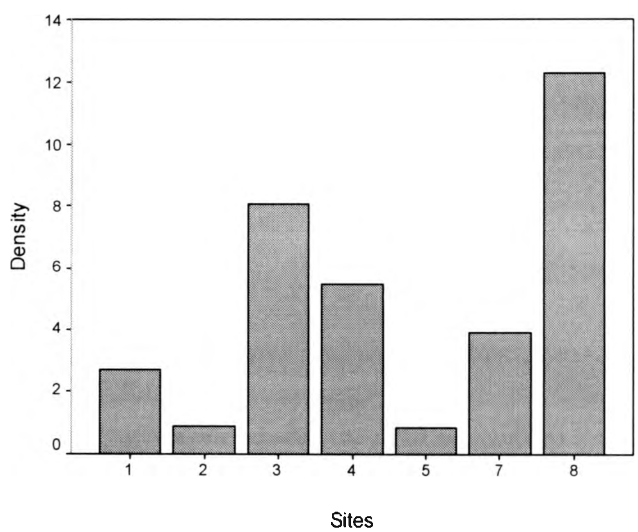

Figure 12. Density of *Abronia macrocarpa* at seven sites. Density ranges from 0.75 to 12.45 plants per m^2. Site 8 is significantly different from other populations with the exception of site 3 ($p<0.005$, $F=8.387$, $df=6$).

Population Structure

Population structure of the seven *A. macrocarpa* populations varied significantly in developmental stages (Figure 13). The percentage of seedlings ranged from 3.7 to 42.2. The percentage of vegetative individuals ranged from 20 to 88.9. The percentage of individuals at anthesis ranged from 5.5 to 40. Sites 3, 4, and 8 had the highest number of seedlings. Sites 1, 2, and 4 had a higher percentage of vegetative individuals. Sites 5, 7, and 8 had a higher proportion of individuals at anthesis. Data met assumptions of normality and homoscedasticity. There was six times more variation between sites than within sites ($F = 6.472435$). Significant differences in age groups exist between the sites ($p = 0.007$, $df = 2$). Tukey's Multiple Comparison results indicate that there is a significant difference between the number of seedlings (A) and vegetative plants (B) (Figure 14), with more vegetative individuals than seedlings. There are no significant differences between the number of seedlings (A) and plants at anthesis (C) or vegetative plants (B) and adults (C).

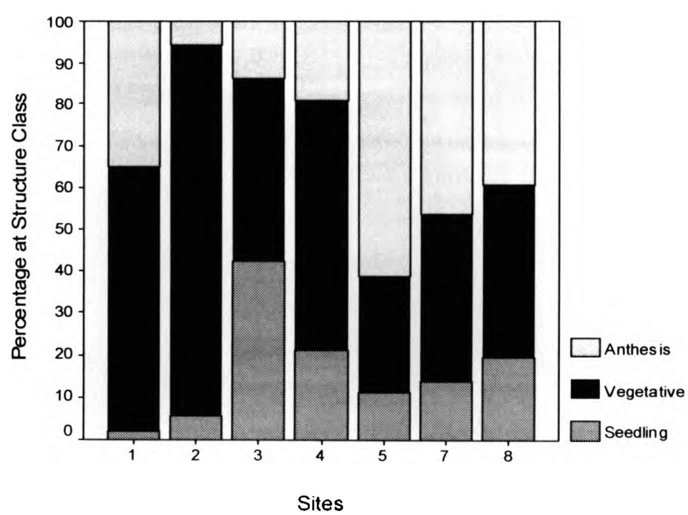

Figure 13. Percentage of *Abronia macrocarpa* plants at three structure classes. Sites varied significantly ($p = 0.007$, $df = 2$) in the number of seedlings compared to the number of vegetative plants.

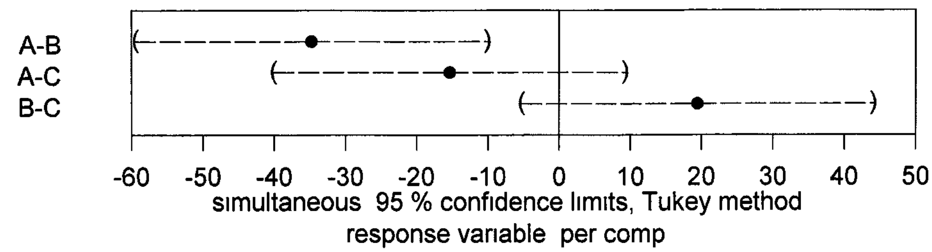

Figure 14. Ninety-five percent confidence intervals for specified linear methods.

Community Structure

The relative density of plant species in communities containing *A. macrocarpa* differed among the locations (Figure 15). The relative density of *A. macrocarpa* in these communities ranged from 0.38 plants per m^2 at sites 2 and 7 to 4.9 plants per m^2 at site 8 (Figure 15).

The analysis of community structure indicates that the majority of plants occurring along with *A. macrocarpa* are small annuals, such as Indian Blanket (*Gaillardia pulchella*), Chickweed (*Cerastium glomeratum*), and Scale Seed (*Spermolepis echinata*). Small annuals had combined relative densities ranging between 47.5 plants per m^2 to 92.3 plants per m^2. Grasses make up a smaller portion of the community, between 9.7 plants per m^2 to 20.7 plants per m^2. Grasses include Rescuegrass (*Bromus unioloides*), Sixweeks Grass (*Vulpia octoflora*), and Little Bluestem (*Schizachyrium scoparium*).

Several annual and perennial species occurred at high enough densities in each community to be reported individually. One of the most common associated species was *Rhododon ciliatus*, commonly known as Sand Mint. Relative density of *R. ciliatus* ranged from 0.02 plants per m^2 at the site 3 location to 25.7 plants per m^2 at site 2. Various species of *Plantago* occurred at densities ranging from 3.2 plants per m^2 to 15.7 plants per m^2. The density of *Tradescantia occidentalis* ranged from 0.9 plants per m^2 to 7.5 plants per m^2 within the seven communities.

Sixty-one percent of the variance in species composition is explained by Principal Component 1 (PC 1) (Table 1). Relatively strong correlations exist between *R. ciliatus* and PC 2, *Plantago* sp. and PC 3, *Croton argyranthemus* and PC 4, and *Opuntia compressa* and PC 5 (Table 1). Table 2 includes a list of associated species found commonly at sites supporting populations of *A. macrocarpa.*

Table 1. Results of Principal Components Analysis.

	Principal Components					
Species	**1**	**2**	**3**	**4**	**5**	**6**
Abronia	0.046	0.210	0.062	-0.080	0.500	
Allium	0.013			0.030	-0.028	
Annuals	0.839	-0.292	-0.033		0.296	0.202
Croton	-0.158	-0.263	-0.428	-0.738	-0.204	0.187
Grass	-0.147	0.406	0.486	-0.402	0.553	0.186
Hymenopappus	-0.012	0.051	-0.030	-0.013	0.013	
Linaria	0.012	-0.051	0.041	0.110	0.021	
Mimosa	0.221	0.174	0.034	-0.462	0.518	
Cnidosulus			-0.048			
Chaemacrista	0.011			0.043	0.058	
Phacelia		0.013	0.018	0.019	0.014	
Phlox	0.010	-0.023	-0.016	0.029	-0.062	
Plantago	-0.141	0.398	-0.692	0.333	0.339	0.207
Q. stellata		-0.012	-0.015	0.053	-0.105	
Rhododon	-0.472	-0.645	0.172	0.299	0.262	0.191
Tradescantia	0.060	0.100	0.183	0.262	-0.389	0.260
Vicia		0.016	-0.027	-0.147	0.036	
Ilex		0.025	-0.040	0.013		
Senecio	-0.024	-0.087	0.203	-0.123		
Yucca			0.027			
Opuntia	0.021		-0.013	0.012	0.719	

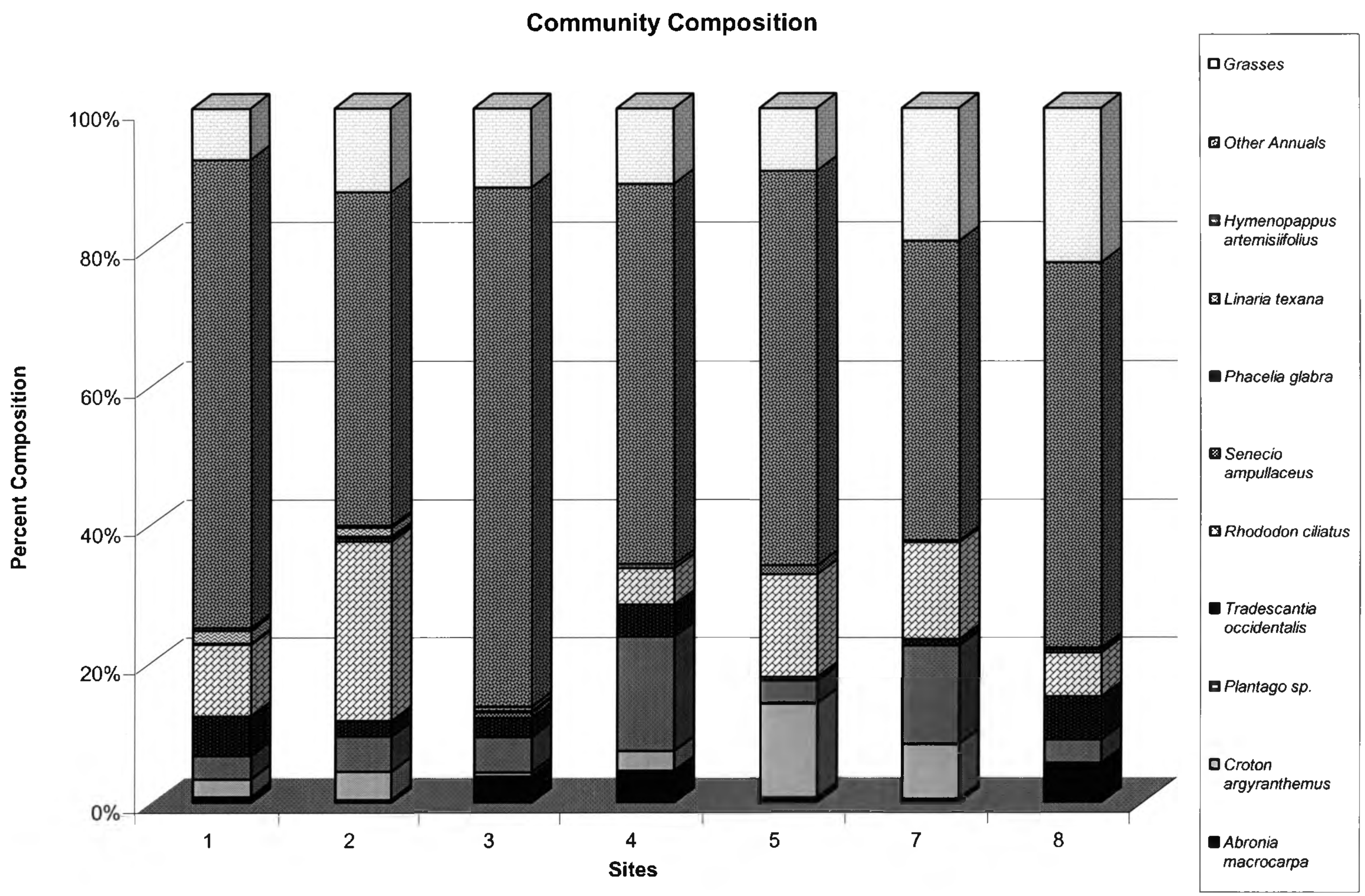

Figure 15. Relative density of associated species within communities supporting *Abronia macrocarpa*.

Table 2. Plants commonly associated with communities supporting *Abronia macrocarpa.*

Family	Scientific Name	Common Name
Agavaceae	*Yucca arkansana*	Arkansas Yucca
Apocynaceae	*Apocynum cannabinum*	Indian Hemp
Apiaceae	*Spermolepis echinata*	Scale seed
Asteraceae	*Aphanostephus ramosissimus*	Lazy Daisy
	Coreopsis tinctoria	Golden Tickseed
	Gaillardia amblyodon	Maroon Blanketflower
	Gaillardia pulchella	Indian Blanket
	Helenium amarum	Sneezeweed
	Heterotheca subaxillaris	Camphorweed
	Hymenopappus artemesiifolius	Old Plainsman
	Senecio ampullaceus	Texas Groundsel
	Rudbeckia hirta	Black-Eyed Susan
Aquifoliaceae	*Ilex vomitoria*	Yaupon
Brassicaceae	*Lepidium virginicum*	Peppergrass
Cactaceae	*Opuntia compressa*	Eastern Prickly Pear
Capparaceae	*Polanisia erosa*	Clammy-weed
Caryophyllaceae	*Cerastium glomeratum*	Chick-weed
Commelinaceae	*Tradescantia occidentalis*	Spiderwort
Convulvulaceae	*Stylisma pickeringii*	Pickering's Dawnflower
Cuppressaceae	*Juniperus virginiana*	Eastern Red Cedar
Euphorbiaceae	*Croton argyranthemus*	Silver Croton
Fabaceae	*Chamaecrista fasciculata*	Partridge Pea
	Mimosa nuttallii	Sensitive Briar
	Vicia ludoviciana	Vetch
Fagaceae	*Quercus stellata*	Post Oak
	Quercus incana	Sandjack Oak

Family	**Scientific Name**	**Common Name**
Hydrophyllaceae	*Phacelia glabra*	Phacelia
Lamiaceae	*Monarda citriodora*	Lemon Beebalm
	Rhododon ciliatus	Sand Mint
Liliaceae	*Allium drummondii*	Wild Onion
	Nothoscordum bivalve	Crow-poison
	Smilax bona-nox	Greenbrier
Onagraceae	*Oenothera laciniata*	Cut Leaf Evening Primrose
Papaveraceae	*Argemone albiflora*	White Prickly Poppy
Platanaceae	*Plantago aristata*	Bracted Plantain
	Plantago major	Common Plantain
	Plantago virginica	Dwarf Plantain
Poaceae	*Bromus unioloides*	Rescue Grass
	Dichanthelium oligosanthes	Rosette Grass
	Schizachyrium scoparium	Little Bluestem
	Vulpia octoflora	Sixweeks Grass
Polemoniaceae	*Phlox drummondii*	Phlox
Primulaceae	*Anagallis arvensis*	Scarlet pimpernel
Scrophulariaceae	*Penstemon murrayanus*	Beard-Tongue
	Linaria texana	Toad-Flax
Rosaceae	*Rubus trivialis*	Southern dewberry
Vitaceae	*Vitis mustangensis*	Mustang Grape

The communities where *A. macrocarpa* grows demonstrate some interesting trends concerning cover categories. As Figure 16 shows, the percent bare ground ranges from 25% (Site 1) to 66.75% (Site 4), the percent litter ranges from 9.4 % (Site 3) to 29.25% (Site 1), and the percent vegetative cover ranges from 16.25% (Site 4) to 40% (Site 2). The four sites with the highest density of *A. macrocarpa* plants all have greater than 50% bare ground (Figure 17). This demonstrates a trend that as bare ground reaches 50%, the density of *A. macrocarpa* increases.

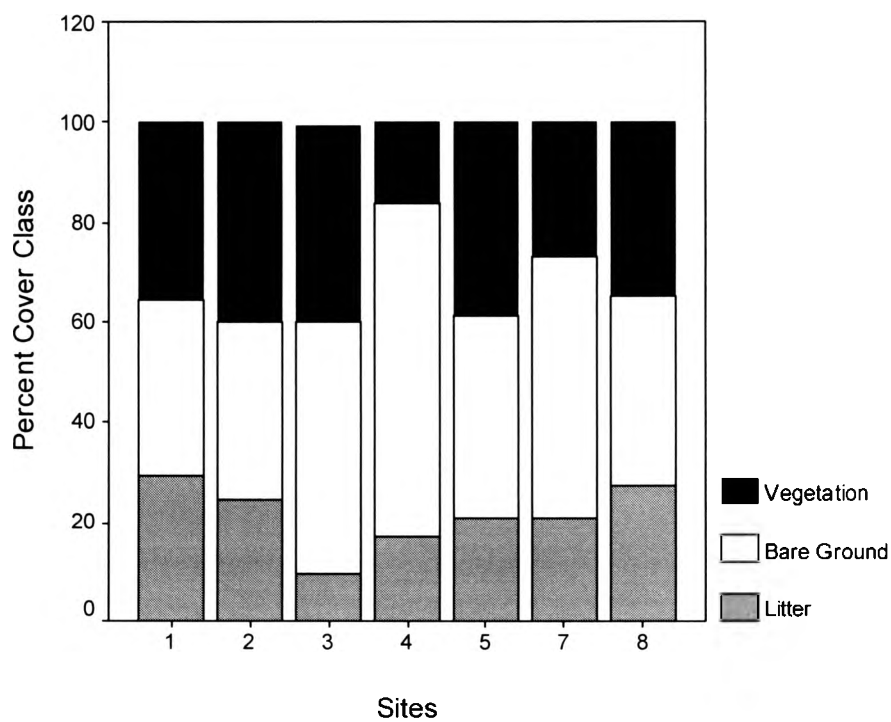

Figure 16. Mean percent cover class for each community containing *Abronia macrocarpa.*

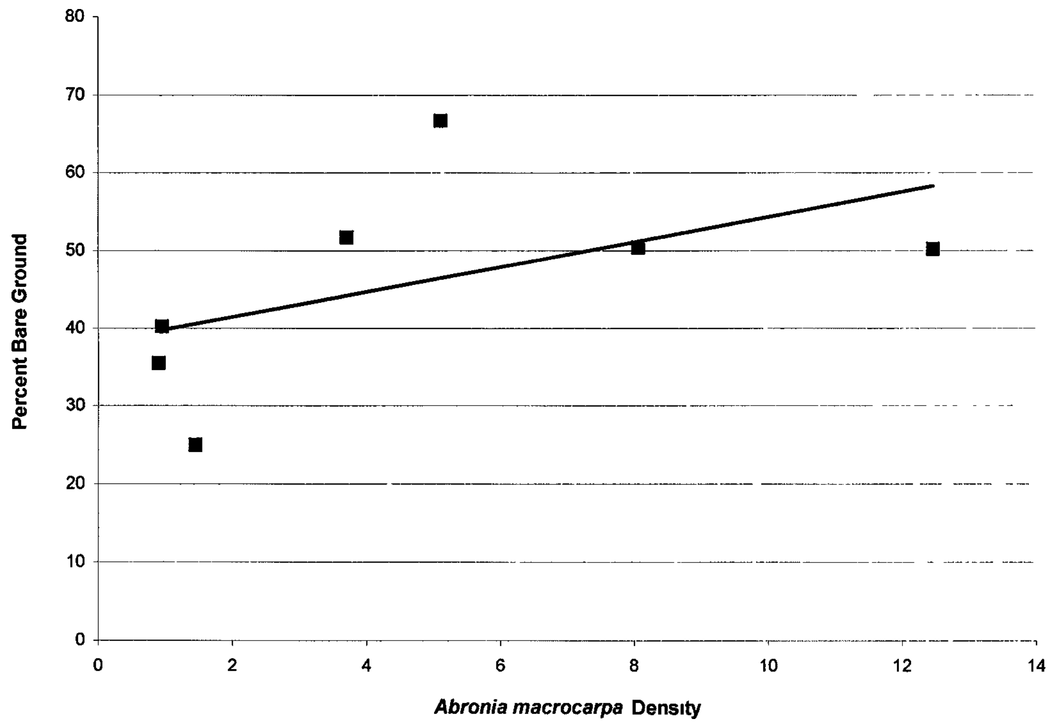

Figure 17. *Abronia macrocarpa* density as compared to the percentage of bare ground at population sites.

Community Similarity

The Coefficient of Community Index indicates that the communities are very similar. The coefficient ranges from 0.67 between sites 2 and 4 and 0.99 between sites 1 and 7 (Table 3). The data indicate that the communities are fairly similar, with more than half of the species in common between various sites.

Table 3. Coefficient of Community Index. Coefficient ranges from 0 to1. Communities with all species in common have an index value of 1 whereas communities that share no species in common have a value of 0.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 7	Site 8
Site 1	-	0.89	0.95	0.71	0.85	0.99	0.87
Site 2	0.89	-	0.95	0.67	0.75	0.9	0.96
Site 3	0.95	0.95	-	0.7	0.78	0.94	0.91
Site 4	0.71	0.67	0.7	-	0.85	0.72	0.71
Site 5	0.85	0.75	0.78	0.85	-	0.86	0.72
Site 7	0.99	0.9	0.94	0.72	0.86	-	0.87
Site 8	0.87	0.96	0.91	0.71	0.72	0.87	-

Edaphic Features

Soil analysis indicates that the majority of populations have a pH that is slightly to moderately acidic, with a range from 5.3 to 6.6. The exception to this is population site 6 which had a pH of 4.8 and is strongly acidic (Figure 18).

A complete list of soil nutrients is provided in Table 4. Nitrates were considered to be low to very low, ranging from 2 to 11 ppm (Figure 19). Those sites with the highest levels of nitrates both occurred in Freestone County. Phosphorus was present at low to high levels ranging from 13 to 29 ppm (Figure 19). Potassium was detected at low levels ranging from 24 to 39 ppm (Figure 19). Calcium levels were moderate to high ranging from 87 to 398 ppm. The lowest level of calcium was detected at site 6. Magnesium levels were low to moderate ranging from 11 to 26 ppm. Moderate to high levels of sulfur were detected ranging from 8 to 10 ppm.

Of the micronutrients, sodium was present in the soil of all sites at moderate levels ranging from 164 to 197 ppm. Iron was detected at very high levels at all sites, ranging from 6.03 to 33.20 ppm. Zinc was present in moderate to very high levels ranging from 0.24 to 3.78 ppm. The highest level of zinc was detected at site 6. Manganese was considered to be at very high levels at all sites ranging from 1.16 to 12.19. Copper was present at moderate to very high levels ranging from 0.05 to 0.38 ppm.

No multicoliniarity was detected in the data analyzed. Residual standard error was 20.35 with 5 degrees of freedom. Multiple R^2 value was 0.06436. F-statistic was 0.3439, df = 1,5, and p value was 0.5830. There is no correlation between the chemical parameters and the relative density of *A. macrocarpa* ($F = 0.1598$, $df = 4,2$, $p = 0.9413$). Residual standard error was 2.896 and multiple R^2 value was 0.2422.

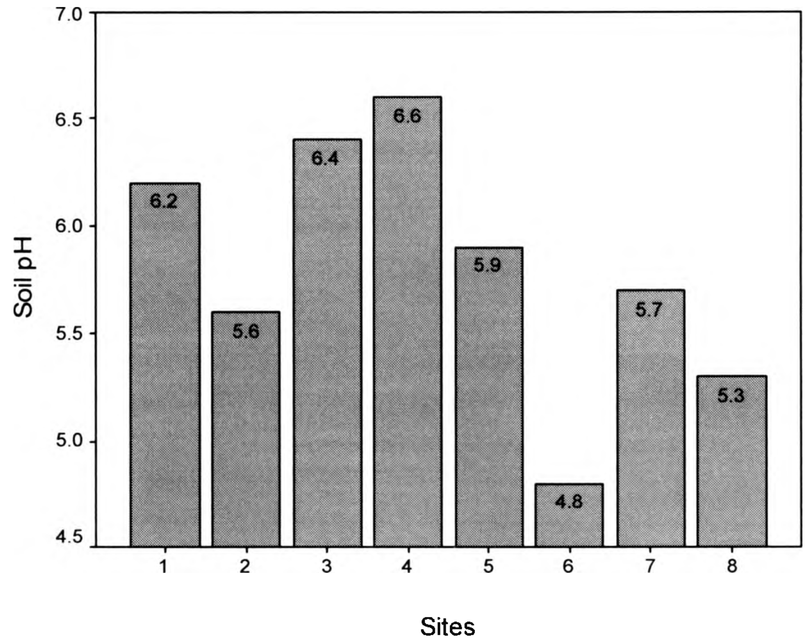

Figure 18. Soil pH of sites supporting *Abronia macrocarpa.*

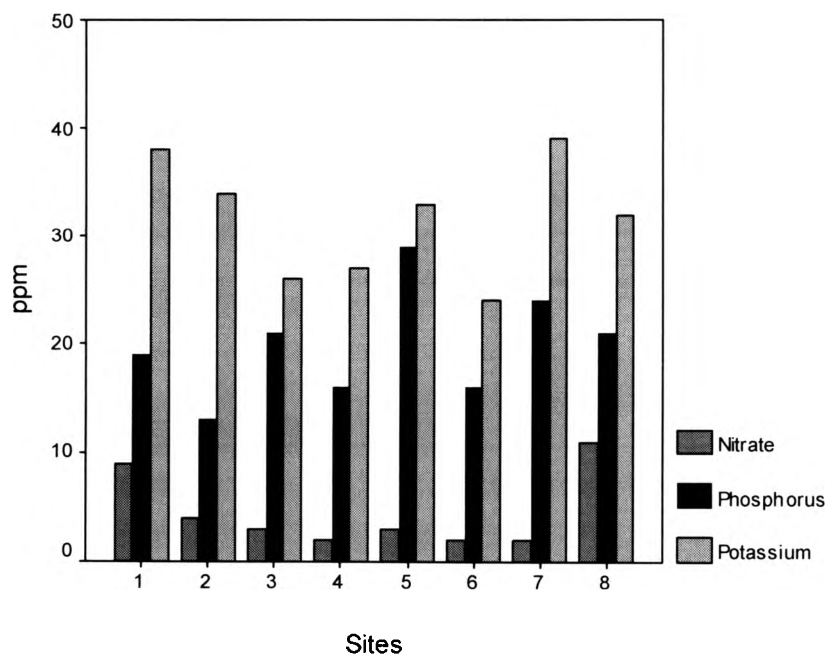

Figure 19. Nitrate, phosphorus, and potassium soil concentrations (ppm) of sites supporting *Abronia macrocarpa.*

Table 4. Nutrient levels in the soil of communities containing *Abronia macrocarpa*. Totals are in parts per million (ppm).

Site	NO_3	P	K	Ca	Mg	S	Na	Fe	Zn	Mn	Cu
1	9	19	38	289	24	8	185	13.31	0.42	3.65	0.07
2	4	13	34	210	21	9	163	6.47	0.18	5.26	0.38
3	3	21	26	371	16	10	193	6.02	0.61	1.19	0.08
4	2	16	27	131	12	8	162	5.79	0.24	12.19	0.08
5	3	29	33	398	19	9	197	8.66	0.25	3.86	0.09
6	2	16	24	87	11	10	164	18.81	3.78	1.16	0.38
7	2	24	39	136	26	9	171	33.2	0.58	10.84	0.25
8	11	21	32	193	20	10	175	7.58	0.58	2.06	0.05

Response to Disturbance

There is a significant difference (p=0.01, df=38) in the density of *A. macrocarpa* between the disturbed and undisturbed portions of the Hilltop Lakes site (Site 4) (Figure 20). Density of the undisturbed portion of the community was 5.2 plants per m^2, whereas density of the disturbed portion was 0.2 plants per m^2.

There is a significant difference among the structure classes between the disturbed and undisturbed portions of the site. Approximately 20% of the individuals found in the undisturbed area were at anthesis (p=0.01), 21% were seedlings (p=0.05), and the remaining 59% were vegetative (p=0.003). No seedlings were recorded in quadrats located in the disturbed area. A third of the plants were at the vegetative stage and the remaining 70% were at anthesis in the disturbed area (Figure 21).

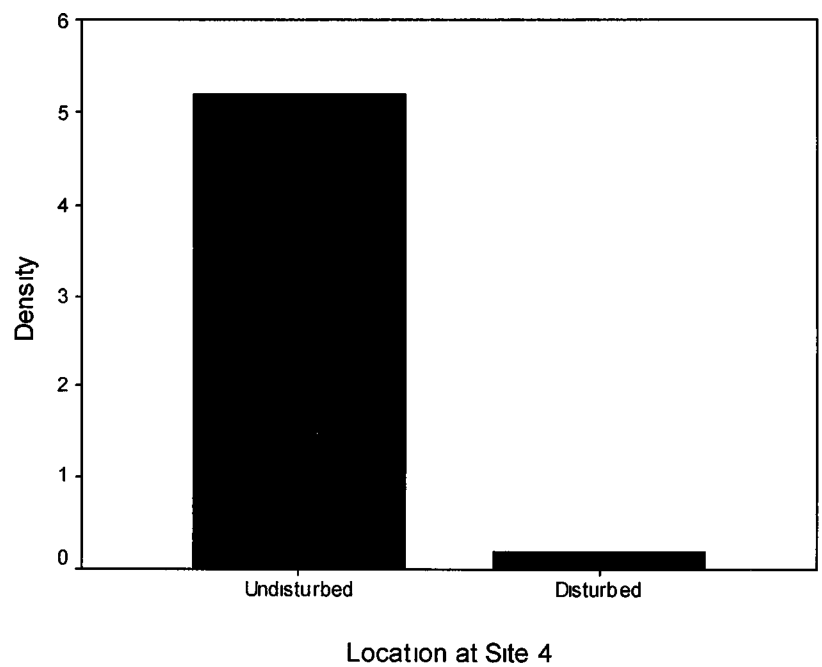

Figure 20. Density of *Abronia macrocarpa* at the disturbed and undisturbed portions of Hilltop Lakes site (Site 4) in 2005. There is a significant difference between the two areas (p=0.01, df=38). Disturbance took place in 1992.

The relative density of *A. macrocarpa* in the disturbed area was 0.07%, in the undisturbed area it was 4.3%. The disturbed area was dominated primarily by *Chenopodium ambrosioides* 46%, *Plantago* sp. 4.9%, Spiderwort *(T. occidentalis)* 1.3%, and annuals 37.77% (Figure 22). The undisturbed portion of the community contained a variety of grasses 10%, *Plantago* sp. 15.75%, Sand Mint (*R. ciliatus*) 5%, Spiderwort 4.42%, and other small annuals 52.57%. Perennials such as *Opuntia compressa* and *Yucca arkansana* were also present in the disturbed and undisturbed portions of the site.

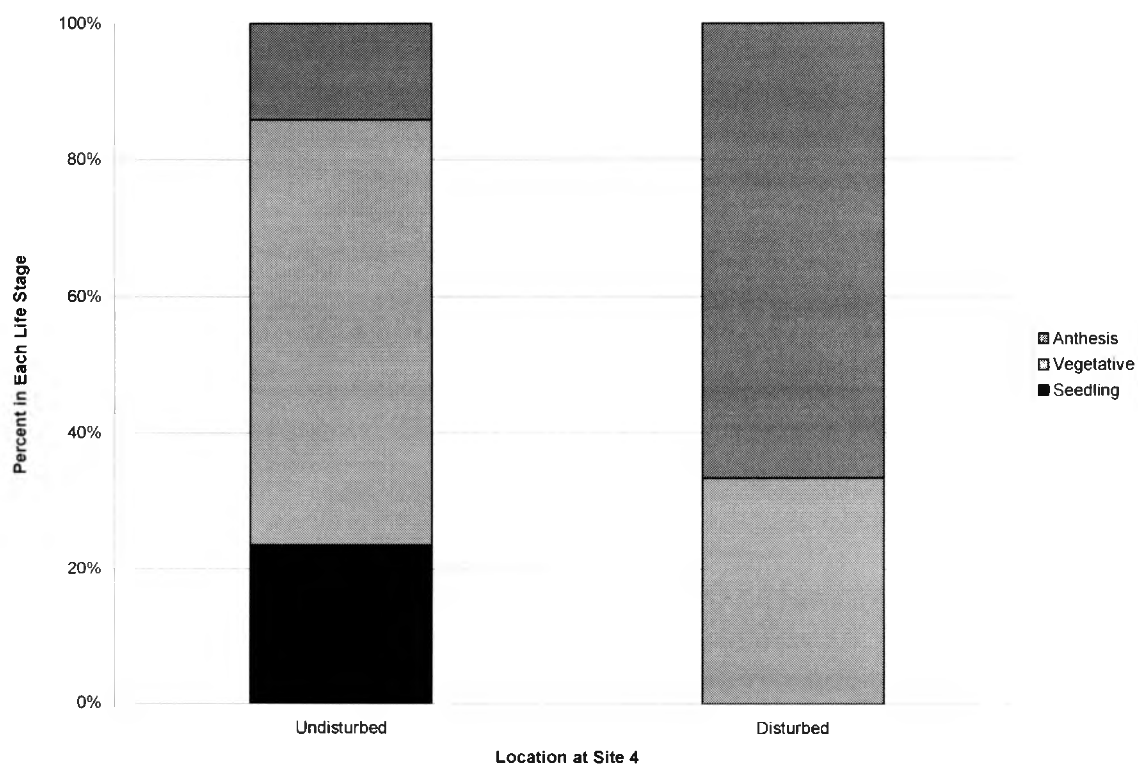

Figure 21. Percentage of *Abronia macrocarpa* of each structure class in the disturbed and undisturbed portions of the Hilltop Lakes site (Site 4) in 2005. Significant differences in the number of seedlings (p=0.05), vegetative plants (p=0.003), and plants at anthesis (p=0.01) were noted.

The cover classes in the disturbed area were composed of a mean of 58.4% vegetative cover, 29.6% litter, and 12% bare ground. There is a significant difference in the amount of bare ground and vegetative cover ($p<0.001$, $df=2,38$, $F=33.46$ bare ground, $F=37.113$ vegetation). There was no significant difference in the amount of litter cover, with more variation occurring within the sites than between the disturbed and undisturbed areas. The undisturbed area had a greater percentage of bare ground 66.75%, with a near equal mix of vegetative 16.25% and litter cover 17% (Figure 21).

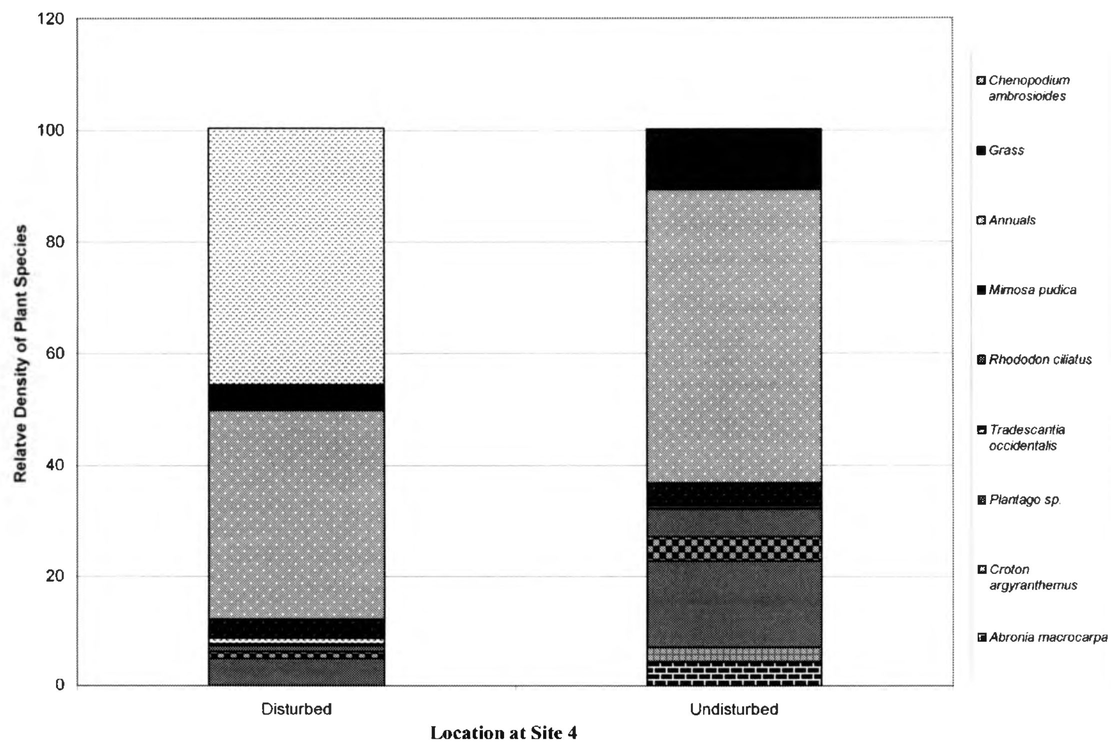

Figure 22. Community composition of the disturbed and undisturbed portions of the Hilltop Lakes site (Site 4) in 2005.

The soil pH between the disturbed and undisturbed portions of the site differed. The soil pH in the undisturbed portion at 6.6 is slightly acidic, and is 7.2 or slightly alkaline in the disturbed area (Figure 23). The soil nutrient analysis demonstrates a higher concentration of calcium in the disturbed area than in the undisturbed area (Table 5). The disturbed area also had a higher concentration of phosphorus, potassium, magnesium, and iron. The undisturbed area had a higher concentration of manganese and sodium. The nitrate concentration of both portions of the site were comparable with 3 ppm in the disturbed area and 2 ppm in the undisturbed area.

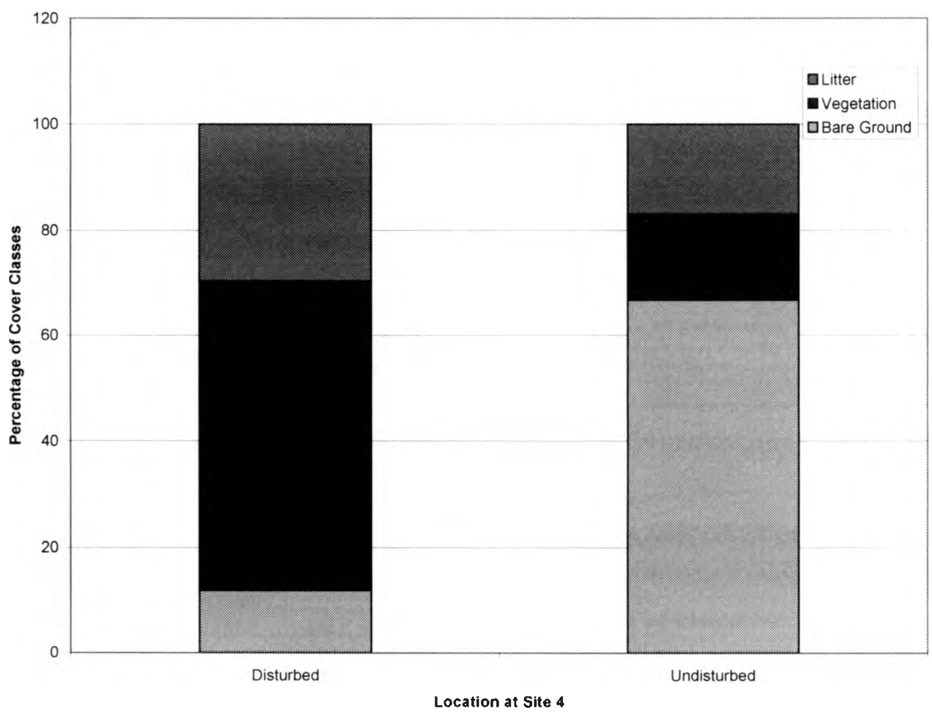

Figure 23. Comparison of cover classes of the disturbed and undisturbed portions of the Hilltop Lakes site (Site 4) in 2005. Significant differences occur between the disturbed and undisturbed portions of the site ($p<.001$, $df=2,38$, $F=33.46$ bare ground, $F=37.113$ vegetation).

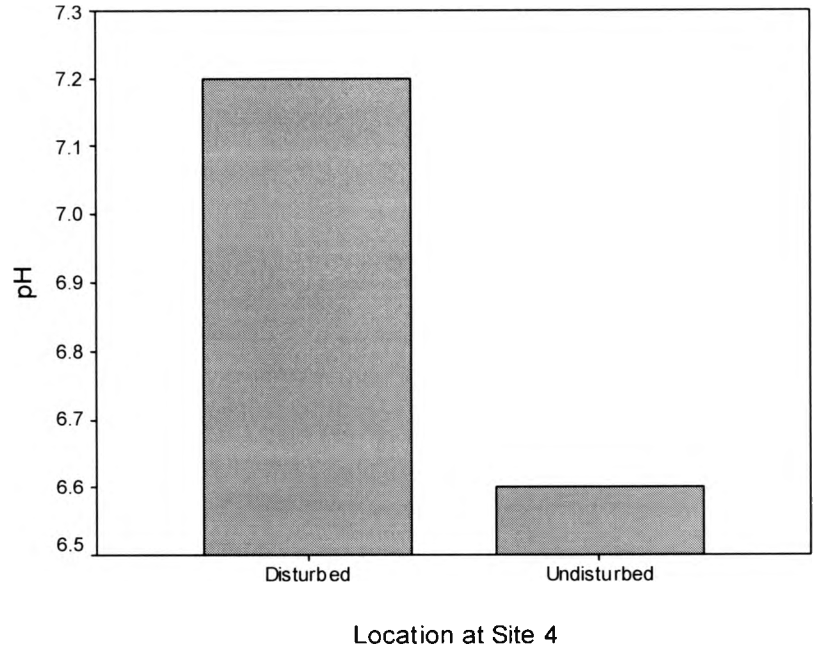

Figure 24. Soil pH of the disturbed and undisturbed portions of the Hilltop Lakes site (Site 4).

Table 5. Nutrient levels in the soil of the disturbed and undisturbed areas of Site 4. Totals are in parts per million (ppm).

	Nitrate	Phosphorus	Potassium	Magnesium	Sulfur	Iron
Disturbed	3	18	41	25	8	6.97
Undisturbed	2	16	27	12	8	5.79
	Zinc	Manganese	Copper	Calcium	Sodium	
Disturbed	0.47	2.7	0.06	403	146	
Undisturbed	0.24	12.9	0.08	131	162	

The spatial distribution of the disturbed area of the site demonstrates that *A. macrocarpa* has not recolonized more than 60% of the total area originally disturbed (Figure 25). The majority of *A. macrocarpa* individuals are located in the southwestern corner and along the eastern edge of the area. A comparison of the data collected in 1998 (Williamson, unpublished data) demonstrates that the area inhabited by *A. macrocarpa* has not greatly increased in size (Figure 26), although density has increased at the edges of the disturbed area. Many *A. macrocarpa* individuals recorded in 1998 (Williamson, unpublished data) in the more central portion of the disturbed area are no longer present (Figure 26). In 2005 a total of 522 individuals were recorded in the disturbed area including 13 seedlings, 323 vegetative plants, and 186 plants at anthesis. In 1998, 418 plants were recorded including 85 seedlings, 254 vegetative plants, and 79 plants at anthesis. The number of vegetative individuals and those at anthesis have increased by 21% and 58% respectively. The number of seedlings has been reduced by nearly 87%.

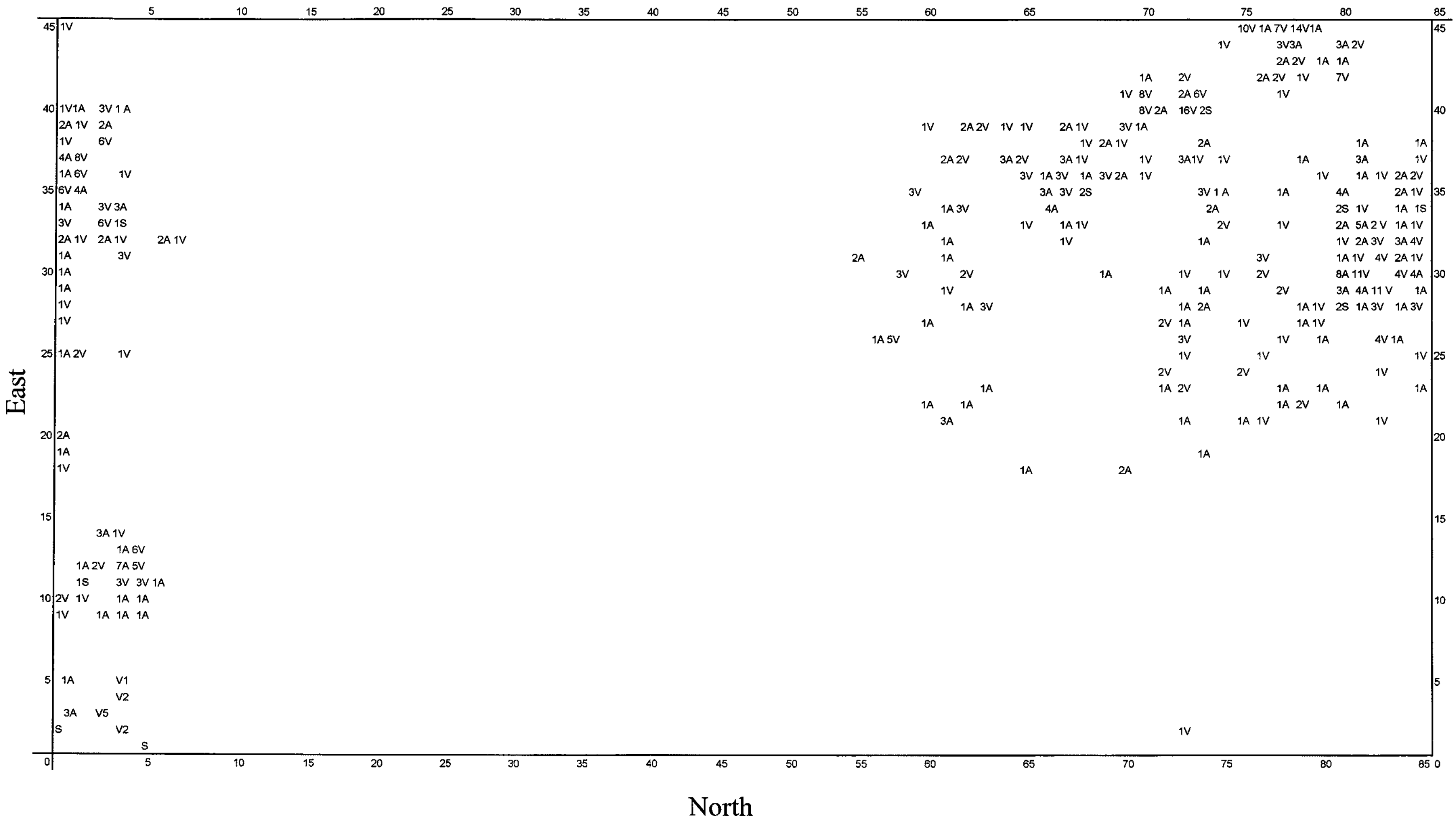

Figure 25. Map of the disturbed portion of the *Abronia macrocarpa* population at the Hilltop Lakes site (Site 4). Data collected March 2005.

S=Seedlings, V=Vegetative, A=Anthesis. Numbers next to letters represent the number of individuals in that structure class. Area

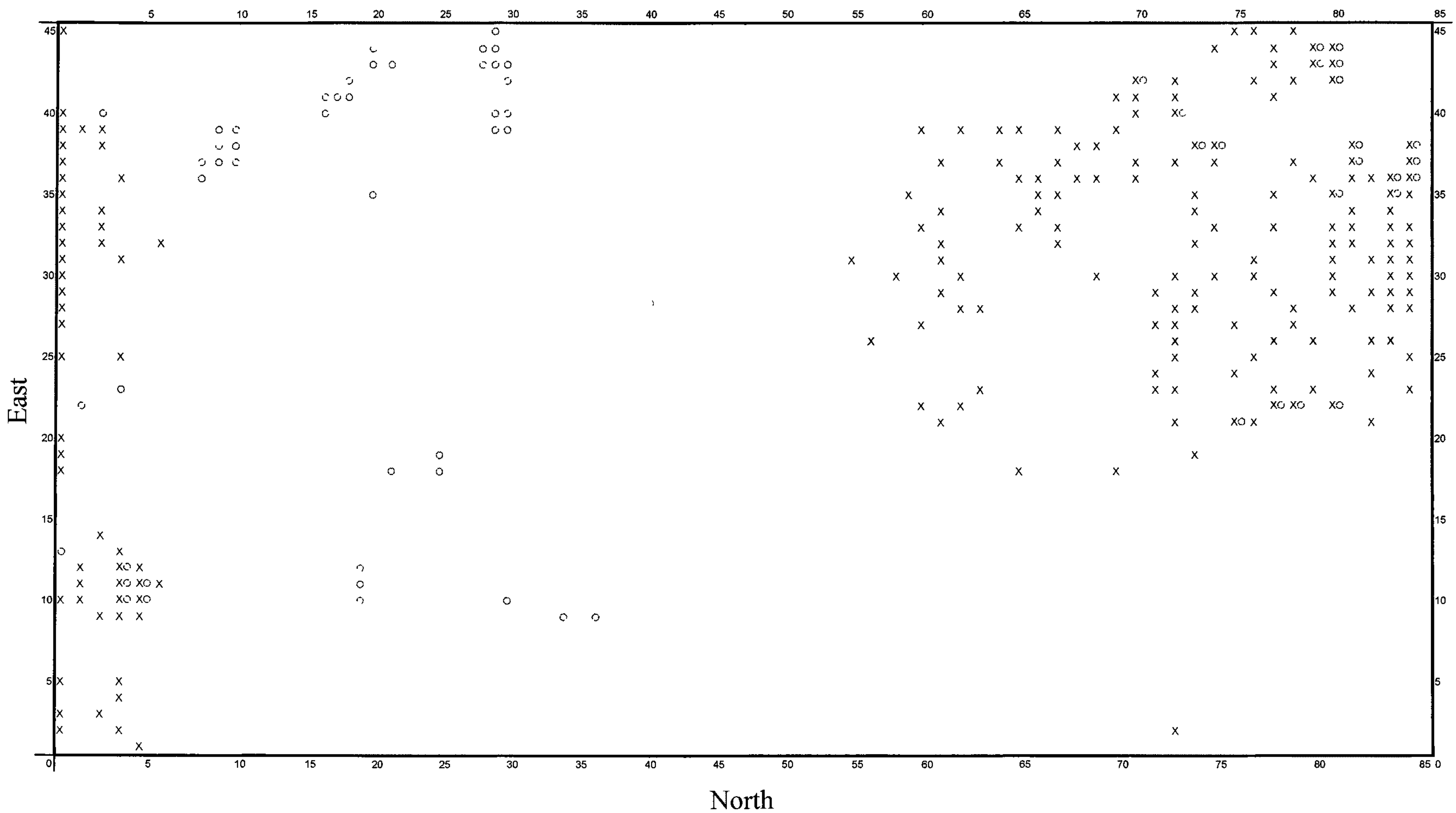

Figure 26. Map of the disturbed portion of the *Abronia macrocarpa* population at the Hilltop Lakes site (Site 4) comparing data collected in 1998 and 2005.

X=Location of *Abronia macrocarpa* collected in 2005; O=Location of *Abronia macrocarpa* collected in 1998. Area in meters.

CHAPTER IV

DISCUSSION

In developing strategies for the conservation of rare and endangered species it is important to understand population dynamics, habitat requirements, and the ability of the organism to respond and recover following disturbances. This study takes an ecological approach to elucidate factors important to the conservation of *A. macrocarpa*, an endangered Texas endemic. The data collected in this study provide valuable information that can be used as baseline monitoring data for existing populations; to determine possible reintroduction sites; and to provide insights into strategies to alleviate the effects of disturbances.

Demographic analysis of populations is commonly used in the study of rare and endangered plants as a method to determine factors that might influence current and future populations (Kluse and Doak, 1999). Monitoring changes in population density or structure can help determine if the population is increasing or declining. By monitoring a population of *Epacris stuartti*, Keith (2002) was able to document a decrease in the population size of over 30% over seven years. Without having quantitative population data, decreases might not be detected for a long period of time. The known populations of *A. macrocarpa* demonstrate a range of densities, from approximately one plant per m^2

at sites two and five to more than 12 individuals per m^2 at site eight. Density of *A. macrocarpa* appears to be correlated with presence of bare ground. When bare ground is at or above 50% of the cover class, density of *A. macrocarpa* is greater. The population structure of *A. macrocarpa* also varies among the sites. Most of the sites have a high number of vegetative individuals, with fewer plants at anthesis or at the seedling stage. Couch (1996) reported a Type III seedling survivorship curve at Site 4, with fewer seedlings surviving initial establishment and increasing survivorship over time. The significant difference between the number of seedling and vegetative individuals provide support for this concept. Various factors can influence population structure, such as nutrient and water availability. Patterns of population structure have also been linked to the vegetative composition of the ecosystem (Oostermeijer et al., 1994), where an increase in shrubs and grasses is correlated with populations composed mostly of adult plants, and few to no juvenile or seedlings. The demographic data collected in this study can be used as a baseline for monitoring future changes in *A. macrocarpa* populations.

This study revealed differences among populations of *A. macrocarpa* at both population and community levels. These differences can be due to a variety of biotic and abiotic factors. Soil is a factor that plays an important part in plant community development by affecting composition (Oostermeijer et al., 1998) or individual plant development. The soil analysis indicated that the locations have acidic soils, with low nitrogen content. Because the soils are composed mostly of sand, which has high permeability, nitrogen and basic cations are leached from the soil making these nutrients unavailable. Soil pH also affects the availability of mineral nutrients. In slightly to moderately acidic soils iron, manganese, copper and zinc are found in higher concentrations (Barbour et al., 1999). In many ecosystems nitrogen has the greatest influence on plant growth (Chapin, 1980; Vitousek et al., 1993), and might influence the growth rate of *A. macrocarpa*. At each of the population sites, there are several associated nitrogen fixing plants, of these *Vicia ludoviciana* and *Chamaecrista fasciculata* were relatively rare within the community. However, *Mimosa nuttallii* is an abundant member of the community at one site (Site 8). The presence of these plants can help increase the amount of available nitrogen. Site 8 has the highest plant density and the highest soil nitrate content. This site also has the highest density of *M. nuttallii* as 5.8% of the community, which could help account for higher nitrogen levels. Although there was not a significant correlation between *A. macrocarpa* density and soil nitrate, only two sites had nitrate concentrations higher than 4 ppm. A larger sample size would be needed to substantiate any relationships between soil nutrients and plant growth.

Despite some differences in species richness and abundance, communities that contain *A. macrocarpa* are remarkably similar. The principal component analysis indicated that variation in species composition among the sites exists, as well as strong correlations between *R. ciliatus, Plantago* sp., and *C. argyranthemus* and the plant community that supports *A. macrocarpa*. The principal component analysis demonstrates that variation in species composition cannot predict habitat for *A. macrocarpa*, however there are species that are common to all of the sites. The lowest community coefficient is 0.67 and the highest 0.99. Of the species present, over half are shared among the various populations. Community composition data indicate that there is a subset of species that occurs within all of the sites containing *A. macrocarpa*. *Tradescantia occidentalis, Hymenopappus artemesiifolius, Senecio ampullaceus, C. argyranthemus, R. ciliatus*, and

Plantago aristata are present in all of the communities. Each site also has mottes of trees and shrubs, such as *Quercus stellata, Q. incana*, *Yucca arkansana*, and *Ilex vomitoria* Knowledge of associated species and soil pH provided in this study might aid in recovery of *A. macrocarpa*.

The recovery criteria for *A. macrocarpa* require the existence of 20 populations of 600 individuals for downlisting or delisting (U.S. Fish and Wildlife Service, 1992). If 20 naturally occurring populations do not exist, populations can be created by reintroduction of the taxon into its historical range to obtain the goal of recovery. The establishment of new populations of endangered plants is dependent on an understanding of the life cycle of the species as well as various abiotic and biotic factors that affect the ecosystems in which they naturally occur.

Conservation biology has shifted from a focus on studying individual species to understanding the ecosystems of which species are a part (Balmford and Cowling, 2006; Shochat et al., 2006; Franklin, 1993). In fact, the goal of the Endangered Species Act is to conserve the ecosystems upon which endangered species depend. Community composition and soil chemistry are both important ecosystem factors that should be considered when delineating habitat to support a rare species. This study has revealed specific habitat requirements that should be considered when selecting potential sites for the reintroduction of *A. macrocarpa*.

Soil chemistry should fall within similar ranges of the known *A. macrocarpa* sites. The community should support commonly associated species with a community similarity index of at least 0.65. Because the sites with high *A. macrocarpa* densities have a higher percentage of bare ground, this should also be taken into consideration in selecting reintroduction sites. Seedling recruitment is low in many of the populations, and a combination of seeding and transplanting might be necessary over a period of several years to help establish the population. Because survival increases over time, protecting seedlings through this stage could help establish new populations.

Not only might it be necessary to create new populations to recover the species, but protecting existing populations is also important. Because all the known populations of *A. macrocarpa* exist on private property, the threat of anthropogenic disturbance is ever present. In a variety of ecosystems, disturbances are natural processes which influence the health and maintenance of a community. The productivity levels of the environment can affect the ease of invasion and the degree of impact on the area (Huston, 1994), with undisturbed productive environments less prone to invasion. Some plant communities depend on disturbances such as fire for regeneration (Pickett et al., 1989; Sousa, 1984), while in some systems fire can be disadvantageous (Setterfield, 2002). Disturbances can open areas up to biological invasions (Keeley, 2006; Bellingham et al., 2005; Hill et al., 2005; King and Grace, 2000). The severity and type of disturbance affects the impact on individual species (Coffin and Lauenroth, 1988). The ability of an organism to recover following a disturbance is key to an organism's long-term survival.

A large scale disturbance altered the *A. macrocarpa* population located at Hilltop Lakes (Site 4), in 1992 when all of the plants occurring within a central portion of the population were eradicated by construction of an oil well. Since then the population of *A. macrocarpa* has been slowly recovering. Population density and structure, community composition and cover classification of the disturbed and undisturbed areas are strikingly different. The undisturbed portion of site 4 has over five *A. macrocarpa* plants per square meter, whereas the disturbed portion has fewer than one. Although no seedlings were reported in the structure analysis for the disturbed area, 13 seedlings were located while mapping the disturbed area. The spatial analysis data show that the number of seedlings documented is low (0.02%). In 1998 (Williamson, pers. comm.) the number of seedlings was reported much higher, with 135 seedlings in the disturbed area compared to the 13 observed in this study. The disturbed area had approximately 12% bare ground in comparison to 65% in the undisturbed area of the population. Having a large percentage of vegetative cover might decrease the ability of *A. macrocarpa* to grow in the area.

The majority of the vegetative cover in the disturbed area was provided by single species, *Chenopodium ambrosioides*. *Chenopodium ambrosioides* is a weedy annual or perennial, that has been used for cooking and medicinal purposes (Diggs et al., 2000). *Chenopodium ambrosioides* is an introduced species that is considered to be invasive (Southern Weed Society, 1998). *Chenopodium ambrosioides* was reported as present at site 4 by Couch (1996), but not as a significant part of the habitat. The taxon was not observed to occur in the undisturbed area of the site in this study.

Another conspicuous difference was in the soil analysis. The undisturbed portion of the site had a pH that was slightly acidic, similar to other sites supporting populations of *A. macrocarpa*. The disturbed area had a slightly alkaline soil with calcium concentrations over 400 ppm. The caliche pad on which the oil well was erected has never been removed and may leach calcium into the surrounding area. Road construction has been documented to change soil density, temperature, water content and chemistry (Trombulak and Frissell, 2000). Urban activities, such as the movement of heavy equipment, have also been documented to change California native shrublands into exotic annual communities (Stylinski and Allen, 1999). Changes in plant density, growth, and nutrient accumulation have been recorded following soil disturbances (Mou et al., 1993) and these disturbances create openings for weedy species (Bellingham et al., 2005; Hill et al., 2005; King and Grace, 2000; Hobbs and Huenneke, 1992). Filling ponds, construction, and the movement of heavy equipment occurred during the 1992 disturbance of the Hilltop Lakes population. The disturbance resulted in a change in pH, which might have made the area less suitable for the growth of *A. macrocarpa* or could have facilitated the invasion of *C. ambrosioides.*

Gordon (1998) reported that invasive, non-indigenous plant species have the ability to alter ecosystems through resource competition or even allelopathy. The invasion of *Bromus tectorum* into arid grasslands changed the nitrogen availability in the soil (Evans et al., 2001), due to changes in the biomass and chemistry of leaf litter. Many times invading species can affect species richness and abundance, but are context-specific to the invading species and the area it invades (Vila et al., 2006). Similarly, the increased presence of *C ambrosioides* is likely affecting the ability of *A. macrocarpa* to reinhabit the disturbed portion of the Hilltop Lakes site.

The spatial distribution of *A. macrocarpa* reveals that the disturbed area has been slowly recruiting members along the western edge. The dispersal of fruits is limited to approximately 30 cm, as the seed shadow is highly leptokurtic (Williamson and Werth, 1999). The movement into the disturbed area has likely been from anthocarps produced by existing *A. macrocarpa* individuals growing along the edges. In 1998 there were approximately 48 *A. macrocarpa* plants recorded toward the eastern side of the disturbed area, the majority of these were no longer present in 2005. Again, this is probably due to the increased vegetative cover of *C. ambrosioides* in this area. Over half of the disturbed area has nearly 100% percent vegetative cover, with 46% composed of *C. ambrosioides.* After the ponds were filled the area was completely bare. The amount of bare ground along the western side of the disturbed area has decreased less than the eastern edge. The number of *A. macrocarpa* plants is also higher on the western edge of the disturbed area. The recruitment of seedlings has continued along the western edge, but has been slow to infiltrate further into the disturbed portion of the site. With the increased vegetative presence, especially *C. ambrosioides,* and vegetative litter in the area now (58% vegetative cover, 30% litter), *A. macrocarpa* seedlings might not be able to establish.

From 1992 until 1998, 418 *A. macrocarpa* plants reestablished in the disturbed portion of site 4. In 2005, only 522 plants were recorded in the area. Recruitment of new individuals has slowed over the years, or mortality of existing plants has increased. The increased vegetative cover and thus increased competition are likely responsible for decreased population growth in the disturbed area.

This study has increased our understanding of the population biology of *A. macrocarpa*. The study provides information on community composition and soil chemistry that will aid in selection of habitats for reintroduction. Soil chemistry and invasion of the non-native *C. ambrosioides* are factors that appear to be limiting the recolonization of *A. macrocarpa* in the disturbed area of the Hilltop Lakes population. If populations of *A. macrocarpa* are disturbed in the future, monitoring soil pH and taking steps to maintain a slightly acidic to acidic pH, and protecting the populations from biological invasions might help the species recover more quickly.

LITERATURE CITED

Anderson, B.W., R.D Ohmart, and J. Rice. 1983. Avian and vegetation community structure and their seasonal relationships in the Lower Colorado River Valley. *The Condor* 85:392-405.

Anderson, R.C., J.S. Fralish, J.E. Armstrong, and P.K. Benjamin. 1993. The ecology and biology of *Panax quinquefolium* L. (Araliaceae) in Illinois. *American Midland Naturalist* 129:357-372.

Baer, S.G., J.M. Blair, S.L. Collins, and A.K. Knapp. 2004. Plant community responses to resource availability and heterogeneity during restoration. *Oecologia* 139:617-629.

Balmford, A. and R.M. Cowling. 2006. Fusion or failure? The future of conservation biology. *Conservation Biology* 20:692-695.

Barbour, M.G., J.H. Burk, W.D. Pitts, F.S. Gilliam, and M.W. Schwartz. 1999. *Terrestrial Plant Ecology*. Benjamin/Cummings Publishing Company, Menlo Park, CA.

Bellingham, P.J., E.V.J. Tanner, and J.R. Healy. 2005. Hurricane disturbance accelerates invasion by the alien tree *Pittosporum undulatum* in Jamaican montane rain forests. *Journal of Vegetation Science* 16:675-684.

Berger, M.E. 1973. Recreation potential of Texas rangelands. *Journal of Range Management* 26:92-93.

Brussard, P.F. 1991. The role of ecology in biological conservation. *Ecological Applications* 1:6-12.

Burke, M.J.W. and J.P. Grime. 1996. An experimental study of plant community invasibility. *Ecology* 77:776-790.

Chapin, F.S. 1980. The mineral nutrition of wild plants. *Annual Review of Ecology and Systematics* 11: 233-260.

Cheetham, A.H. and J.E. Hazel. 1969. Binary (presence-absence) similarity coefficients. *Journal of Paleontology* 23:1130-1136.

Coffin, D.P. and W.K. Lauenroth. 1988. The effects of disturbance size and frequency on a shortgrass plant community. *Ecology* 69:1609-1617.

Colling, G., D. Matthies, and C. Reckinger. 2002. Population structure and establishment of the threatened long-lived perennial *Scorzonera humilis* in relation to environment. *Journal of Applied Ecology* 39:310-320.

Collins, S.L. 1987. Interaction of disturbances in tallgrass prairie: a field experiment. *Ecology* 68:1243-1250.

Correll, D.S. and M.C. Johnston. 1979. *Manual of the Vascular Plants of Texas.* University of Texas Dallas. Richardson, TX.

Couch, K.L. 1996. Seedling recruitment and plant recolonization of a disturbed population of *A. macrocarpa* Galloway (Nyctaginaceae). M.S. Thesis. Southwest Texas State University, San Marcos, Texas.

De Deyn, G.B., C.E. Raaijmakers, and W.H. Va Der Putten. 2004. Plant community development is affected by nutrients and soil biota. *Journal of Ecology* 92:824-834.

Diamond, D.D., D.H. Riskind, and S.L. Orzell. 1987. A framework for plant community classification and conservation in Texas. *The Texas Journal of Science* 39:203-221.

Diggs, G.M Jr., B.L. Lipscomb, and R.J. O'Kennon. 2000. *Shinner's and Mahler's Illustrated Flora of North Central Texas*. SIDA, Botanical Miscellany, No. 16. Fort Worth, TX.

Dzwonko, Z. and S. Loster. 1998. Dynamics of species richness and composition in a limestone grassland restored after tree cutting. *Journal of Vegetation Science* 9:387-394.

Ellstrand, N.C. and D.R. Elam. 1993. Population genetic consequences of small population size: implications for plant conservation. *Annual Review of Ecology and Systematics* 24:217-242.

Evans, R.D., R. Rimer, L. Sperry, and J. Belnap. 2001. Exotic plant invasion alters nitrogen dynamics in an arid grassland. *Ecological Applications* 11:1310-1310.

Franklin, J.F. 1993. Preserving biodiversity: Species, ecosystems, or landscapes. *Ecological Applications* 3:202-205.

Friar, E.A., D.L. Boose, T. LaDoux, E.H. Roalson, and R.H. Robichaux. 2001. Population structure in the endangered Mauna Loa silversword, *Argyroxiphium kauense* (Asteraceae), and its bearing on reintroduction. *Molecular Ecology* 10:1657-1663.

Galloway, L. 1972. *Abronia macrocarpa* (Nyctaginaceae): a new species from Texas. *Brittonia* 24:148-149.

Gordon, D.R. 1998. Effects of invasive, non-indigenous plant species on ecosystem process: lessons from Florida. *Ecological Applications* 8:975-989.

Hill, S.J., P.J. Tung, and M.R. Leishman. 2005. Relationships between anthropogenic disturbance, soil properties, and plant invasion in endangered Cumberland Plain Woodland, Australia. *Austral Ecology* 30:775-788.

Hobbs, R.J. and L.F. Huenneke. 1992. Disturbance, diversity and invasion: implications for conservation. *Conservation Biology* 6:324-337.

Huston, M.A. 2004. Management strategies for plant invasions: manipulating productivity, disturbance, and competition. *Diversity and Distributions* 10:167-178.

Janack, E.F. and E.L. Griffin. 2002. Soil Survey of Freestone County, Texas. Natural Resources Conservation Service.

Keeley, J.E. 2006. Fire management impacts on invasive plants in the Western United States. *Conservation* Biology 20:375-384.

Keith, D.A. 2002. Populations dynamics of an endangered heathland shrub, *Epacris stuartii* (Epacridaceae): recruitment, establishment, and survival. *Austral Ecology* 27:67-76.

King, S.E. and J.R. Grace. 2000. The effects of gap size and disturbance type on invasion of wet pine savanna by cogongrass *Imperata cylindrica* (Poaceae). *American Journal of Botany* 87:1279-1286.

Kluse, J. and D.F. Doak. 1999. Demographic performance of a rare California endemic, *Chorianthe pungens* var. *hartwegiana* (Polygonaceae). *American Midland Naturalist* 142:244-256.

Krebs, C.J. 1999. *Ecological Methodology.* Addison-Welsey Educational Publishers, Inc. Menlo Park, CA.

Lacy, R.C. 1988. A report on population genetics in conservation. *Conservation Biology* 2:245-247.

Lesica, P. 1992. Autecology of the endangered plant *Howellia aquatilis*: implications for management and reserve design. *Ecological Applications* 2:411-421.

Lofflin, D.L. and S.R. Kephart. 2005. Outbreeding, seedling establishment, and maladaptation in natural and reintroduced populations of rare and common *Silene douglalii* (Caryophyllaceae). *American Journal of Botany* 92:1691-1700.

McGlaughlin, M., K. Karoly, and T. Kaye. 2002. Genetic variation and its relation to population size in reintroduced populations of pink sand verbena, *Abronia umbelleta* subsp. *breviflora* (Nyctaginaceae). *Conservation Genetics* 3:411-420.

Mou, P., T.J. Fahey, and J.W. Hughes. 1993. Effects of soil disturbance on vegetation recovery and nutrient accumulation following whole tree harvest of a northern hardwood ecosystem. *The Journal of Applied Ecology* 30:661-675.

Neitsch, C.L., J.J. Castille, and M.R. Jurena. 1989. Soil survey of Leon County, Texas. United States Soil Conservation Service.

Oostermeijer, J.G.B., S.H. Luijten, Z.V. Krenova, and H.C.M. Den Nijs. 1998. Relationships between population and habitat characteristics and reproduction of the rare *Gentiana pneumonanthe L. Conservation Biology* 12:1042-1053.

Oostermeijer, J.G.B., R.V'ant Veer, and J.C.M. Den Nijs. 1994. Population structure of the rare, long lived perennial *Gentiana pneumonanthe* in relation to vegetation and management in the Netherlands. *Journal of Applied Ecology* 31:428-438.

Pickett, S.T.A., J. Kolasas, J.J. Armesto, and S.L. Collins. 1989. The ecological concept of disturbance at various hierarchical levels. *Oikos* 54:129-136.

Rowland, J. and M.A. Maun. 2001. Restoration ecology of an endangered plant species: establishment of new populations of *Cirsium pitcheri*. *Society for Ecological Restoration* 9:60-70.

Schmeske, D.W., B.C. Husband, M.H. Ruckleshuas, C. Goodwillie, I.M. Parker, and J.G. Bishop. 1994. Evaluating approaches to the conservation of rare and endangered plants. *Ecology* 75:584-606.

Setterfield, S.A.. 2002. Seedling establishment in an Australian tropical savanna: effects of seed supply, soil disturbance, and fire. *Journal of Applied Ecology* 30:949-959.

Shochat, E., P.S. Warren, S.H. Faeth, N.E.McIntyre, and D. Hope. 2006. From patterns to emerging processes in mechanistic urban ecology. *Trends in Ecology and Evolution* 21:186-191.

Sousa, W. 1984. The role of disturbance in natural communities. *Annual Review of Ecology and Systematics* 5:353-391.

Southern Weed Science Society. 1998. Weeds of the United States and Canada. CD-ROM. Southern Weed Science Society. Champaign, Illinois.

Stylinski, C.D. and E.B. Allen. 1999. Lack of native species recovery following severe exotic disturbance in Southern California shrublands. *Journal of Applied Ecology* 36:544-554.

Texas Parks and Wildlife. 2005. Endangered and threatened species found in Texas. <http://www.tpwd.state.tx.us/huntwild/wild/species/?c=endangered> Retrieved January 27, 2006.

Trombulak, S.C. and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18-30.

U.S. Fish and Wildlife Service. 1988. Endangered and threatened wildlife and plants: determination of endangered status for *Abronia macrocarpa* (large-fruited sand-verbena). *Federal Register* 43:37975.

U. S. Fish and Wildlife Service. 1992. Large-fruited sand verbena (*Abronia macrocarpa*) recovery plan. Albuquerque, New Mexico.

Vila, M., M. Tessier, C.M. Suehs, G. Brundu, L. Carta, A. Galanidis, P. Lambdon, M. Manca, F. Mediel, E. Moragues, A. Traveset, A.Y. Troumbis, and P.E. Hulme. 2006. Local and regional assessments of the impacts of plant invaders on vegetation structure and soil properties of Mediterranean islands. *Journal of Biogeography* 33:853-861.

Vitousek, P.M., L.R. Walker, L.D. Whiteaker, and P.A.Matson. 1993. Nutrient limitations to plant growth during primary succession in Hawaii Volcanoes National Park. *Biogeochemistry* 23:197-215.

Wilcove, D.S. 1989. Protecting biological diversity in multiple-use lands: lessons from the U.S. Forest Service. *Trends in Ecology and Evolution* 4:385-388.

Williamson, P.S., L. Muliani, and G. Janssen. 1994. Pollination biology of *Abronia macrocarpa* (Nyctaginaceae), an endangered Texas species. *Southwestern Naturalist* 39:336-341.

Williamson, P.S. and S.K. Bazeer. 1997. Self incompatibility in *Abronia macrocarpa. Southwestern Naturalist* 42:409-415.

Williamson, P.S. and C.R. Werth. 1999. Levels and patterns of genetic variation in the endangered species *Abronia macrocarpa* (Nyctaginaceae). *American Journal of Botany* 86:293-301.

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