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Spatial Delineation of *Acer grandidentatum* within the Owl and Bear Creek Watersheds, Fort Hood Military Installation, Texas

Faulkner, Melinda S[1]. , McBroom, Matthew W[2]. & Farrish, Kenneth W[3].

Abstract

Disjunct populations of bigtooth maple (*Acer grandidentatum*) exist as Pleistocene relicts in several counties in Texas, with isolated populations found within the Owl Mountain Province of Fort Hood Military Installation. Transect vegetation surveys conducted by the Fort Hood Natural Resources Branch in 1996 and 2011 identified nine distinct areas of *A. grandidentatum* habitat covering 71 hectares within the 9,000 hectare study area. During spring 2014, fifty-four nested vegetation plots were established within known maple habitat to inventory woody and emergent species. These data were used to create a vegetation model in ERDAS by isolating the spectral intensity of *A. grandidentatum* to determine additional maple populations, locating an additional 129 hectares of *A. grandidentatum* habitat. Sixty-one nested plots within the newly defined maple habitat were compared to determine the similarities and differences between modeled and established maple habitat. Independent-samples T-tests were conducted to determine the differences between stand dynamics with regards to *A. grandidentatum* and Ashe juniper (*Juniperus ashei*) in established and modeled vegetation stands at $\alpha = 0.05$. Statistical analyses for both the established and modeled bigtooth maple habitat revealed that the Owl Creek watershed represents a later successional habitat with maples expressed in near equal proportion in the canopy and understory. The Bear Creek watershed is highly segmented with less continuous maple and hardwood habitat;hardwoods are still prominent, but Ashe juniper represents a largerportion of the vegetation community in the canopy and understory, indicating greater disturbance.

Keywords: bigtooth maple, remote sensing, landscape ecology, karst, faunal succession, climate change

1. Introduction

The Lampasas Cut Plain region of Central Texas is a species rich, karst terrain that supports a variety of vegetation habitats from mesic canyons to xeric uplands (Riskind & Diamond, 1986). The Cut Plainis considered to be southern extensions of the Great Plains of North America (Hunt, 1974), and sometimes the northern extension of the Edwards Plateau, but is distinctly different as a physiographic province and ecoregion (Faulkner & Bryant, 2018; Texas Natural Resource Information System, 2016; Figure 1). The landscape and topography are largely controlled by the erosional behavior of the underlying Lower Cretaceous carbonates; with down cutting by the Brazos River and its tributaries dissecting the mostly flat mesa-like drainage divides (Haywardet al.,1990). The topography becomes rolling in areas proximal to streams, and represents a more mature landscape than the Edwards Plateau to the south and west.

The dissected southern portion of the Edwards Plateau and parts of the Lampasas Cut Plain support mesic forest and woodland vegetation; these plant communities owe much of their origin to the Sierra Madre Oriental and its outliers, and to floristic contributions from the eastern deciduous forests (Riskind & Diamond, 1986). Many of the mesa-like drainage divides within the Lampasas Cut Plain are more xeric and open, and strongly influenced by the Great Plains grasslands to the north (Diggs et al., 1999).

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[1] Department of Geology, Stephen F. Austin State University, P.O. Box 13011 SFA Station, Nacogdoches, TX 75962-3011 mgshaw@sfasu.edu. Phone: 936-468-2236, Fax: 936-468-2437

[2] Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, P.O. Box 6109, Nacogdoches, TX 75962-6109

[3] Division of Environmental Science, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, P.O. Box 13073, Nacogdoches, TX 75962-3073

Juniper-oak woodlands are widespread on limestone terraces across uplands in the Lampasas Cut Plain, usually overkarstic features or Quaternary terrace deposits (Huxman et al., 2005; Diamond, 1997). On the more xeric rolling hills to the west, the semi-desert grasslands are biotic contributions from the dry plateaus and massifs of northern Mexico and Trans-Pecos Texas (Riskind & Diamond, 1986).

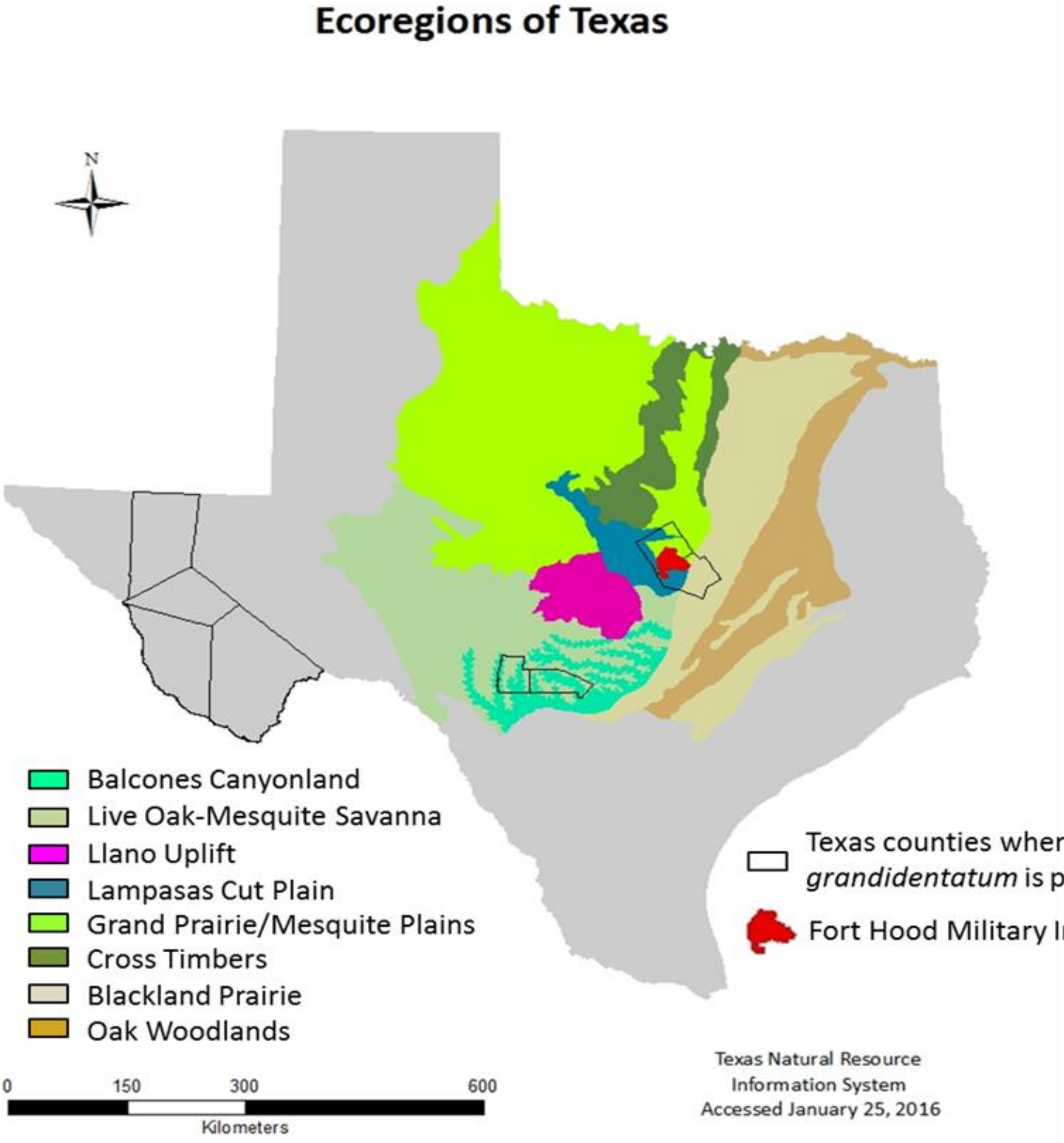

Figure 1. Ecoregions of Texas. The Fort Hood Military Installation is uniquely situated between the Edwards Plateau ecoregion and the Cross Timbers and Prairie ecoregion, providing high quality habitat for wildlife and endangered avian species.

Within these dissected canyons in Central Texas, disjunct populations of bigtooth maple (*Acer grandidentatum*) exist as Pleistocene relicts, isolated from larger populations by several hundred miles (Riskind& Diamond, 1986). *A. grandidentatum* is a small, deciduous hardwood tree indigenous to North America, existing as a continuous population in the intermountain regions of the western United States from southern Idaho through the Wasatch Mountains of Utah (Tollefson, 2006). The geographic range spans almost 18° of latitude, varies greatly within elevation limits, and occurs on both xeric and mesic sites (Adler et al., 1996; Flanagan et al., 1992). Throughout its continuous range, it is most often located on cool, moist sites in canyons, ravines, along mountain streams, and on lower slopes (Oterdoom, 1994). It is relatively tolerant of low soil water potentials, and can grow with oaks on drier, open slopes (Querejeta et al., 2007; Tollefson, 2006; Correll & Johnston, 1970). Commonly referred to as big tooth maple, regionally it can be known by other common names including lost maple, canyon maple, Uvalde maple, Sabinal maple, Plateau bigtooth maple, Wasatch maple, Southwestern bigtooth maple, Western sugar maple or Rocky Mountain sugar maple (Dickinson, 2011). Although there has been some debate of the phylogenetic grouping of big tooth maple, most current research refers to it as *A. grandidentatum* (Gehlbach & Gardner, 1983; Desmarais, 1952).

Smaller, disjunct populations of *A. grandidentatum* can be found at lower latitudes in southwestern Oklahoma, Colorado, New Mexico, Arizona, Texas, and Couhuila, Mexico (Tollefson, 2006). Isolated populations in Texas are located in the Guadalupe and Wichita Mountains of West Texas, and several counties within the Edwards Plateau and Lampasas Cut Plain of Central Texas (Ludeke et al., 2005).

Over the past 10,000 years, temperatures warmed and water resources became focused along incising canyons across the Edwards Plateau and Lampasas Cut Plain, and populations of *A. grandidentatum* responded to the changing climate (Larkin & Bomar, 1983). Today, isolated populations of *A. grandidentatum* continue to exist in sheltered canyons along the Balcones Escarpment, Edwards Plateau, and Lampasas Cut Plain regions. Several of these isolated populations can be found in Lost Maples State Natural Area in Bandera and Real counties (Dickinson, 2011), and within the Owl Mountain Province of the Fort Hood Military Installation in Bell and Coryell counties (Hammer, 2011; Ludeke et al., 2005; Gehlbach & Gardner 1983).

Since 2011, the Fort Hood Natural Resources Management Branch has been responsible for implementing programs to catalogue and monitor natural resources on the installation and has contracted with civilians, state agencies, and environmental consulting firms to help realize their goals (Pekins, 2012; Reddell et al., 2011). The purpose of this study was fourfold: document stand dynamics and associated populations within established *A. grandidentatum* habitat; develop a remote sensing-based model to determine locations where bigtooth maple may exist;ground-truth this model to find potential bigtooth maple habitat; and compare stand dynamics of bigtooth maple habitat found in Owl Creek and Bear Creek watersheds. These data will help the U.S. Army employ best management practices with regards to training activities, water resources, and environmentally sensitive vegetation habitats.

2. Evolution of the Edwards Plateau and Lampasas Cut Plain

The genesis of the Edwards Plateau and Lampasas Cut Plain began in the late Paleozoic with the Ouachita orogenic event, which brought Gondwana in contact with North America and initiated the eventual formation of Pangaea (Culotta et al., 1992). The result of this collision was a curved zone of sub-surface imbricated Paleozoic rocks that extended from the Marathon region of West Texas into Mississippi (Flawn et al.,1961). The Ouachita orogenic belt began to subside in Mesozoic time, coincident with the Zuni transgression that controlled deposition during the Cretaceous Period across the Comanche Shelf (McCann, 2012; Rose, 1972; Figure 2). By the end of the Cretaceous, a thick marine carbonate sequence covered most of the Ouachita System.

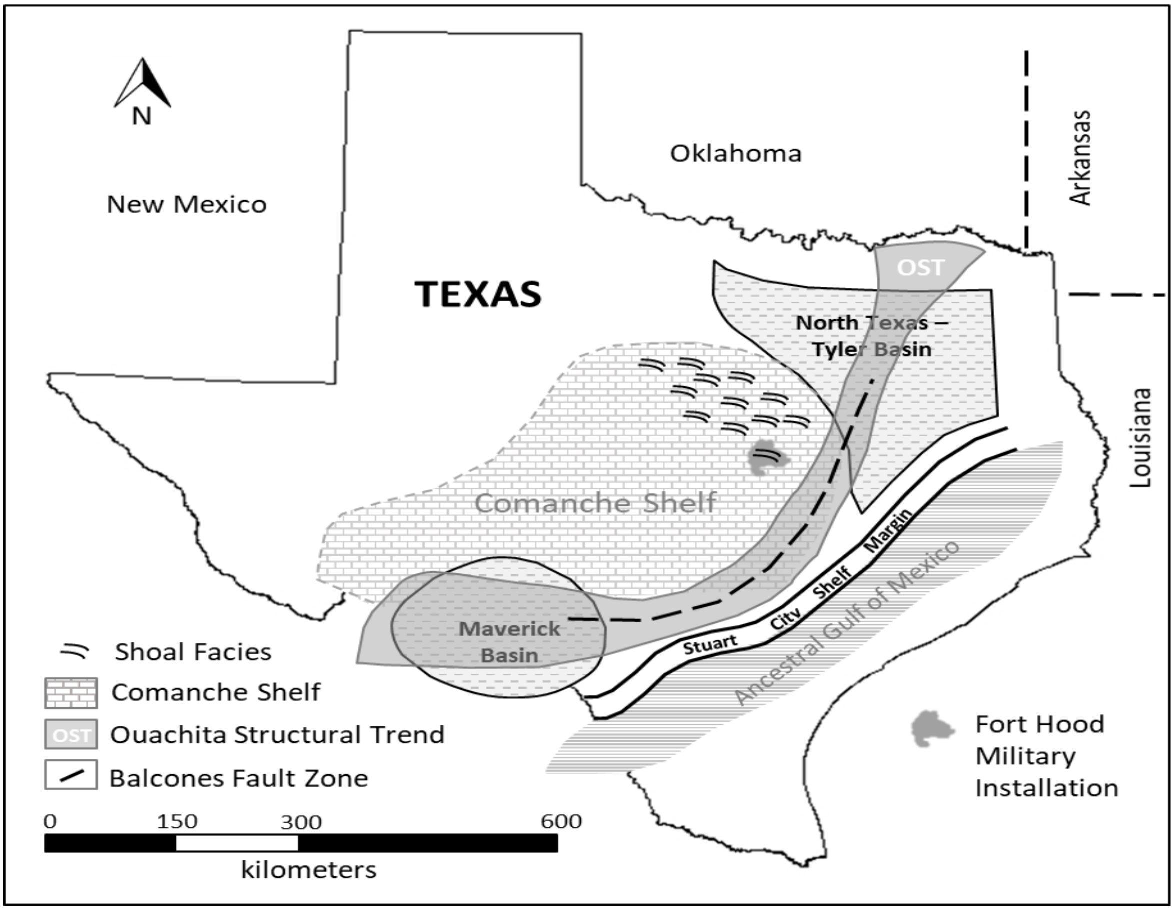

Figure 2. Location map showing the major structural trends influencing strata in the Central Texas region. Shoal facies such as the Owl Mountain Provinces were formed on the Comanche Shelf during the Zuni transgressive sequence (modified from Anaya & Jones, 2009; Walker, 1979; Fisher & Rodda, 1969).

InCentral Texas, the initial Gulf of Mexico basin existed to the southeast (Nelson, 1973). The final shaping of the Gulf of Mexico occurred during the Laramide orogeny, as peninsular Mexico was transported eastward forming the Sierra Madres and constricting circulation in the Gulf (Caran et al., 1982).

By Miocene time, the Balcones Fault Zone had been superimposed on the Ouachita deformation zone (Faulkner et al., 2019; Ferrill & Morris, 2008; Caran et al., 1982; Figure 2),displacing the Mesozoic to lower Paleocene section above the Ouachita System subcrop,and initiating the uplift and subsequent dissection of the Lower Cretaceous strata (Caran et al., 1982).The subsurface Ouachita structures acted as a hinge for downwarping into the ancestral Gulf of Mexico (Ferrill & Morris, 2008; Caran et al., 1982);this downwarping, along with upward flexing of the continental interior west of the Balcones/Ouachita trend, continued throughout the Cenozoic. Uplift in the area altered base level of many of the first and second order streams flowing across the region and they began to erode the softer rocks and sediment of the Upper Cretaceous and lower Paleocene, sending massive sediment influxes east toward the widening Gulf of Mexico (Hayward et al., 1990; Figure 2).

3. Climate Fluctuations and Vegetation Communities

North American ice sheets reached their maximum growth around 20,000 years ago; the climate of Texas was cooler and moisture effectiveness was greater, resulting in the presence of plant species that occur in more mesic sites and cooler environments (Van Devender & Spaulding, 1979). The mesic climate encouraged existing forests; the spruce, juniper, Douglas fir, and pine forests of the West Texas Mountains expanded downward to lower altitudes, where they mixed with grasslands to form parklands and savannahs (Mecke, 1996; Nordtet al., 1994). Pollen records show that from about 22,500 to 12,000 B.C. the forests were dominated by cooler-weather oak, elm, spruce, maple, hazelnut, alder, and birch (Nordtet al., 1994). By 8,000 B.C.E the ice sheets were gone, bringing a warmer and drier climate to the southwestern U.S. and Texas (Bryant & Shaffer, 1977). During the last 10,000 years, the climate in the central and southwestern regions of the United States has fluctuated but gradually warmed to its present day trend toward the semi-arid to arid environment found across the region.

This trend continues today; therefore, some of the current vegetation of Texas may have developed under a previous set of climatic conditions characterized by cooler, more mesic conditions than exist today (Smeinset al., 1997; Riskind& Diamond, 1986).

The vegetation of the Lampasas Cut Plain responded to the change in climate by a shift in vegetation dominance of piñon and juniper to a dominance of scrub oak and Ashe juniper (Fuhlendorf&Smeins, 1996). East of the Balcones Escarpment, the forests lost some of their cool-loving species such as alder, maple, spruce, and hazelnut. Basswood, dogwood, chestnut, and a few other forest species that grow best in cooler, wet habitats did not disappear entirely but were reduced to minor components in the new deciduous forests (Diggs et al., 1999). Over time, as moister climates shifted to the east, relict populations of Pleistocene vegetation contracted to mesic slot canyons in Central and West Texas associated with springs and seeps where consistent moisture was more readily available. Today, the climate of the Lampasas Cut Plain is sub-humid and becomes increasingly arid to the west and cooler to the north (Phillips & Ehleringer, 1995). Courtesy of the Gulf Stream, prevailing winds are generally from the south and the general decrease in moisture content of Gulf air as it flows northwestward across the plain is the controlling factor responsible for this difference in moisture regime (Bradley & Malstaff, 2004).

4. **Anthropogenic Effects on Central Texas Vegetation Communities**

Across the Lampasas Cut Plain, archaeological and historical records show this area has supported different populations over the past twelve thousand years as indicated by artifacts found in rock shelters and river terrace campsites (Freeman et al., 2001; Pugsley, 1992; Doughty,1983). Humans would have been attracted to the springs and rivers that supported their hunter-gatherer lifestyles and provided water sources for herds of grazing animals which they followed (Hester, 1986). As groups moved in and out of the area, their lifestyles changed too; hunter-gatherers gave way to more settled communities who moved from site to site within an area, following seasonal food sources. Through selective harvesting and use of various plants and hunting of animals, these early inhabitants influenced local abundances of many species (Doughty, 1983). Many of these early inhabitants were also nomadic and served as effective dispersal agents for reproductive propagules of some plant species (Smeinset al., 1997).

Through time, these inhabitants exerted more influence on their environment by altering the composition and structure of vegetative communities (Smeins, 1984). By at least 5,000 years ago, they were using fire to prepare food (Hester, 1986), and possibly as a vegetation and wildlife management tool (Smeins, 1980).Lightning fires, as well as accidental and intentional fires, likely caused significant long-term impacts on the composition and structure of native vegetation (Fuhlendorf&Smeins, 1996).

The impact of fire on the vegetation would have been mitigated to some extent by the type of landscape in which it occurred;heterogeneous landscapes of varying topography, rocky outcrops and patchy surface fuels are affected very differently from areas of level terrain with a continuous cover of fine fuels (Wells, 1970).

The first land grant in Texas was awarded to Moses Austin in 1821, and immigration into Central Texas soon followed. The Brazos River and the Camino Real became the main conduits for settlement of the interior part of Texas (Pugsley,1992). Land clearing to provide open areas for grazing, improving the growth and quality of grasses, and acreage for planting was commonplace.The introduction of windmills in the 1880s opened fertile alluvial areas in more remote regions (Yelderman et al.,1987). Rapid overstocking of the rangelands ensued and with the advent of more settlers, the availability of barbed wire, and windmills to provide water, the animals were confined, which led to destructive grazing of many rangelands (Smeinset al., 1997). As the more palatable grasses and forbs decreased or even disappeared, many ranchers switched to cattle, sheep, and goat operations, often grazing all three to better utilize the now dominant shrubby vegetation. These factors, combined with the exponential increase of white-tailed deer (*Odocoileusvirginianus*)populations, further deteriorated the landscape.

By 1930, continuous grazing combined with range fencing and the control of wildfire greatly reduced the growth of more desirable grasses, allowing many trees and shrubs to invade the uplands. As encroaching species spread and utilized water and nutrient resources, competition significantly reduced the production and diversity of associated plant species (Huxmanet al., 2005). Many of these areas deteriorated into the shortgrass, rock, shrub, cacti, and woody vegetationthat currently dominate the landscape (Smeinset al., 1997).Although the uplands of Central Texas were probably never a wide expanse of open grassland, today a grassland-woodland mosaic currently exists on varying soils across extensive portions of the area (Smeinset al., 1997; Fowler & Simmons, 2008).

5. **Vegetation Communities on the Fort Hood Military Installation**

The Fort Hood Military Installation is located in the southeastern section of the Lampasas Cut Plain and currently encompasses approximately 880 km^2 in Bell and Coryell counties (Hammer, 2011). Fort Hood owes its ecological diversity partly to its location at the intersection of two ecoregions: the Edwards Plateau and Cross Timbers and Prairie ecoregions (Figure 1). This location, coupled with the installation's topographic, geological, and edaphic diversity, provides an isolated island of high quality habitat for many threatened and endangered species. Land use surrounding the installation has greatly modified and degraded many such habitats through urbanization, infrastructure support for the burgeoning population, and agriculture.

Training lands on the installation are divided into three major areas: West Fort Hood is primarily used for heavy mechanical (tracked and wheeled) maneuver training;the Live Fire Impact Range is located in the center of the installation and is used for pyrotechnic training, and East Fort Hood is used primarily for dismounted and wheeled exercises, and some small-scale tracked vehicle training (Hammer, 2011; Hayden et al., 2001; Figure 3). Vegetation and soil disturbance resulting from military activities maintains much of the vegetation in early succession, particularly evident in the training areas (Hammer, 2011; Teague & Reemts, 2007). More remote areas of the eastern side support later successional vegetation,with disturbance in these areas associated with the cutting of vegetation, construction of individual fighting positions ("foxholes"), road maintenance, and other activities associated with dismounted training (Teague & Reemts, 2007). Some of the acreage in these training areas are multi-use facilities with areas set aside as endangered species habitat and recreational areas for military families. The Army also allows other non-military uses of Fort Hood lands such as fishing, hunting, and grazing. These uses, together with military training, affect the soil, water, vegetation and animals that occur on the installation (Hayden et al., 2001).

Since the establishment of Fort Hood in the 1940s, the area has undergone extensive land use changes associated with military training; vegetation communities are heterogeneous and patchy, often intergrading abruptly amongst different types. Woody vegetation is characterized by contiguous, closed-canopy, Ashe juniper-oak (*J. ashei-Quercus*spp.) forests on mesa slopes, tops, and canyons,with some postoak/blackjack oak (*Q. stellata/Quercus marilandica*) forests (Teague & Reemts, 2007).Shin oak (*Q. sinuate* var.*breviloba*)shrubland/grassland matrices found where wildfire has occurred. Open grasslands occur on some valleys and rolling uplands, and in small patches near and amongst mesa forest/shrubland stands (Hammer, 2011). Riparian corridors are characterized by juniper-oak forests and forest belts of southern pecan (*Caryaillinoinensis*), walnut (*Juglans*spp.), American sycamore (*Platanusoccidentalis*), eastern cottonwood (*Populusdeltoides*), bur oak (*Q. macrocarpa*), black willow (*Salix nigra*), and red elm (*Ulmusrubra*) trees (Teague & Reemts, 2007; Figure 4).

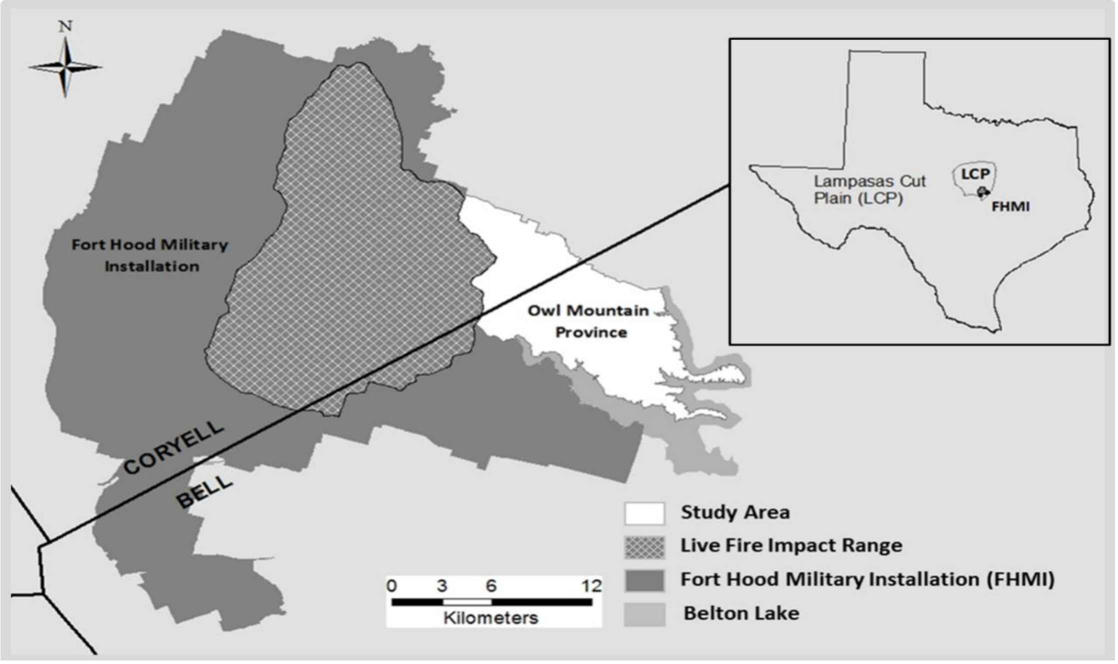

Figure 3. The Owl Mountain Province is the northeastern peninsula of the Fort Hood Military Installation. The area is used for troop maneuvers and training as well as endangered species habitat and grazing acreage.

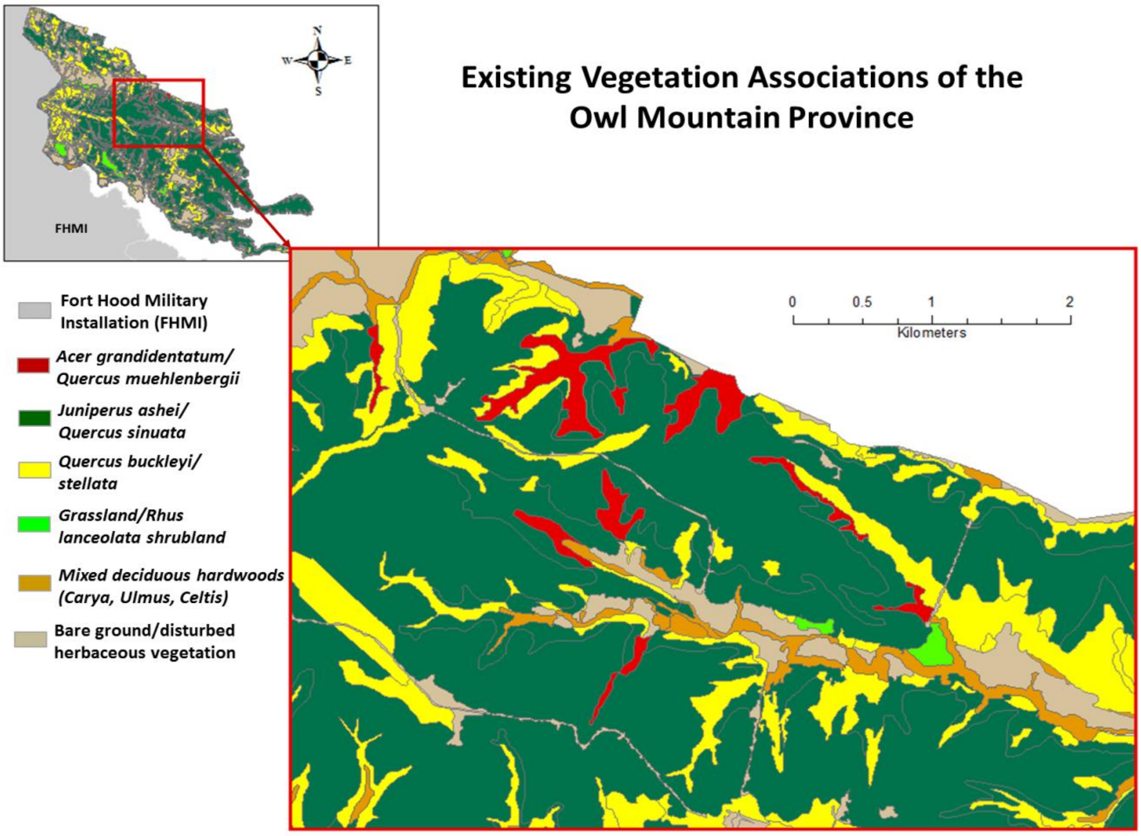

Figure 4. Vegetation associations found in the Owl Mountain Province (modified from Hammer, 2011 and Teague & Reemts, 2007).

Training on Fort Hood is the primary cause of wildfires on the installation, particularly in the Live Fire Impact Range. Tracers, incendiary devices, smoke generators, and pyrotechnic devices provide year round sources of ignition (Hayden et al., 2001). Under certain conditions, training related wildfires occur almost daily in the Live Fire area, which serves to maintain large expanses of grassland and fire-adapted vegetation in this area. In February 1996, three grass fires were ignited by military training activities and spread into the adjacent oak-juniper woodlands as crown fires. The fires burned for over two weeks and consumed more than 4,000 hectares of woodland, eventually burning 2,728 hectares of endangered species habitat (Hammer, 2011; Reemts & Hansen, 2008; Hayden et al., 2001). Areas historically dominated by grassland in the training areas of East and West Fort Hood have fewer, less intense fires because of the effects of vehicle traffic and grazing on reducing fuels (Hammer, 2011). These areas either remain in early successional vegetation (annual forbs and grasses) due to frequent disturbance or are invaded by Ashe juniper in areas where disturbance is less frequent or intense (Teague & Reemts, 2007).

6. Study Area

The Owl Mountain Province is located in the northeastern section of the Fort Hood Military Installation (Figure 3); the province is a multi-use areautilized by the U.S. Army for troop maneuvers, with the southern and western sections extensively modified by road construction and military training infrastructure. The terrain is rugged and dominated by xeric, plateaued drainage divides hosting thick, scattered clusters of Ashe juniper, Texas ash (*Fraxinustexensis*), and *Q. buckleyi* (Hammer, 2011; Teague &Reemts, 2007). Where the landscape has been partially denuded, cacti and shrubs such as prairie sumac(*Rhuslanceolate*)and false willow(*Baccharisneglecta*) grow in small sinks and fractures where meteoric water resources are focused. The northern and eastern sections are more remote with acreage set aside as grazing land and wildlife habitat (Pekins, 2012; Hammer, 2011; Hayden et al., 2001). This area is also home to several protected avian species such as Golden-cheeked Warbler (*Dendroicachrysoparia*)and Black-capped Vireo(*Vireo atricapilla*); and much of the eastern section of the province is left mostly undisturbed by military activities as endangered species habitat (Picinich, 2011). The plateaus are bordered by steep scarps and incised canyons along the edges of the plateaus hosting mesic woodland species such as pecan(*C.illoinensis*), Texas cedar elm (*Ulmuscrassifolia*Nutt.),Chinkapin oak(*Quercus muehlenbergii*), sugarberry(*Celtislaevigata*),Edwards Plateau Sedge (*Carexedwardsiana*), and bigtooth maple (*A. grandidentatum*) (Hammer, 2011; Teague & Reemts, 2007; Figure 4).

The soils of the study area were developed over Lower Cretaceous carbonate rocks from the Fredericksburg Group, namely the Walnut, Comanche Peak, and Edwards limestones and marls (Barnes, 1970). The lower valleys along established drainage are covered by deeper, alluvial soils from the Topsey and Denton soil series;these soils range from fine-silty to fine-loamy carbonatic, thermic, UdicCalciustolls and were derived over the Walnut and lower members of the Comanche Peak clays and marls (NRCS, 2012; Picinich, 2011). The incised canyons and steeper scarps contain rocky, alluvial soils from the Real-Rock outcrop complex formed over the upper members of the Comanche Peak, a loamy-skeletal carbonatic, thermic, shallow, TypicCalciustoll. The upland plateaus are mantled by shallow, residual soils (<30cm) from the Eckrant Series, a clayey-skeletal smectitic, thermic, Lithic Haplustoll formed over the more resistant Edwards limestone (NRCS, 2012; Fowler & Simmons, 2008). The soils are dark colored, calcareous, and moderately alkaline with textures ranging from loamy to clayey, depending on the substrate and profile development. In established maple habitat, Real-Rock soils are characterized as gravelly, clay loam, forming on slopes ranging up to 40 degrees (NRCS, 2012). The typical soil profile is less than 45cm deep with a low available water capacity (<3.5cm) (NRCS, 2012; Picinich, 2011).

Geologic and hydrologic sampling has been ongoing in the study area since September 2011. Water chemistry from surface springs atop the plateau document a meteoric origin for much of the flowing water at the surface. These springs are flowing within the Edwards, and do not appear to be connected with soil moisture associated within established maple habitat (Faulkner et al., 2018).

7. **Methodology**

The Nature Conservancy and the Fort Hood Natural Resources Management Branch conducted vegetation surveys within the installation in 1996 and 2011, respectively (Hammer, 2011; Teague & Reemts, 2007; The Nature Conservancy, 2003). These surveys were part of a larger monitoring and management action for threatened and endangered avian species habitat required as the result of biological opinions issued to the U.S. Army by the U.S. Fish and Wildlife Service (Hayden et al., 2001). These surveys, coupled with aerial photograph interpretation, identified nine distinct areas of *A. grandidentatum* habitat within the Owl Mountain Province (Figure 4),covering approximately 71 hectares(Hammer, 2011; Teague & Reemts, 2007; Table 1).

In order to determine the spatial distribution of *A. grandidentatum* within thedesignated habitat, fifty-four 78.5m^2 nested circular plots were established to inventory woody species and emergent vegetation. All woody species within a 5m radius plot greater than 6m in height were measured for diameter at breast height (dbh) and identified; all emergent woody vegetation were identified and counted within a 3m radius plot. Field data from the plots were used to determine the number of maple trees per hectare (TPH), basal area per hectare (BAPH), and the stems per hectare (SPH) for each designated maple habitat. Environmental parameters such as elevation, aspect, canopy characteristics, geologic materials, snags, and other general site descriptions were recorded.

Once the initial data had been processed, new potential maple habitat was delineated using the remote sensing application ERDAS to isolate the spectral intensity of *A. grandidentatum*. A Landsat 8 short-wave infrared vegetation map (Figure 5) was obtained from the U.S. Geological Survey and the spectralsignatures for bigtooth maple were isolated (Figure 6). Locations where the spectral intensity remained were used as a remote sensing model to locate existing but as yet undocumented *A. grandidentatum* habitat in the Owl and Bear Creek watersheds. Vegetation mapping in modeled habitat documented an additional 129 hectares of *A. grandidentatum* habitat located in ten distinct stands. Sixty-one additional 78.5m^2 nested plots were established in these new stands to inventory population dynamics of woody and emergent vegetation. Independent-samples T-tests were conducted to determine the differences between stand dynamics with regards to *A. grandidentatum,J. ashei,* and other hardwoods in established and modeled vegetation stands within the Owl Creek and Bear Creek watersheds at $\alpha = 0.05$.

Table1. Original bigtooth maple habitat as delineated by Fort Hood vegetation surveys (Hammer, 2011; Teague & Reemts, 2007)

Fort Hood Field ID	Vegetation Association	Source	Hectares	# of Plots	Plot Area (m^2)	Total Plot Area (m^2)
0	*Acergrandidentatum* *Quercus muehlenbergii* *Carexedwardsiana*	1996 transect 3	3.41	5	78.5	392.50
1	*Acer grandidentatum* *Quercus muehlenbergii* *Carexedwardsiana*	map validation 50; 1996 transect 45	7.39	5	78.5	392.50
46	*Acer grandidentatum* *Quercus muehlenbergii* *Carexedwardsiana*	map validation 262; 1996 transect 104	14.21	10	78.5	785.00
215	*Acer grandidentatum* *Quercus muehlenbergii* *Carexedwardsiana*	1996 transect 96	4.04	4	78.5	314.00
369	*Acer grandidentatum* *Quercus muehlenbergii* *Carexedwardsiana*	map 370; observation point ER74	5.79	4	78.5	314.00
389	*Acer grandidentatum* *Quercus muehlenbergii* *Carexedwardsiana*	1996 transect 38, 39, & 40	1.39	2	78.5	157.00
476	*Acer grandidentatum* *Quercus muehlenbergii* *Carexedwardsiana*	map validation 178; 1996 transect 38, 39, & 40	25.77	16	78.5	1,256.00
483	*Acer grandidentatum* *Quercus muehlenbergii* *Carexedwardsiana*	1996 transect 115	3.54	4	78.5	314.00
560	*Acer grandidentatum* *Quercus muehlenbergii* *Carexedwardsiana*	1996 transect 109	5.51	4	78.5	314.00
	Totals		**71.03**	**54**		**4,239.00**

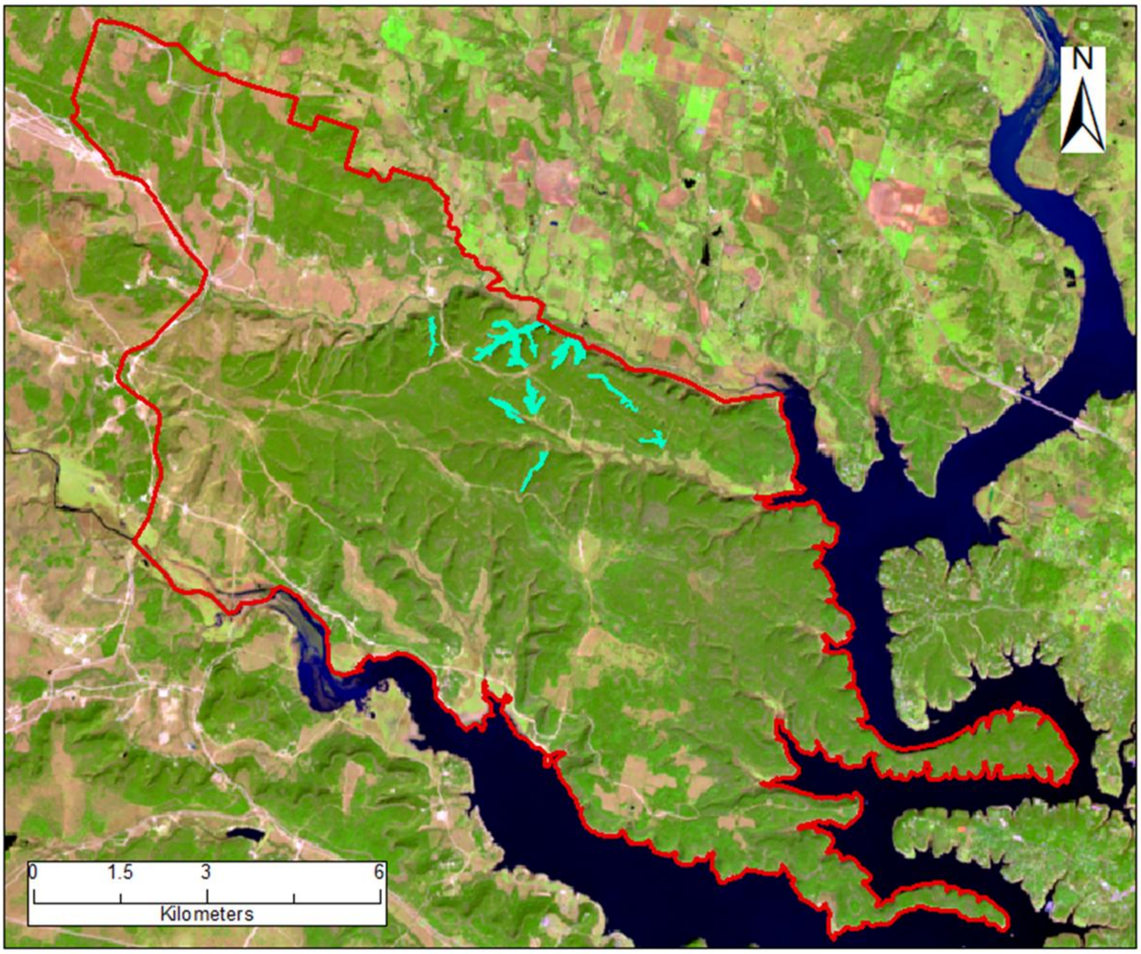

Figure 5. Landsat 8 short-wave infrared image from U.S. Geological Survey database accessed January 22, 2016;image captured June 7, 2015. Established maple habitat is highlighted.

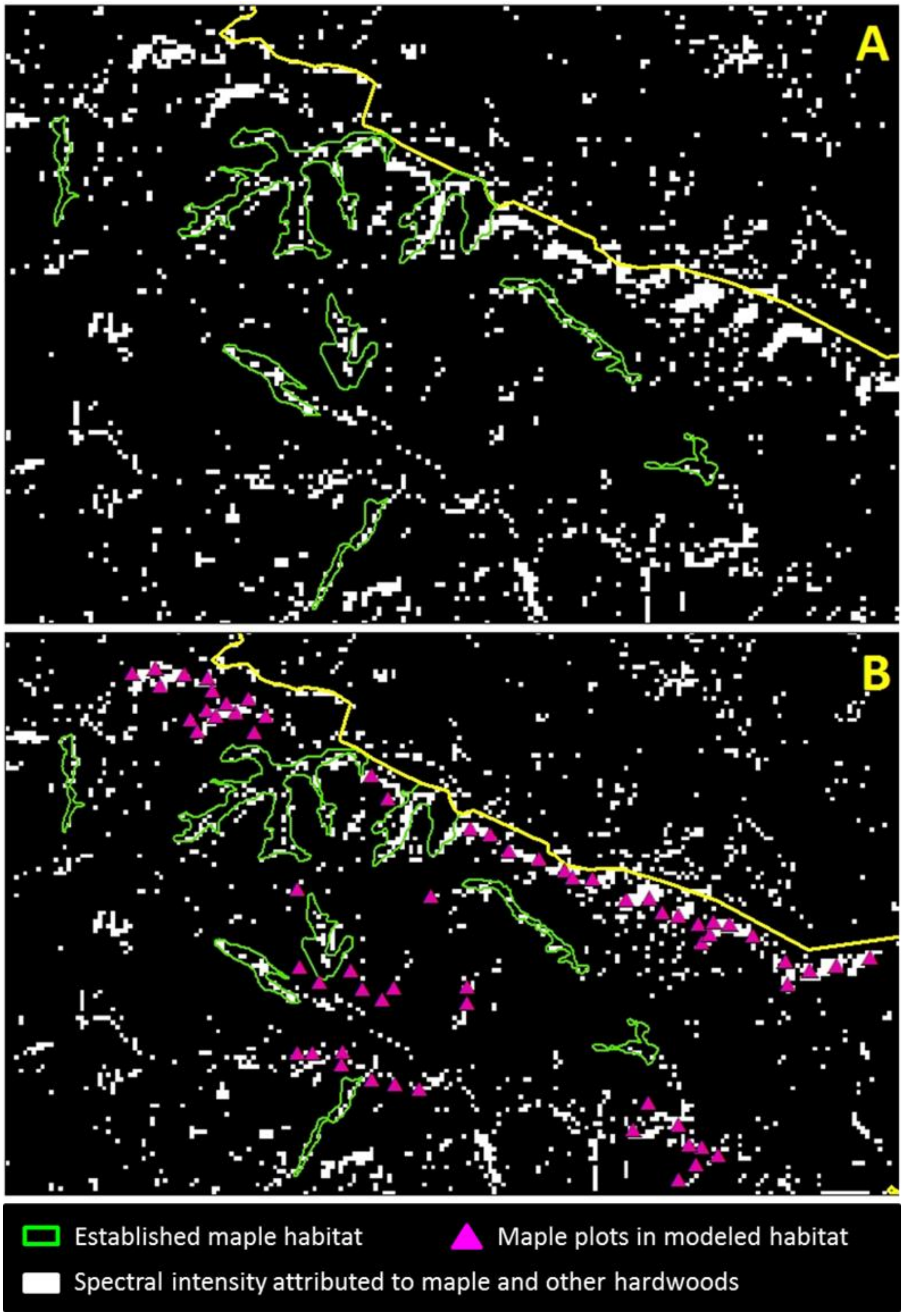

Figure 6. ERDAS model used to delineate additional maple habitat. The shapefile for established maple habitat was used to isolate the spectral intensity attributed to bigtooth maple and other hardwoods (A). Mapping yielded 61 additional vegetation plots within newly defined maple habitat as well as three isolated occurrences (B).

8. Results and Discussion

Most of the established *A. grandidentatum* habitat exists within incised canyons along the scarps of the Owl and Bear Creek watersheds (Figures 4 and 7).Site conditions in these existing habitats can be described as mesic, narrow, slot canyons and/or semi-sheltered woodlands where *A. grandidentatum* can exist as co-dominant trees with a variety of oaks and elms or as part of the lower canopy. In some of the delineated maple habitat, *A. grandidentatum*is found with *J. ashei*;in these areas, maples are not dominant and only expressed in the understory. In areas where canopy openings have occurred as a result of snags and mortality, larger oaks (*Quercus spp.)* dominate the canopy with *A. grandidentatum* regenerating in the understory.

Many of these sites also function as wildlife habitat, particularly for foraging species such as feral pigs (*Susscrofa*), and soil disturbance is abundant. Unless the canopy opening has been recent, most of the canopies are closed with sparse cover by grasses and forbs.

These established sites exist today with a variety of aspects: north, northeast, south, and southeast (Figures4 and 7) and are associated with stream drainage, although ephemeral water flows only after major precipitation events. Most meteoric water is communicated directly into and discharges from the Edwards; no existing springs or seeps have been documented in established or modeled maple habitat (Faulkner et al., 2018). Slopes within these canyonsrange from less than 5° near stream channels to over 40° closer to the scarps (NRCS, 2012).The terrain is rocky with shallow soils (<45 cm); rock falls are common, as are snags and tree falls related to erosion of the over-steepened scarps.The soils are well drained and found along rocky slopes associated the Comanche Peak limestone and marl.

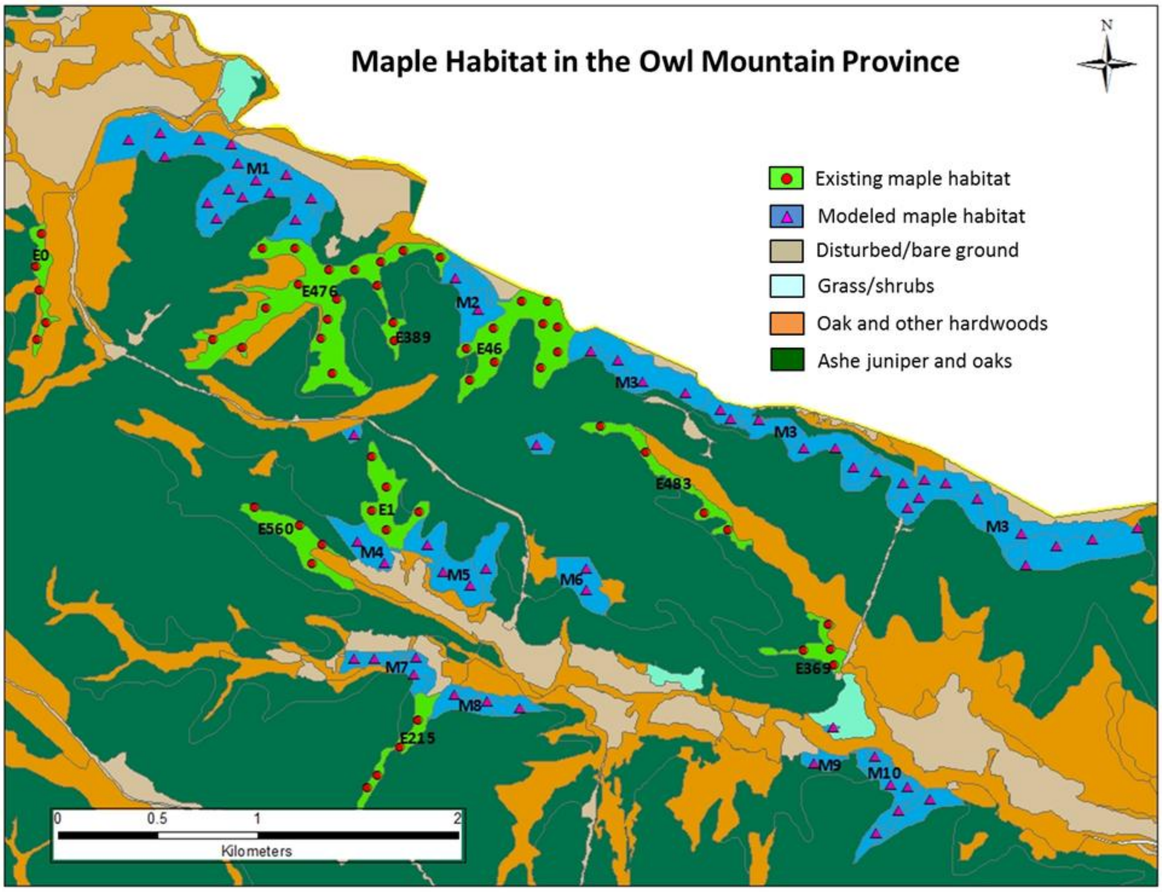

Figure 7. Designated stands and plot locations in established and modeled maple habitat.

Results from vegetation sampling in established *A. grandidentatum* habitat can be found in Table 2. There was a significant difference in the stand dynamics with respect to maple and hardwood trees per hectare between the Owl Creek and Bear Creek watersheds; maples and hardwoods represent 80% of the trees per hectare in the Owl Creek watershed and only 61% of the TPH in the Bear Creek watershed. The Bear Creek watershed also contains more Ashe juniper (39%; M=212.31 TPH) than Owl Creek (20%; M=131.25 TPH). The Owl Creek habitat represents a more mature stand, with oaks and maples well represented in the canopy (80%) and understory (87%). The Bear Creek watershed is fragmented by roads and heavily traveled by military and civilian vehicles, and grasslands are grazed by cattle and other wildlife. In the Bear Creek plots, Ashe juniper represents over 34% of the basal area per hectare (M=4.07 m^2 BAPH) compared to 15% in the Owl Creek watershed (M=1.88 m^2 BAPH). Disturbances can increase competition between established vegetation communities with pioneer species such as *J. ashei* colonizing on recently opened sites. In the understory, maples and other hardwoods produce more emergent vegetation, but *J. ashei* may be more successful at establishing on marginal sites and would have an advantage when competing for resources and growing space on disturbed sites. Ashe juniper stems per hectare in the Owl Creek sites (M=782.50 SPH) represented 12% of the understory and 25% of the understory in the Bear Creek sites (M=1482.31).

Statistical analyses of the established plots between watersheds revealed a significant difference between Ashe juniper populations regarding trees per hectare ($p<0.0330$), basal area per hectare ($p<0.0129$), and stems per hectare ($p<0.0264$). Other hardwoods trees per hectare also reported a significant difference ($p<0.0032$). All other parameters were not significantly different, ($p>0.05$).

Table 2. Comparison of established vegetation plots within the Owl and Bear Creek watershed. Independent-samples T-tests were conducted at $\alpha=0.05$.

Watershed Comparison between established plots	**Mean**		**df**	***P***
	Owl Creek (n=33)	**Bear Creek (n=21)**		
Bigtooth maple				
Trees per hectare	274.08	181.98	39	0.0613
Basal area per hectare (m^2)	4.37	3.18	32	0.1495
Stems per hectare	2808.42	2189.77	40	0.0513
Ashe juniper				
Trees per hectare	131.25	212.31	36	0.0330
Basal area per hectare (m^2)	1.88	4.07	27	0.0129
Stems per hectare	782.50	1482.31	33	0.0264
Other hardwoods				
Trees per hectare	247.06	151.65	41	0.0032
Basal area per hectare (m^2)	5.99	4.59	35	0.1438
Stems per hectare	2594.03	2240.30	29	0.4279

Recent vegetation mapping in modeled maple habitat expanded the range of *A. grandidentatum* along open scarps with a north, northeast and southwest aspect (Figure 7). Much of the newly delineated *A. grandidentatum* occurrences are along the northern border of the installation in the Owl Creek watershed (Figure 8). This scarp trends northwest/southeast and connects modeled *A. grandidentatum* habitat with previously established maple vegetation (Figure 7). In the newly delineated sites, *A. grandidentatum* exists as a dominant species in the canopy and understory (Table 3);*J. ashei* is present, but not dominant along the open scarps. Here, *A. grandidentatum* habitats are bordered by *J. ashei* and various hardwoods on the lowlands along the roads at the edges of open grasslands, as well as along the top of the plateaus. The Owl Creek watershed contains more area of newly delineated maple habitat (87 hectares); only 42 hectares were identified in the Bear Creek watershed. New Bear Creek habitats are primarily associated with previously existing maple habitat, but are less extensive due to the fragmented nature of the Bear Creek watershed (Figure 7).

Newly delineated maple plots were compared to determine if there was a significant difference in maple habitat identified in the two watersheds (Table 3). Maple trees represented 64% of the trees per hectare in the Owl Creek watershed (M=460.56 TPH) and 60% of the basal area per hectare (5.78 m^2 BAPH); basal area per hectare of other hardwoods was not as prominent in modeled habitat, representing less than 11% in the Owl Creek watershed (M=0.99 m^2 BAPH). The Owl Creek sites may represent a later successional habitat with maples out-competing oaks in these more open sites just as they do in their continuous populations; maples are shade tolerant and can adapt to more xeric environments and lower soil water potentials, particularly during periodic droughts. Within the Bear Creek watershed, maples represented 54% of the trees per hectare (M=347.42 TPH) and basal area per hectare (5.76 m^2 BAPH); other hardwoods represented 17% of the basal area per hectare (M=1.84 m^2 BAPH). The Bear Creek sites experienced greater disturbance and represent habitat where competition between Ashe juniper (28%, M=3.03 m^2 BAPH) and hardwoods is still present; reflected in the basal area per hectare of Ashe juniper.

Figure 8. Maples are present in the understory (A) and canopy (B) of the Owl Creek watershed. Much of this area is set aside as wildlife habitat and does not experience heavy traffic or landscape modifications for military training exercises.

Table3. Comparison of modeled vegetation plots within the Owl and Bear Creek watershed. Independent-samples T-tests were conducted at α=0.05.

Watershed Comparison between modeled plots	Mean		df	*P*
	Owl Creek (n=39)	Bear Creek (n=22)		
Bigtooth maple				
Trees per hectare	460.56	347.42	53	0.0001
Basal area per hectare (m^2)	5.78	5.76	47	0.9583
Stems per hectare	3473.83	2765.54	50	0.3764
Ashe juniper				
Trees per hectare	195.98	191.08	57	0.8407
Basal area per hectare (m^2)	2.81	3.03	52	0.6075
Stems per hectare	979.57	1816.90	42	0.0003
Other hardwoods				
Trees per hectare	58.79	104.23	49	0.1421
Basal area per hectare (m^2)	0.99	1.84	39	0.1076
Stems per hectare	943.29	1447.09	55	0.0004

Understory dynamics for other hardwoods are not expressed in the canopy, supporting maple's advantage when competing for resources on marginal sites. In the Bear Creek watershed, maple stems per hectare represent 45% of the understory (M=2765.54 SPH) and other hardwoods represent 24% (M=1447.09 SPH). Ashe juniper represents 30% of the stems per hectare (M=1816.90 SPH), reflecting the competition between species on these more fragmented and disturbed sites (Figure 9).

Statistical analyses of the modeled plots between watersheds revealed a significant difference between maple trees per hectare (p<0.0001), Ashe juniper stems per hectare (p<0.0003), and other hardwoods stems per hectare (p<0.0004). All other parameters were not significantly different, (p>0.05).

Figure 9. Disturbance and fragmentation of maple habitat in the Bear Creek watershed provides encroachment opportunities for pioneer species such as Ashe juniper. Maples are prominent in the understory (A, B, and C) but are not well represented in the canopy.

Bigtooth maple provides browse for wildlife and livestock, but is generally consumed in small to moderate amounts. Its forage value is "fair" as its tall growth form limits forage availability (Tollefson, 2006). Grazing acreage within the Owl Mountain Province supports cattle (Hayden et al., 2001), but these animals tend to remain within the Bear Creek watershed and on the plateaus where grasses are more abundant.Most cattle do not forage along the more isolated scarps of the Owl Creek watershed away from their supplemental feed sources provided by ranchers and as such, herbivory by cattle may affect maple populations within the Bear Creek watershed disproportionally with respect to the Owl Creek watershed.

9. *Acer grandidentatum* in the Owl Mountain Province

Long-term climatic changes in the region have affected the moisture availability for these populations. Even though this area has experienced drought over the past few years, *A. grandidentatum* populations have been able to receive moisture from periodic precipitation and deeper seated fluids due to porosity differences in underlying lithologies (Faulkner& Bryant, 2018). In karst regions, matrix porosity associated with lithofacies variation and solutional porosity associated with regional deformational events transmit deeper seated fluids to mesic sites to augment soil moisture.

While established *A. grandidentatum* habitat was confined to narrow canyons, newly delineated habitat follows regional deformation trends along open scarps (Faulkner et al.,2019). Soils in established and modeled habitats are rocky and well drained, rock outcrops within these sites are common, and meteoric inputs are generally transmitted directly into the subsurface through karst conduits such as sinkholes, joints, and surface caves (Faulkner et al.,2013; Figures 8 & 9).

The underlying geologic material derived from the Comanche Peak is interbedded with the overlying Edwards limestone along these scarps and can provide confining layers that force ascending fluids to discharge along these scarps, providing moisture to support mesic vegetation communities (Figure 10). Water relations on karst sites are quite complex;highly fractured rockswith solutional to vuggy to cavernous permeability can enjoy wide fluctuations in water availabilityand woody plant growth in these regions must adapt to this highly variable water regime. Within the Owl and Bear Creek watersheds, the structural development of lineament trends controlling fluid transmission are expressed as cave developmentin the subsurface, joints in outcrop, stream segment orientation, and lithologic porosity differences that determine the general transmission of ascending fluids in the study area to augment soil moisture (Faulkner et al., 2018). These trends are one of the primary controls on areas where maples exist, as well as anthropogenic and natural disturbance (Figure 10).

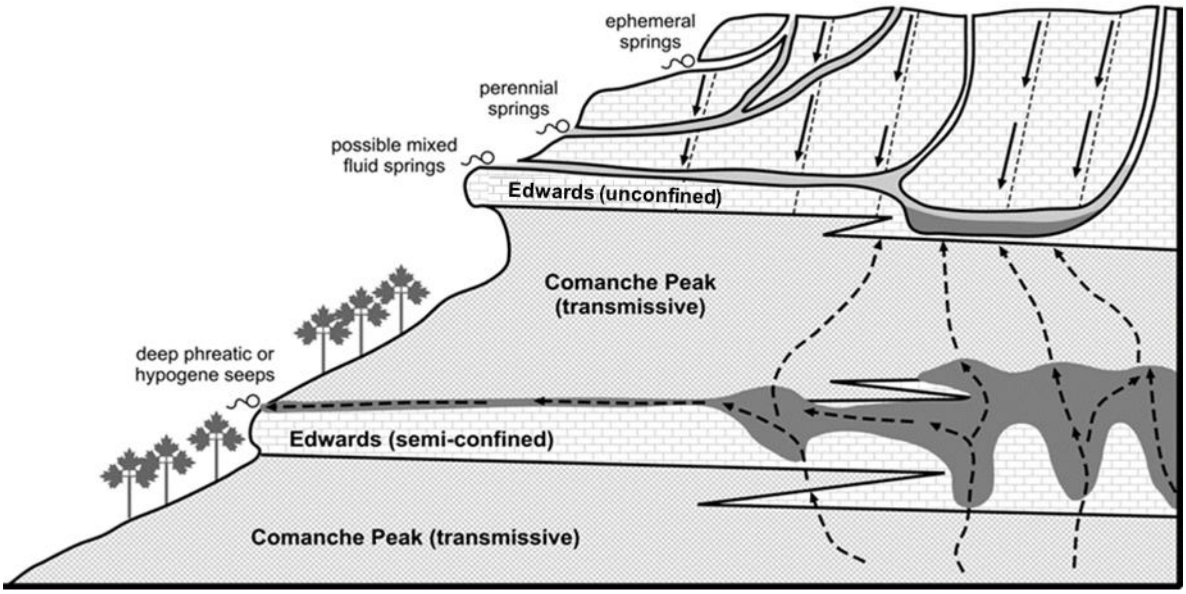

Figure 10. Hydrogeologic model of maple habitat within the Owl Mountain Province. Many mesic vegetation sites exhibit no surface flow; these sites are maintained by phreatic and/or hypogenic water resources that augment soil moisture.

Reproduction and regeneration is necessary to sustain maple habitat.*A. grandidentatum* can reproduce sexually; flowers on the plant appear along with leaves every two to three years, generally after colder, wet winters. Reproduction by seed is most important for establishment of *A. grandidentatum* in new areas and seeds germinate more readily when they have dispersed farther from parent trees. Sexual reproduction also increases genetic variability but may be suppressed by climate fluctuations and breeding population proximity (Donovan & Ehleringer, 1994). Seed dispersal within the Bear Creek watershed might not be as successful as many of these sites are quite fragmented and have experienced greater disturbance by wildlife, grazing, and military and civilian traffic. The Owl Creek watershed is more remote and the roads within it are significantly less traveled, providing a more optimum environment for maple regeneration and seed dispersal.

These trees also reproduce by layering and sprouting from the root crown. Layering is considered to be a more effective means of stand replacement than seed dispersal and germination, and occurs naturally in *A. grandidentatum* when the lower branches come in contact with the soil and form new roots (Corbin & Page, 2011). After the roots have formed the layer may grow independently of the parent plant, or may continue to be attached to it. Layering is common in older plants and is a more effective method of reproduction; studies in Pole Canyon, Utah on five-year old seedlings originating from germinated seeds numbered only 455 plants/hectare while stems originating from layering numbered 4,151 plants/hectare (Tollefson, 2006). Sprouting from the root crown is common when the trees have been exposed to disturbance by fire, herbivory, flooding, or broken stems. Rooting behavior by *S. scrofa,* generally thought of as a destructive process, may actually help regenerate *A. grandidentatum* in the understory by encouraging sprouting from the root crown. While both of these asexual methods of reproduction are generally more successful, they reduce genetic variability in both continuous and isolated populations.

Original vegetation mapping had isolated populations confined to narrow canyons within the Owl and Bear Creek watersheds. Recent vegetation modeling and mapping has significantly increased the delineated area where maples exist (Figures 6 and7), and has redefined the site description where these trees can and do thrive. In the newly delineated habitat, maples exist on open, rocky slopes as a dominant species in the canopy, and regenerate in the understory (Figures 8 & 9). Reproduction of maples was thought to occur mostly through layering and sprouting, significantly decreasing their genetic diversity. As a result of this new vegetation model, it appears likely that seed dispersal is responsible for some of the expansion of maple habitat, particularly along the exposed scarps in the Owl Creek watershed.

In addition to open scarps, three random occurrences of *A. grandidentatum* were found on top of the Owl Mountain plateau, in areas where disturbance is much greater and water resources are scarce. These trees were growing in proximity to the road in open areas surrounded by *J. ashei* and scrub oaks and were not associated with any of the established or modeled maple habitat (Figure 7). It may be that the Fort Hood maples are more resilient than originally thought, as these trees were thriving in areas with shallow soils and in competition for limited water resources atop the plateau.

10. **Conclusions**

A. grandidentatum exists as a disjunct, relict population in Central Texas. These isolated populations were presumed to be relicts from the most recent Pleistocene Ice Age; as temperatures warmed and water resources became focused along incising canyons, mesic vegetation communities, including *A. grandidentatum*, contracted to sheltered canyons and woodlands with adequate water resources. In Texas, original site descriptions of these relict vegetation communities were modeled after *A. grandidentatum* populations located in Bandera and Real counties in the Lost Maples State Natural Area. Within the study area, the spatial distribution of *A. grandidentatum* was once thought to be confined to mesic sites in narrow slot canyons within the Owl Mountain Province of the Fort Hood Military Installation.

Recent vegetation mapping in the Owl and Bear Creek watersheds has greatly expanded both the site description and locations where maples exist (Figure 7). Just as they do in continuous populations, *A. grandidentatum* can grow on open slopes with oaks and other species that are able to equilibrate to lower soil water potentials (Figures 8 & 9). Soil moisture is augmented by ascending fluids transmitted by matrix porosity along the northwest trend of the scarps in the Owl and Bear Creek watersheds, and by solutional porosity associated with regional deformation trends (Figure 10).

Future maple conservation and establishment efforts should be focused in areas where military and civilian traffic can be kept to a minimum, possibly with exclosures to control disturbance from herbivory and grazing. In areas where bigtooth maple is introduced, some Ashe juniper control might be necessary as long as those controls are balanced with the acreage required to provide endangered species habitat for the golden-cheeked warbler in mature juniper-oak woodlands. At present, Fort Hood has set aside 88,541 hectares of golden-cheek warbler habitat, some of the largest remaining patches of contiguous breeding habitat in the Lampasas Cut Plain, with the largest expanse in the Owl Mountain Province (Peak, 2011; Hayden et al., 2001).

In the near future, the fire suppression in the Owl Mountain Province may favor the encroachment of pioneer species such as *J. ashei*. Vegetation in areas designated as maple habitat consists of deciduous mixed-oak hardwood woodlands; in areas that have been disturbed by road building and vegetation removal, *J. ashei* has encroached and may initially out-compete other vegetation for resources. *J. ashei* can uptake, retain and use water very efficiently for a variety of reasons; extensive shallow root systems take advantage of soil waters and deeper tap roots are able to penetrate through fractured bedrock to perched water tables (Huxmanet al., 2005). In addition, *J. ashei* has a much denser, closed canopy with more available surface area on which precipitation can adhere and eventually be lost to the atmosphere due to evapotranspiration (Thurow& Hester, 1997). Since *J. ashei* borders existing maple habitat, it will compete for growing space and resources as disturbance provides encroachment opportunities. While disturbance may appear to favor pioneer species such as *J. ashei*, bigtooth maples are shade tolerant and able to exist in varying moisture regimes, allowing them to survive in the understory while patiently waiting for their day in the sun.

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