VEGETATION COLONIZATION OF EXPERIMENTAL GRAVE SITES IN CENTRAL TEXAS

THESIS

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VEGETATION COLONIZATION OF EXPERIMENTAL

GRAVE SITES IN CENTRAL TEXAS

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The field of forensic anthropology deals with the analysis of human skeletal remains in the context of law enforcement. The primary foci are sex, age, race, and stature, which are all components necessary to establish the biological profile of an individual (Dirkmaat 2008; Stewart 1979). Increased cooperation with law enforcement agencies on investigative cases has highlighted areas that require more knowledge and research and therefore has increased the scope of forensic anthropology (Dirkmaat 2008). The process of decomposition of human remains has also been the focus of multiple studies (Galloway 1997; Love and Marks 2003; Mann et al. 1990; Rhine and Dawson 1997; Vass et al. 2002) but more research is needed to understand the effects of decomposition on the environment. This study focuses on the effect of decomposition in an outdoor setting in San Marcos, Texas, on the surrounding vegetation. The surrounding vegetation was monitored in order to determine the effect of the decomposition on the types of plants growing in the immediate vicinity.

I conducted this research in the Edwards Plateau, an area of central Texas primarily composed of limestone amid several distinct subregions that support a variety of specific habitats (Riskind and Diamond 1986). The soil types along the Edwards Plateau are different and distinct because of these subregions. They range from shallow to deep, and are rocky and calcareous due to the fact that they lie on top of limestone or caliche (Riskind and Diamond 1986). The climate and environment of the Edwards Plateau is highly variable and supports forests, woodlands and grasslands with regional variation seen in the endemic flora species.

The focus of this study was to determine if a burial containing a body promotes the same type of plant growth as an empty burial. It is generally known that decomposition initially kills vegetation (France 1992), but it is not yet known which species of plants grow in the presence of human and pig decomposition in central Texas. I had no *a priori* expectations about the particular species of plants that would eventually colonize the area as this information is not yet known in this area of Texas. However, I expected that the plants growing on the sites would initially die from the act of digging the graves and growth further inhibited by the presence of decomposition. I also expected there to be a difference in the plants colonizing burials containing pigs compared to the empty control burial.

1.2 Postmortem Interval

Forensic anthropology is a subfield of physical anthropology that has traditionally focused on identification of human skeletal remains (Stewart 1979). The recognition and acceptance of the forensic anthropologist as an expert in the recovery and identification of human skeletal remains in law enforcement cases has expanded the field to include more than the biological profile (Glassman 2003). Extensive research conducted by forensic anthropologists have allowed them to assist law enforcement with determinations of postmortem interval (PMI) (Haglund and Sorg 1997), or time since death.

The determination of the PMI is essential to law enforcement investigations (Wells and LaMotte 2001). Knowing the timeline associated with an individual's death can be crucial in determining the events surrounding that death. PMI is important in narrowing the field in terms of identification of the victim and in the case of homicide, can help detectives to steer the investigation in the right direction in terms of speaking to valuable witnesses and determining possible suspects (Geberth 1997). During the first few hours after death, pathologists gather valuable information, such as the body's temperature (algor mortis), the pooling of the blood (livor mortis), and amount of muscle stiffness (rigor mortis) (Love and Marks 2003). These three processes are used within the first 24 hours since death by pathologists to determine the amount of time that has passed since the individual's death and discovery of the body. However, as the soft tissue breaks down, these three types of information are unavailable and the pathologist must turn to other sources to try and determine the time since death. At this point, forensic anthropologists can lend their knowledge to the case (Rhine and Dawson 1997). Forensic anthropologists use their expertise in the decay process and excavation of human remains; proper excavation can minimize postmortem trauma to the remains and maximize collection of all human material and other evidence, leading to the most accurate PMI possible (Haglund and Sorg 1997). In order to determine PMI as accurately as possible and properly excavate human remains, it is crucial that forensic anthropologists have accurate knowledge of the process of decomposition and those factors that can affect the rate of decomposition (Mann et al. 1990). Any source of information that can narrow down the PMI is essential, including botanical knowledge of an area where a body has been discovered, as in this study.

1.3 Forensic Taphonomy

The term taphonomy was originally proposed as a term meaning the study of the laws of burial and was originally used by paleoanthropologists and archaeologists for fossil and ancient remains. This definition has since extended to mean the accumulation and modification of osteological assemblages from time of death to time of recovery (Haglund and Sorg 1997). In terms of forensic taphonomy, the definition refers specifically to the processes that affect decomposition and dispersal of remains in a much shorter time period than that used by paleoanthropologists or archaeologists (Nawrocki 1996). The aim of forensic taphonomy is to understand the processes of decomposition and the factors that influence them. Forensic taphonomy can aid in estimating PMI and also differentiating between ante-, peri- and postmortem trauma (Sauer 1997), which may assist speculations regarding the cause and manner of death (Carter and Tibbett 2003). Decay rates of human remains are affected by many factors, including temperature, insect and scavenger activity, and perimortem trauma (Love and Marks 2003). All of these variables can affect the decay rate of human remains and must be taken into consideration by the forensic anthropologist. Because forensic taphonomy is used to take into consideration all factors related to the decomposition and dispersal of remains including the environment, observation of the vegetation in the immediate area should be included.

1.4 Process of Decomposition

All bodies go through a cycle of decomposition that varies between different environments. For example, bodies in hot, humid weather tend to decompose quickly while bodies in cold weather will decompose at a much slower rate. Decomposition in the body begins minutes after death, starting with the process of autolysis, or somatic cell death (Gill-King 1997). This initial process releases nutrient-rich fluids from cells, causing fluid-filled blisters to appear along the body, leading to skin slippage. Following the process of autolysis, the release of nutrients and decrease in intercellular pH due to loss of the buffer system, a process within living cells that maintains the pH at the optimum level, causes proliferation of internal bacteria (Love and Marks 2003). This process, called putrefaction, refers to the destruction of soft tissues of the body by micro-organisms, transforming the tissues into gases, liquids and simple molecules (Campobasso et al. 2001). The body undergoes a greenish discoloration due to increased bacterial colonies and bloating due to gas accumulation, which eventually purges (Vass et al. 2002). Once the gas has been purged, the next process, called active decay, begins. This process involves the transformation of proteins and fats into volatile fatty acids and other decomposition products (Vass 2001). The environment plays a large role in the process of decomposition, causing specific variations in the pattern of decomposition (Rhine and Dawson 1997). Mummification or adipocere formation can often occur due to environmental factors changing the chemical decomposition process. Adipocere is a grey, fatty substance that is formed from the soft tissues of a body and can cause resistance to decomposition (Fielder and Graw 2003). Mummification often occurs in environments with high temperatures and low humidity, effectively preserving some of the tissues indefinitely (Galloway 1997).

1.5 *Sus scrofa* as a substitute for human subjects

Using animals in place of humans is a common practice in scientific research. Micozzi (1991) examined decomposition of animals in place of humans, and compared the decomposition rates of several animals to the decay rates of humans. He concluded that pigs (*Sus scrofa*) are the most suitable replacement for humans in decomposition research because pigs and humans share so many similar traits, such as intestinal flora, muscle to fat ratio and the relative hairlessness of the skin (France 1992). Also, the size and weight of domestic pigs are broadly approximate to average sized humans. Although human bodies are preferable to use in decomposition studies, they are not always available. In this case, pigs are a viable substitute (Haglund and Sorg 1997). For these reasons, I used pig cadavers in my study.

1.6 Forensic Botany

Forensic botany is a field that applies plant science to the resolution of legal questions. The field is developing into a useful tool that encompasses several sub-fields, such as palynology (the study of spores and pollen), dendrochronology (the study of tree rings), limnology (the study of freshwater ponds and lakes) and molecular biology. The field of forensic botany is constantly growing as new applications to forensic cases are being realized (Dommelen 2002). Past studies have identified the usefulness of utilizing plant root systems growing through bone to determine PMI (Quatrehomme et al. 1997; Willey and Heilman 1987). In these studies, forensic botanists applied information about plant growth cycles to determine how long plant roots were growing through skeletal remains, therefore establishing a minimum PMI. Forensic botany is often used to link victims or suspects to crime scenes, to discover the presence of controlled substances, or to identify plant substances in the stomach contents of victims (Bock and Norris 1997). For example, the presence of certain species of pollen has been useful in linking suspects to a particular crime scene, ultimately leading to arrests and convictions. While all applications of forensic botany are useful, the application that is important to forensic anthropology and to my study in particular is the understanding of how the process of decomposition affects vegetation, determination of the postmortem interval, and the location of clandestine graves

1.7 Effect on Soil and Vegetation

The process of decomposition leaches chemical compounds into the soil that affect the surrounding vegetation. The initial effect is a die-off of the plants in the immediate area due to an increase in soil acidity (Vass et al. 1992). The volatile fatty acids produced during active decay typically cause the area of primary decomposition to be marked with dark, greasy soil and yellowed vegetation (Love and Marks 2003). Some of the volatile fatty acids identified in decomposition fluids are formic acid, acetic acid, propionic acid, butyric acid, valeric acid, caproic acid, heptanoic acid and oxalic acid (Vass et al. 1992). As well as these volatile fatty acids, two compounds unique to decomposition fluid are also present, called putrescine and cadaverine (Carter and Tibbett 2003). These compounds eventually break down further into other, less acidic compounds and their introduction changes the nutrient content of the soil, which could have significant effects on the surrounding vegetation. My study focuses on the effects of these compounds on the vegetation in the immediate area.

1.8 Plant Colonization and Succession

When an area of the ground is disturbed, vegetation begins to re-colonize the area as part of a process known as succession. A general definition of colonization is the observation of patterns of changes in species abundance in response to disturbances in the environment (McCook 1994). When the vegetation in a particular area is disturbed, it quickly begins the growth cycle, gradually re-colonizing the disturbed area. These types of changes generally involve the appearance and dominance of species with progressively greater size, age, and shade tolerance and progressively lower dispersal abilities and growth rates (McCook 1994). Succession has been defined as a gradient in time where species turnover is partially a function of changing resource availabilities (Carson and Barrett 1988). Certain species of plants colonize disturbed areas, and gradually other species eventually begin to grow in the area as well. Succession can be easily observed by an individual who is knowledgeable about the native plants in a particular area, but is not so easily understood because there are many factors that affect the rate at which colonization and succession occur and the types of plants that begin this process. In my study, the colonization of the study sites was observed as the time period of the study is too short to observe true succession. However, continued observation of my study sites could later offer insight into succession over grave sites.

1.9 Location of Clandestine Graves

Ecological knowledge of plants in the area can be used as a tool for determining the presence of graves (France 1992; France et al. 1997). For example, Carter and Tibbett (2003) observed specific species of fungi (*Rhopalomyces* sp. and *Hebeloma* sp.) that are attracted to burials because of the nutrients leached into the soil through decomposition. Because the soil composition would be altered by the presence of different nutrients and volatile fatty acids, it is expected that different plants will colonize the area until the soil composition has returned to its normal state, allowing an expert to find a burial based on the plant growth. Another factor to consider is that decay rates depend on the area where the decomposition is taking place. Prior studies have shown that surface decomposition is typically faster than decomposition in a burial (Fielder and Graw 2003; Vass et al. 1992). Burials tend to slow decomposition by decreasing gas diffusion, limiting macro- and microorganism activity and increasing the amount of carbon dioxide which can lead to anaerobic conditions (Statheropoulos et al. 2004). The difference in the rate of decomposition may cause different reactions in the surrounding vegetation based on the timing of events during the decomposition process. In a legal investigation in which a forensic anthropologist assists, understanding how the presence of decomposition affects the colonization of vegetation in the area could be instrumental in locating clandestine graves. (France et al. 1997). Necrosearch International, Ltd. is a Colorado based organization that frequently utilizes the knowledge of botanists and plant ecologists to search for patterns of localized, unusual plant growth that may indicate a clandestine grave (Bock and Norris 1997). Searching for clandestine graves requires the knowledge of the local flora, however an individual familiar with local plants can easily locate an area of disturbance weeks, months and even years afterwards (Bock and Norris

1997). The goals of my study were similar to those of Necrosearch International, Ltd. in that I also observed the re-vegetation of grave sites.

CHAPTER 2

MATERIALS AND METHODS

2.1 Location

Research was conducted at the Forensic Anthropology Research Facility, located on Texas State University-San Marcos' Freeman Ranch, in San Marcos, TX. Freeman Ranch is a 4,204 acre area of land situated in southeastern Hays County, between Wimberley and San Marcos, approximately five miles from campus off Ranch Road 12. It is in the Balcones Canyonlands along the eastern edge of the Edwards Plateau and within the recharge zone of the Edwards aquifer.

2.2 Location Preparation

To prepare for the study, three holes were dug approximately 3 feet apart using a backhoe. The holes were slightly filled in and evened out so that they were all three feet deep.

Midway through the research period, there was a minor setback at the study site. Freeman Ranch is an active working ranch that utilizes the land for grazing cattle. The pasture where the pigs were located is one such grazing area. The cows were moved back into this pasture around the same time that a few isolated plants started growing on the burials. During my next visit after the cows had been moved into the pasture, I observed no plant growth. It is likely that the cows either trampled or ate any plants growing in the vicinity. To rectify this problem, a cattle pen was put around the burials and the surface pig to keep away any grazing animals from further damaging the research site. Normal observation was resumed after the cattle pen was put around the study site. Plant growth was observed almost immediately.

2.3 Subject Information

As human cadavers were unavailable at one time when this study began, three domestic pigs were obtained from a local farmer who was culling his herd, and transported to the site at Freeman Ranch. Each of the pigs was roughly the same size, around one hundred pounds each with an average weight of 106.6 lbs, a weight estimated adequate to obtain results that would be similar to those a human body would produce. Pig 1 weighed 104 pounds, pig 2 weighed 107 pounds and pig 3 weighed 109 pounds. Three human bodies were also incorporated into the study. These bodies represent subjects in FACTS' willed human body donation program, and were incorporated as they were brought to the facility. Due to this, the start date for each donation is different and dependent on the date the donation arrived to the facility. Since the pigs were brought out to the site on the same day, they were considered the primary study subjects. The human donations were then considered the secondary study subjects as their results would still yield valuable opportunistic data.

2.4 Cages

A metal cage was used to cover the pig left on the surface in order to deter any scavenger activity of both the pig and the vegetation that would eventually begin to grow. The burials did not require a cage as they were deep enough to deter scavengers that may have otherwise dug down to a shallow grave. A cattle pen was eventually required around the entire site to protect the vegetation that did begin to grow. The pen was built by the ranch hands that work at Freeman Ranch using the equipment already on site.

2.5 Camera and Photography

A Kodak® EasyShare MD853 camera was used for all photographs taken during observations. The camera has an 8.2-megapixel resolution which ensured high quality close-up pictures of any plants observed. High quality pictures are important when attempting to identify plant species through photographs and not specimens. During this study, no plant specimens were collected in order to allow further growth of the plant.

2.6 Placement of Subjects

On July 22, 2008 two of the three pigs were placed in separate burials, and one was left out on the surface six feet away from the burials. The two burials were filled in, along with a third hole that was filled in with dirt but did not contain a pig, as a control. The surface pig was covered with a six foot long metal cage to deter any scavenger activity. The first human body to be incorporated was the first donation to the Forensic Anthropology Research Facility, and the individual was placed out on the surface in April 19, 2008 and was subsequently buried on July 19, 2008. The individual was approximately 168 cm in height and weighed 140 lbs. The other two bodies are also donations to the Forensic Anthropology Research Facility and both were immediately buried upon arrival rather than being allowed to decompose on the surface first. The second body was brought out to the Forensic Anthropology Research Facility on October 1, 2008, was approximately 153 cm in height and weighed 330 lbs. The third donation was brought out on October 14, 2008, was approximately 175 cm in height and weighed 293 lbs.

2.7 Observations

The site was observed every few days at the beginning of the study, and eventually the time of each observation was lengthened to once a week, to study the effects of vegetation growth. Every observation consisted of a survey of the study site and photographs to document the process. Any and all changes to the vegetation were noted and documented. The three burials containing human bodies were observed in the same way as the pigs, by weekly visits and photographs to document any change in the vegetation. In terms of identifying any vegetation growing over the burial or decomposition sites, Dr. David E. Lemke, a biologist from Texas State specializing in plant taxonomy and familiar with vegetation at Freeman Ranch, assisted with the identification of the vegetation. Any plants discovered growing over the sites were carefully monitored and documented and left alone so as not to disturb the growth of the plant.

CHAPTER 3

RESULTS

Table 1 lists of all the plant species that were observed and identified, along with the date of their first observation and the site on which they were observed. For maps of the geographic distribution of each of these plant species and pictures of each plant, see Appendix A. Table 2 lists the sites observed throughout the course of this study and the plant species observed at each of these sites, allowing for any overlap to be easily noticed. The last column of Table 2 is a count of how many different species were present at each site. Using this column, it is apparent that the empty control site had a higher count of species growing over it than any of the other burials, which could indicate that the presence of decomposition has inhibited the growth of some of the pioneer species. However, as the numbers are low there is no way to test if this difference is statistically significant.

Table 1: Observations of Identified Plant Species.

Plant Species	Common Name	Day First Observed	Date of Observation	Location of Plant
Amaranthus retroflexus	Red-root Pigweed	Day 53	September 12, 2008	Donation #1
Bothriochloa ischaemum	King Ranch Bluestem	Day 102	October 31, 2008	Burial #2
Calyptocarpus vialis	Straggler Daisy	Day 230	March 30, 2009	Donation #1
Euphorbia dentata	Spurge	Day 66	September 25, 2008	Burial #1
Kallstroemia parviflora	Mexican poppy	Day 209	March 2, 2009	Burial #2
Lesquerella recurvata	Bladderpod	Day 243	April 7, 2009	Control Burial
Oxalis dillenii	Yellow Wood sorrel	Day 209	March 2, 2009	Burial #1 Control Burial
Oxalis drummondii	Wood sorrel	Day 102	October 31, 2008	Burial #1
Physalis cinerascens	Yellow Ground Cherry	Day 66	September 25, 2008	Burial #1
Portulaca sp.		Day 243	April 7, 2009	Burial #1
Prosopis glandulosa	Honey Mesquite	Day 66	September 25, 2008	Burial #2 Control Burial
Sida abutifolia	Spreading fanpetals	Day 66	September 25, 2008	Control Burial
Sonchus asper	Sowthistle	Day 243	April 7, 2009	Control Burial
Tragia ramosa	Noseburn	Day 66	September 25, 2008	Burial #1
Vicia ludoviciana	Deer pea vetch	Day 177	March 27, 2009	Donation #2

Table 2. Identified Plant Species and their Location.

	Empty Control Burial	Pig Burial #1	Pig Burial #2	Pig Surface Site #1	Human Donation Site #1	Human Donation Site #2	Human Donation Site #3
Amaranthus retroflexus					X		
Bothriochloa ischaemum			X				
Calyptocarpus vialis					X		
Euphorbia dentata	X						
Kallstroemia parviflora			X				
Lesquerella recurvata	X						
Oxalis dillenii	X	X					
Oxalis drummondii		X					
Physalis cinerascens		X					
Portulaca sp.		X					
Prosopis glandulosa	X		X	X			
Sida abutifolia	X						
Sonchus asper	X						
Tragia ramosa		X					
Vicia ludoviciana						X	
Total Number of Plants	6	5	3	1	2	1	0

3.1 Description of Vegetation

Oxalis spp.

Oxalis drummondii and *Oxalis dillenii*, wood sorrel and yellow wood sorrel respectively, are two plants that were identified growing on the burials. *Oxalis drummondii* was observed on burial #1 during the Fall, while *O. dillenii* was observed on burial #1 and the empty control burial during the Spring season. These results are unsurprising because *O. drummondii* grows and blooms during the Fall and *O. dillenii* grows and blooms during the Spring and Summer (Barnes et al. 2000). *Oxalis dillenii* was observed in more abundance than *O. drummondii*, but based on the times of the year when *O. drummondii* blooms, it is likely that it simply did not have enough time to flourish in the area while *O. dillenii* has a much longer bloom period and so is observed more frequently. Both of the species are found in abundance at Freeman Ranch (Barnes et al. 2000). *Oxalis drummondii* is not typically known as a disturbed earth plant, it is found in limestone soils which are abundant at Freeman Ranch. However, *O. dillennii* is frequently found at disturbed sites which can explain its presence on both burial #1 and the empty control burial (Diggs et al. 1999). It may also be noted that plant species of the family Oxalidaceae have oxalic acid in their tissues (Diggs et al. 1999). Oxalic acid has been identified as one of the main components found in the soil during the decomposition process when volatile fatty acids are leaching into the soil (Vass 2001). While chemical testing is needed to determine if there is a correlation between the oxalic acid in the tissues of the plant and oxalic acid found in the soil during decomposition, this may be an explanation that can be explored through further research. Chemical testing was not used in this study as the focus was merely the colonization of the burials.

Prosopis glandulosa

Prosopis glandulosa, also known as honey mesquite, was found on both burial #1 and especially on burial #2. The plant was not found on the control burial throughout the duration of the study. Mesquite is known as an invasive plant on ranchlands as it tends to spread rapidly due to the cattle grazing and the lack of prairie fires, but it also has the benefit of enriching the soil with organic matter and nutrients (Diggs et al. 1999). The mesquite tree is well known in Texas for its ability to weather harsh environments, and actually thrives in heat and drought (Turner 2009). The tree can survive long drought periods due to the large, deep taproot it can form in its search for water (Diggs et al. 1999). Based on this information, the presence of the mesquite on the burials may be due to the hardiness of the mesquite plant and its ability to endure harsh environments. The mesquite plants may also be one of the few plants growing at the site because it can easily survive the severe drought that is currently plaguing central Texas (Turner 2009).

Amaranthus retroflexus

Amaranthus retroflexus, also known as red-root pigweed, is a non-native plant of Texas that is typically considered to be a weed (Turner 2009). This plant was only found on the burial of the first human donation and was the first plant observed on any of the sites. Red-root pigweed has historically been cultivated because of the grain it produces and the edible leaves, is found in weedy areas, and is frequently found at disturbed sites (Diggs et al. 1999; Turner 2009). In fact, it is more uncommon to find *A. retroflexus* at undisturbed sites as opposed to disturbed sites. *Amaranthus retroflexus* has a growing period from May to October, which may account for its absence on any other burials

(Diggs et al. 1999). Like the mesquite tree, *A. retroflexus* is also a hardy plant that can grow in a variety of soils and under drought conditions (Turner 2009). This plant species has yet to be observed on any of the burials at the primary site, even though it can be expected due to its drought resistance. Further observation may eventually yield more individuals of this plant species.

Sida abutifolia

This plant species, also known as spreading fan petals, was found frequently on the empty control burial. *Sida abutifolia* is commonly found at Freeman Ranch and has been frequently found at disturbed sites, limestone outcrops, and waste areas (Barnes et al. 2000; Diggs et al. 1999). *Sida abutifolia* is also well known as a plant that commonly colonizes intercanopy patches within juniper forests, and so is common among the juniper trees at Freeman Ranch (Van Auken 2000). *Sida abutifolia* has a growing period from April to October, and was only found on the empty control burial during this period (Diggs et al. 1999). As this plant seems to flourish on disturbed sites, it seems that it would be observed frequently among the primary and secondary burials; however it has only been observed on the control burial. This may be due to the presence of decomposition in the area around the burials, as the soil composition may be too harsh for *S. abutifolia* to colonize the burials.

Euphorbia dentata

Also known as toothed spurge, this plant is commonly found at Freeman Ranch and is generally known as a weed (Barnes et al. 2000). *Euphorbia dentata* is frequently found in fields, and on roadsides and other various disturbed sites (Diggs et al. 1999).

Plants of the genus *Euphorbia* are known to contain complex, toxic terpenes that can cause dermatitis and gastric distress, particularly among livestock (Diggs et al. 1999). This plant was only observed on the control burial on one occasion and has not been observed since the initial observation. The bloom time for *E. dentata* is midsummer to early Fall, and so the initial observation which took place during the late summer was obviously during the bloom time and it is likely that is has not been observed again because the bloom time for the plant was over (Dunn 1979).

Physalis cinerascens

Physalis cinerascens was found on one of the pig burials and is commonly known as a smallflower ground cherry (Barnes et al. 2000). The plant has an extensive root system and deep taproot, characteristics that allow the plant to be drought tolerant (Sullivan 1984). In fact, the plant prefers drier environments as it does not flourish in wet soils. The plant is also commonly found at disturbed, open sites and is common to see growing along the road (Sullivan 1984). The growth period for *P. cinerascens* is from April to October (Diggs et al. 1999).

Bothriochloa ischaemum

Commonly known as King Ranch bluestem, this plant was found on one of the pig burials, is locally abundant at Freeman Ranch and is a common species of disturbed sites on the Edwards Plateau (Barnes et al. 2000). Along with this specific species identified, there were other species from the Poaceae, or grass family but at the time of observation they were unidentifiable. Only one individual of the *B. ischaemum* was observed and identified on burial #2, even though King Ranch Bluestem is quite common at Freeman Ranch on the calcareous soils and is even found along roadsides and other disturbed sites (Diggs et al. 1999). It is possible that the presence of decomposition inhibited further growth of other *B. ischaemum* individuals.

Kallstroemia parviflora

This plant is commonly known as a Mexican poppy or warty caltrop, was found on burial #2, and is occasionally found at Freeman Ranch (Barnes et al. 2000). The plant has a growth period from April to November and is commonly observed at disturbed sites (Diggs et al. 1999).

Calyptocarpus vialis

Commonly known as straggler daisy, this plant was found on the first human burial, is very abundant at Freeman Ranch, and is one of the dominant species of the herbaceous community at Freeman Ranch (Barnes et al. 2000). This plant is a typical early-successional and grazing-tolerant plant that thrives at the ranch (Barnes et al. 2000). It has a growth period from April to July and can sometimes be a troublesome weed (Diggs et al. 1999).

Sonchus asper

This plant is commonly known as sowthistle, was found on pig burial #1 and is not uncommon in this area of Texas, with a large distribution throughout America (Barnes et al. 2000; USDA 2009). This plant blooms primarily from March to June, but can be seen sporadically throughout the year and is common along roadsides and other disturbed sites (Diggs et al. 1999).

Lesquerella recurvata

This plant is also known as bladderpod and was found on the empty control burial. This plant is commonly found on limestone outcrops and gravelly calcareous prairies (Diggs et al. 1999). It is endemic to Texas and blooms from March to April (Diggs et al. 1999).

Tragia ramosa

Commonly known as catnip noseburn, this plant was found on burial #1. Plants of the genus *Tragia* are well known for their stinging hairs, which can be painful if they come into contact with skin (Diggs et al. 1999). *Tragia ramosa* blooms from April to October and is commonly found at disturbed sites (Diggs et al. 1999).

Vicia ludoviciana

Commonly known as deer pea vetch, this plant was found on the second human burial. The plants of the genus *Vicia* are known to contain alkaloids and can be edible but some species can be quite toxic and can even cause hepatitis in some genetically pre-disposed people (Diggs et al. 1999). *Vicia ludoviciana* is commonly found in rocky or sandy soils and in open woods or roadsides, and the plants bloom from late March to early May (Diggs et al. 1999).

***Portulaca* sp.**

Commonly known as purslane, this plant was found on burial #1. Some species of this genus are known to contain oxalic acid in small quantities. Plants of the *Portulaca* sp. are often found in disturbed areas and bloom from March to November (Diggs et al. 1999).

3.2 Factors Affecting Results

There were complications that arose during the course of this study that inhibited the plant growth and colonization. Freeman Ranch is a working ranch, with cattle being one of the main priorities. One of the herds of cows raised on Freeman Ranch was inadvertently moved into the pasture where the primary study site was located. This occurred between days 55 and 66, as vegetation was noted on day 55 but was absent on day 66. Upon consultation with the ranch manager, it was confirmed that the absence of the vegetation was likely due to cattle grazing and a solution was formulated to solve this problem. The ranch manager and the ranch hands working at Freeman Ranch built a small fence around the primary site that was sufficient to keep the cattle away and allow the vegetation to continue its natural colonization and succession process. The secondary incorporated sites were within the Forensic Anthropology Research Facility and so were automatically protected from cattle and other grazers.

Another complication arose as a result of natural factors that could not be addressed by any type of human intervention as with the problem of the cattle. The area of Texas that this study is took place in is currently in a severe drought, the driest 18-month period on record according to the National Weather Service (NOAA 2009). A severe drought is a limiting factor to any plant growth, and was certainly a limiting factor in this study. While it is known that there are plants that can survive and are even adapted to drought conditions, plant growth all over Freeman Ranch was observed to be detrimentally affected by the drought. It is not known how strongly the drought affected the colonization of the vegetation in this study as there is no previous knowledge of plant colonization and succession in the presence of decomposition in this area. Even though only three of the plants observed on the sites are known to be drought tolerant, the low number of individual plants growing could indicate the detrimental effect the drought has had.

CHAPTER 4

DISCUSSION

4.1 Overview

This study is the first of its kind to be conducted in this area of central Texas. For this reason, I had no *a priori* expectation of the species of plants that would be observed at each site. I expected that the plants growing over the burials would initially be killed by the act of digging the graves, and growth to be further inhibited by decomposition. After an eight month observation period, these expectations were met. Previous studies (Love and Marks 2003; Vass et al. 1992) showed the vegetation surrounding the surface sites initially are killed during the first few days due to the acidity of the volatile fatty acids. The vegetation on the burial sites in my study was destroyed due to the machinery that was brought in to dig the burials. After approximately 50 days, *Amaranthus retroflexus* (red root pigweed) was observed on the burial of the first donated body. The burials containing pigs and the empty control burial experienced regrowth of plants at approximately 60 days after the beginning of the study, with *Euphorbia dentata*, *Physalis cinerascens, Prosopis glandulosa, Sida abutifolia,* and *Tragia ramosa* observed among the three burials. The rest of the plants observed on the various sites colonized the area much later, approximately 100-200 days after research began. The purpose of this study was to determine if there would be a difference based on normal disturbance compared to a disturbance along with decomposition, and if so then more detailed study could be carried out in the future. Based on the descriptions of the fifteen plants observed and identified, eleven plants are commonly found in disturbed areas. Ten of these eleven plants were able to colonize one of the burials containing either a pig or donated human body, indicating that these plants can be used to locate a clandestine grave. The ten plants that successfully colonized a burial within the time period of the study were *Amaranthus retroflexus, Bothriochloa ischaemum, Euphorbia dentata, Kallstroemia parviflora, Physalis cinerascens, Portulaca* sp., *Prosopis glandulosa, Sonchus asper, Tragia ramosa,* and *Vicia ludoviciana*.

The findings of my study were broadly comparable with those of a similar study performed in Colorado (France 1992). France (1992) employed a variety of methods in order to locate clandestine graves, including using botanical knowledge of plants. France's study found that the act of digging a grave sets plant colonization and succession into motion, and that pioneer species will colonize the area first. The vegetation gradually changes as the graves progress through succession but will be identifiable for several years, ultimately leading to their conclusion that knowledge of plants in an area is useful in locating a clandestine grave. My study mirrored the first two findings of the France (1992) study, in that colonization and succession began and pioneer species successfully colonized the area. It is likely that continued observation of my site will eventually show that grave sites can be easily recognized by a trained eye even several years later, as the France (1992) study also found.

Even though this study can assist in the location of clandestine graves, it is only a small piece of a forensic investigation. In order for the search, recovery and analysis of human remains in a forensic context to be as accurate as possible, a multidisciplinary approach must be utilized, as has been done successfully by Necrosearch International, Ltd. Combining the knowledge of forensic taphonomy, the decomposition process, plant colonization and succession, scavenger activity and entomology can only lead to higher success rates in locating clandestine graves. To do this, further research is needed here in Texas to try and obtain as much knowledge as possible about each of these possible aspects of a forensic investigation.

CHAPTER 5

CONCLUSION

This study was intended to determine the pioneer species that would colonize a grave site and if further studies should be carried out in this field of research. Based on the results, it appeared that many of the plants growing over the burials were different than those growing over the empty control. In fact, of all the plant species observed, only two species were observed on both the empty control and the pig burials. This may indicate that the species of plants colonizing a disturbed area are affected by the decomposition, although more detailed study will be needed in order to confirm this. Studying the soil composition while also studying the colonizing plants may offer some insight into the factors affecting plant growth. Previous studies have been carried out at the Anthropological Research Facility at the University of Tennessee in Knoxville on the chemical composition of the soil during the process of decomposition (Vass 2001; Vass et al. 1992), and correlating the amounts of volatile fatty acids to the vegetation colonizing could possibly offer some insight into types of plants colonizing the area.

Another possible future direction should address the issue of seasonality. Different vegetation will colonize the area depending on the season in which the study was started. This study began in the middle of the summer and continued through winter into the spring. However, starting the study during other seasons will certainly yield different results depending on the types of plants that are dominant in a particular season.

Also, the various temperature changes and weather conditions that occur during each season would likely have an effect on the rate of decomposition, and in turn the amounts of volatile fatty acids in the soil and the rate of their subsequent breakdown should be investigated further.

Another avenue of future research can come from continued observation of this study site to observe long term effects of disturbance by decomposition and the time period that a clandestine grave is detectable using vegetation. Counting the number of species and also measuring the amount of ground each individual plant covers and comparing the numbers between the empty control burial and the pig burials would be a way to quantitatively measure the effect of decomposition on succession.

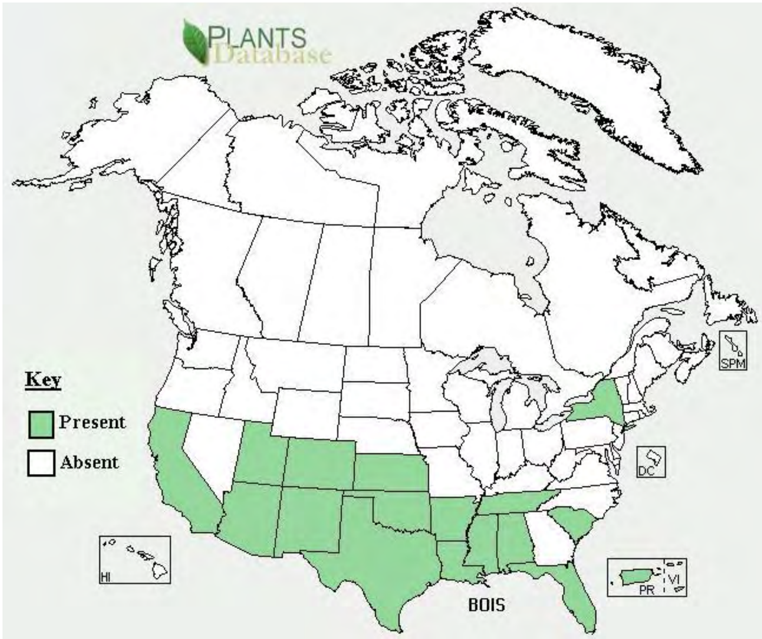
To conclude, of all the species that were observed to be colonizing both the primary and secondary study sites, nearly all are known disturbed earth plants and several are known to be drought tolerant. This result is unsurprising as most of the plants flourishing at Freeman Ranch currently would have to be drought resistant in order to survive. This study was initiated in order to determine if plant colonization and succession showed differential growth patterns over burials or disturbed sites. Based on these preliminary results, the plants do exhibit differential growth patterns depending on the presence of decomposition, but further studies will be needed to confirm and understand this. Specifically, a longer observation period in order to observe the succession of plant growth and not just the colonization could confirm a differential growth pattern. Additionally, a more detailed study that incorporates soil composition and seasonality information would likely yield valuable results that could assist forensic investigators in the identification and location of clandestine graves based on the recognition of plant colonization and succession characteristics.

Appendix A

MAPS AND PHOTOGRAPHS OF SPECIMENS

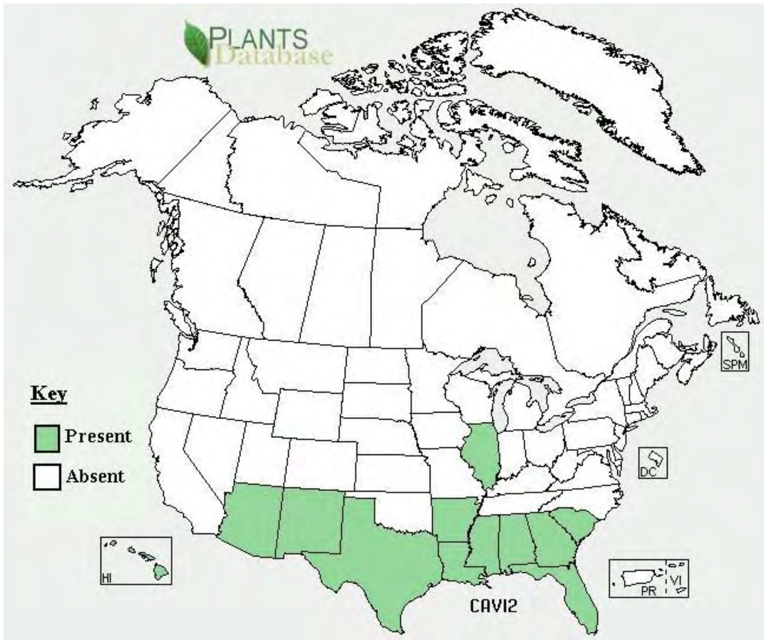
Geographic distribution of *Amaranthus retroflexus* in North America

Photograph of *Amaranthus retroflexus* specimen



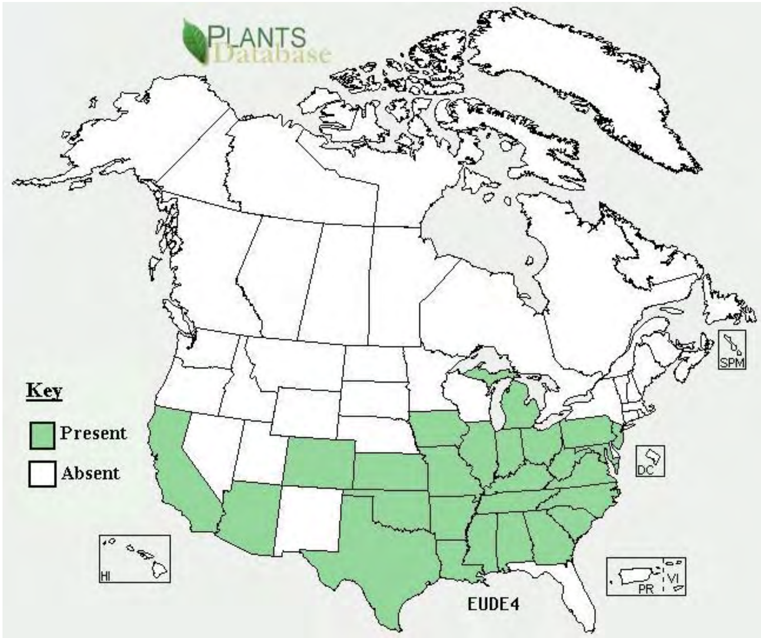
Geographic distribution of *Bothriochloa ischaemum* in North America

Photograph of *Bothriochloa ischaemum* specimen



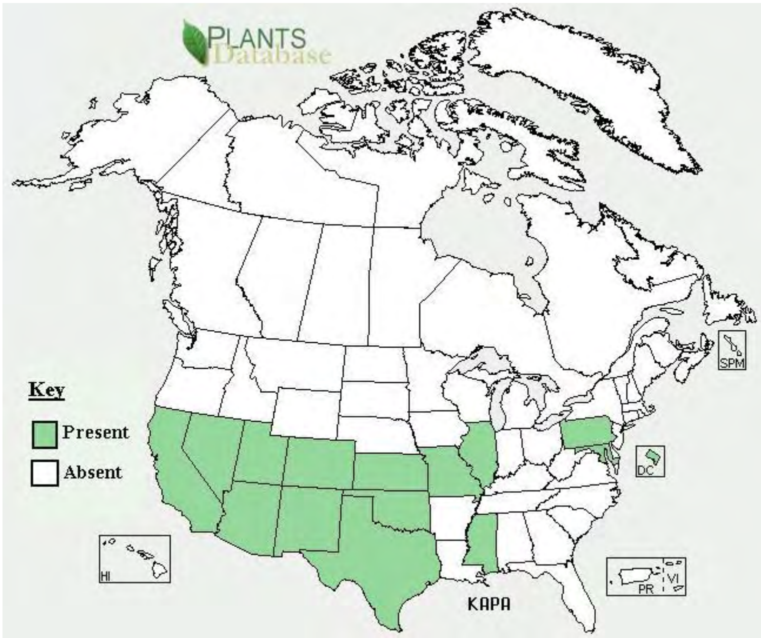
Geographic distribution of *Calyptocarpus vialis* in North America

Photograph of *Calyptocarpus vialis* specimen



Geographic distribution of *Euphorbia dentata* in North America

Photograph of *Euphorbia dentata* specimen

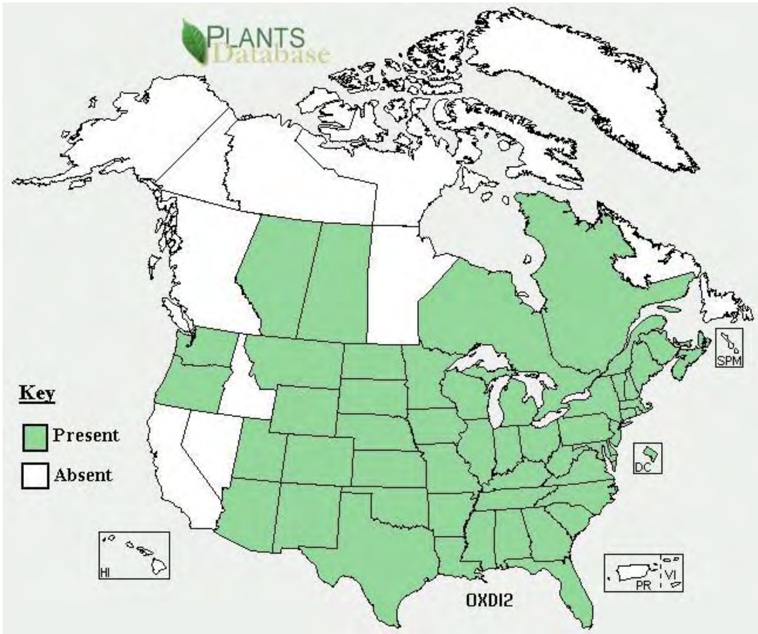


Geographic distribution of *Kallstroemia parviflora* in North America

Photograph of *Kallstroemia parviflora* specimen.

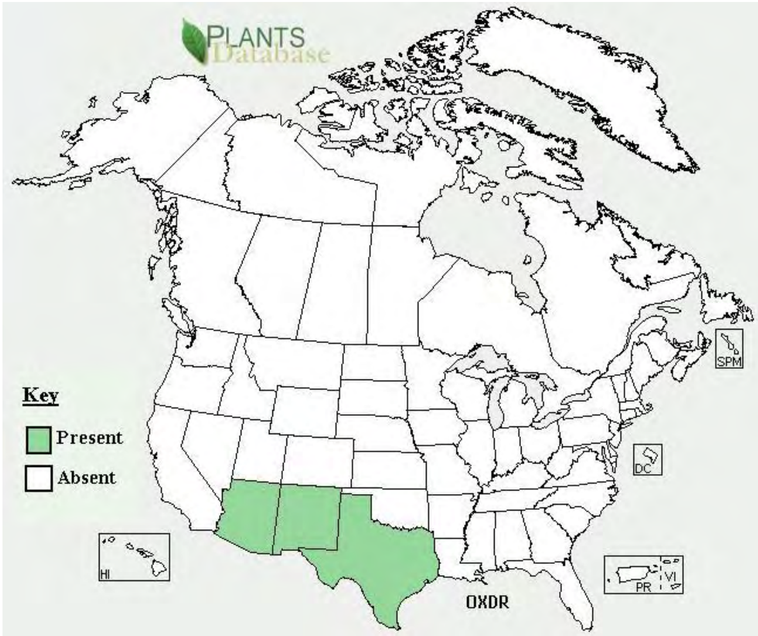
Geographic distribution of *Lesquerella recurvata* in North America

Photograph of *Lesquerella recurvata* specimen



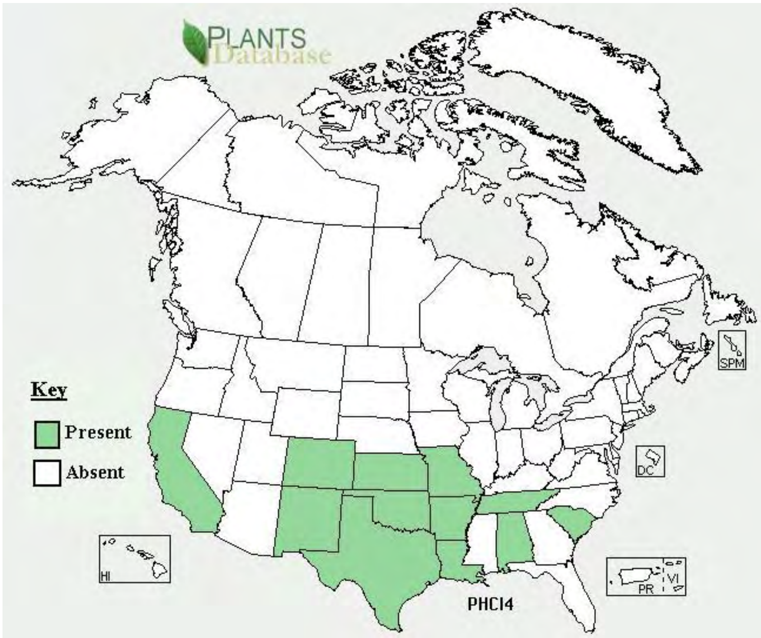
Geographic distribution of *Oxalis dillenii* in North America

Photograph of *Oxalis dillenii* specimen



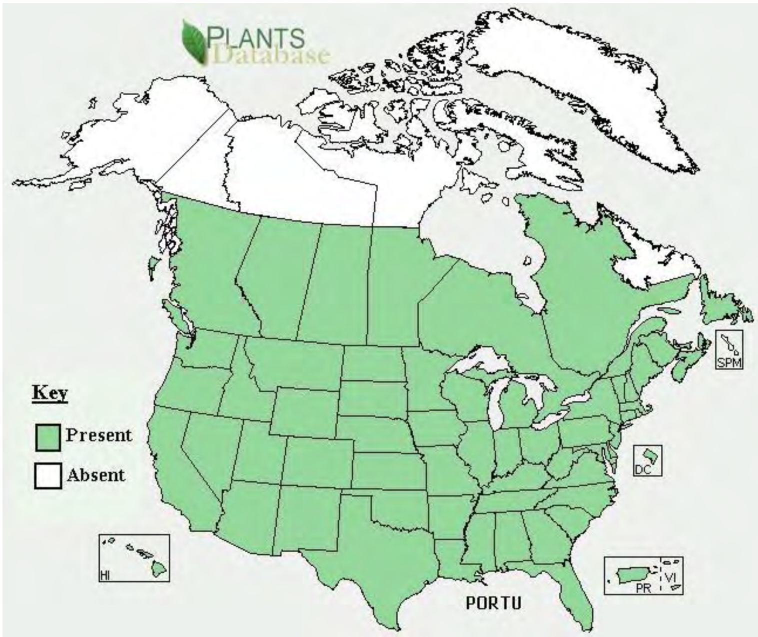
Geographic distribution of *Oxalis drummondii* in North America

Photograph of *Oxalis drummondii*



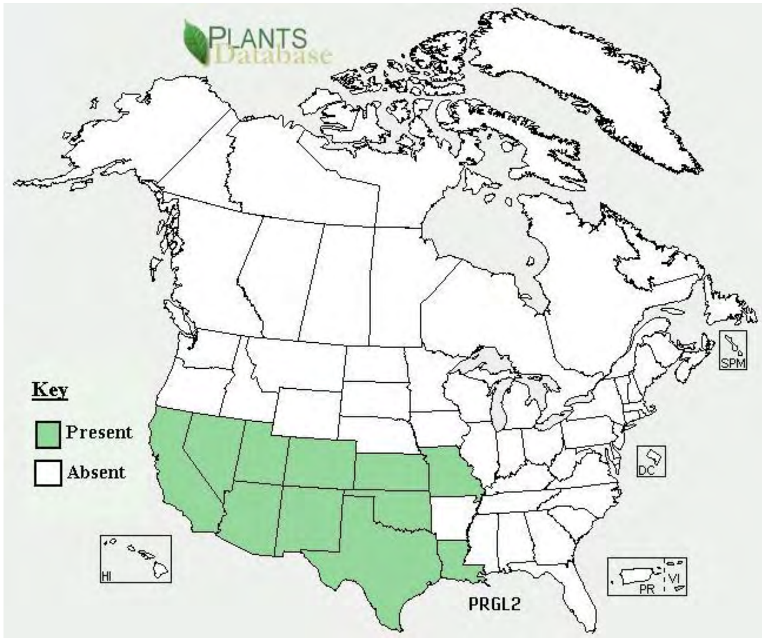
Geographic distribution of *Physalis cinerascens* in North America

Photograph of *Physalis cinerascens* specimen



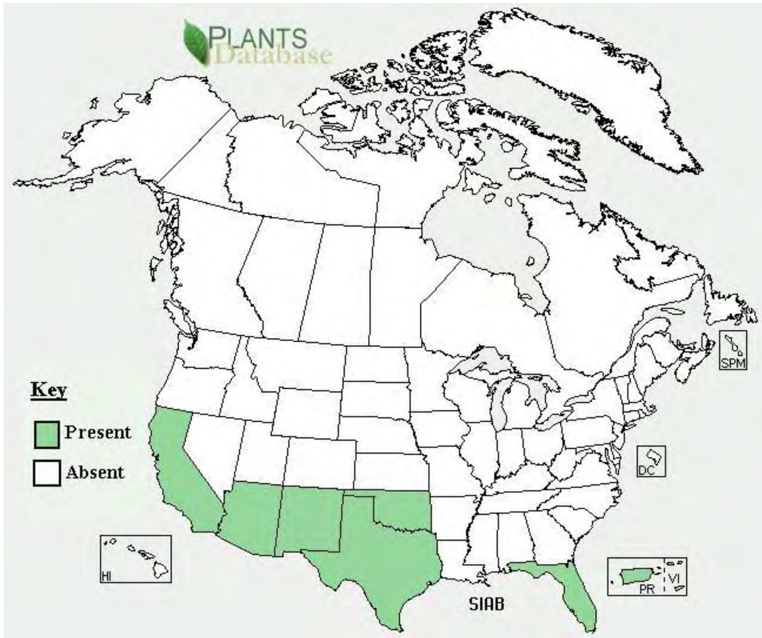
Geographic distribution of *Portulaca* sp. in North America

Photograph of *Portulaca* specimen



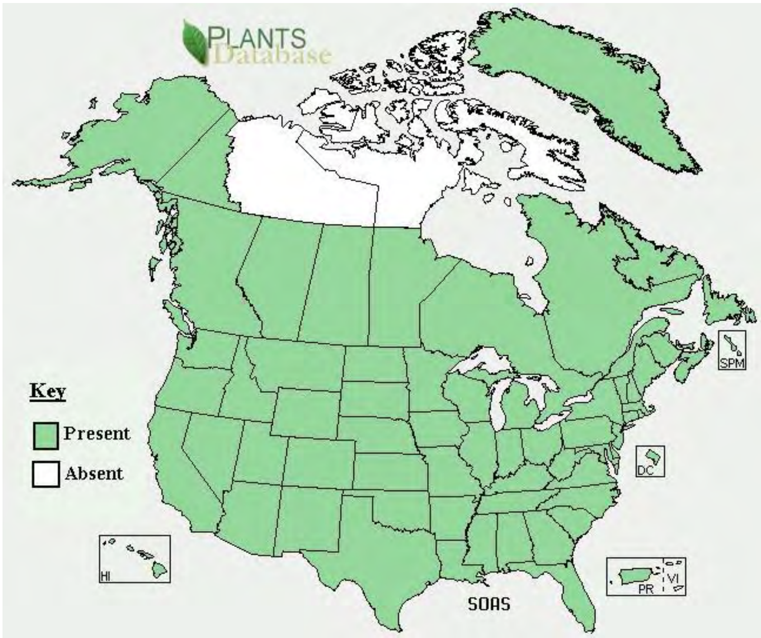
Geographic distribution of *Prosopis glandulosa* in North America

Photograph of *Prosopis glandulosa* specimen



Geographic distribution of *Sida abutifolia* in North America

Photograph of *Sida abutifolia* specimen



Geographic distribution of *Sonchus asper* in North America

Photograph of *Sonchus asper* specimen

Geographic distribution of *Tragia ramosa* in North America

Photograph of *Tragia ramosa* specimen

Geographic distribution of *Vicia ludoviciana* in North America

Photograph of *Vicia ludoviciana* specimen

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