SUSTAINABILITY OF TEEPEE POLE STANDS ON MESCALERO APACHE TRIBAL LANDS: CHARACTERISTICS AND CLIMATE CHANGE EFFECTS

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ABSTRACT

The Mescalero Apache Tribe conduct a Coming of Age Ceremony for young girls who follow a traditional way of life. In order to conduct this ceremony, tall, thin teepee poles made from Douglas-fir trees are needed. Douglas-fir trees capable of producing teepee poles are a culturally important resource for the Mescalero Apache Tribe. We interacted with tribal members, medicine men, and tribal foresters to gain insight on characteristics of teepee pole stands. We established thirty, 0.1 acre (400 m^2) circular plots with nested 0.025 acre (100 m^2) regeneration plots in teepee pole producing stands to characterize composition, structure, age, growth rates, and fuels. Teepee pole producing stands occupy elevation ranges from 6,600 to 8,400 ft (2012 to 2561 m), slopes of 3%-43%, and aspects from Northwest to Northeast. The stands consist of dense, relatively old trees dominated by Douglas-fir, with other species of trees, namely white fir, southwestern white pine, ponderosa pine, Gambel oak, and juniper usually present as a minor component. Douglas-firs in teepee pole producing stands averaged 508 ± 40 trees per acre (TPA) (1255 ± 99 trees per ha (TPH)), 138.1 ± 6.5 ft^2/ac basal area (31.7 ± 1.5 m^2/ha), and 7.3 ± 0.2 in (18.5 ± 0.5 cm) quadratic mean diameters (QMD). Douglas-fir trees in teepee pole producing stands were most commonly 75-100 years old with diameters at breast height (DBH) ranging from 2-10 in (5.1-25.4 cm). In order to assess future trajectories of teepee pole stands, we applied the model Climate-Forest Vegetation Simulator (C-FVS) which

incorporates the effects of climate change scenarios over the next 100 years. We compared three standard scenarios ranging from moderate to severe climate change, Representative Concentration Pathways (RCP) 4.5, 6.0, and 8.5. Simulated future forests at the current plot locations did not contain Douglas-fir after a century of modeling, even under the mildest climate scenario, RCP 4.5. Ninety-seven percent of plots failed to maintain a minimum basal area of 5 ft^2/ac (1.1 m^2/ha) of any species. Complete forest mortality was predicted under RCP 6.0 and RCP 8.5. Comparing bioclimatic niche modeling of Douglas-fir with downscaled future climate scenarios indicated that the species would have to be planted at least 1000 ft (305 m) higher to maintain 21st century viability under RCP 4.5 and 6.0, or at least 2000 ft (610 m) higher under RCP 8.0. The characterization of current teepee pole producing stands and simulations of future effects of climate change provide useful information to the Mescalero Apache Tribe to support management decisions on how they would like to preserve and maintain this cultural important resource.

In the second part of the thesis, we used Geographic Information System (GIS) and remote sensing data to identify teepee pole stands. We found that there are 122 Globally Positioning System (GPS) located teepee pole stands and 76 treatment exclusions throughout MATL. Using the known locations of teepee pole stands as training sites, we attempted to use remote sensing techniques to classify all possible areas of teepee pole producing stands throughout the forested areas of Mescalero. The classification proved to be inadequate for management, due to insufficient training sites to accurately detect teepee pole stands.

ACKNOWLEDGEMENTS

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PREFACE

This thesis is written in “manuscript format”, a format endorsed by the Northern Arizona University School of Forestry and the Northern Arizona University Graduate College. Chapter 2 is formatted for direct submission and eventual publication in a peer-reviewed journal.

CHAPTER 1:

LITERATURE REVIEW

Mescalero Apache History

The Mescalero Apache Tribe represents one of several bands of Apache nations. Currently three bands of Apache comprise Mescalero Apache Tribal Lands: the Chiricahua, Lipan, and Mescalero. Other Apache bands include Jicarilla, Western Apache, White Mountain, Cibecue, San Carlos, and Southern and Northern Tonto Apache.(Historical Research Associates, 1981). Though these bands identify themselves as distinct groups, they share closely related languages. The western Apaches (Mescalero, Lipan, Chiricahua, and San Carlos) speak a variation of southern Athabaskan, while the eastern Apache (Jicarilla, Kiowa-Apache, and Western Apache) speak a variation of northern Athabaskan language (Historical Research Associates, 1981).

Historically the Apache inhabited a vast range of land throughout the southwest and parts of northern Mexico called "Apacheria". This region includes present day Texas, New Mexico, Arizona, Sonora Mexico, and Chihuahua Mexico. Within Apacharia there are vast lands of deserts, canyons, mesas, and alpine mountains. Elevation is what delineates the climatic zones within Apacharia. The Mescalero's territory included areas of the Sacramento Mountains, Gualdalupe Mountains, Tulirosa Basin, and LLando Estacido. Though these areas were the Mescalero's home range, some scholars indicated that they reached areas as far north as Flagstaff, AZ, and as far south as Big Bend, TX, as far west as Papago, AZ, and as far east as the Texas Panhandle (Historical Research Associates, 1981).

On May 27, 1873 President Ulysses S. Grant established the Mescalero Apache Tribal Lands (here after as MATL) on executive order ("Mescalero Apache Tribe 'Our Culture,'" 2018). Mescalero lands cover 463,000 acres located in south-central New Mexico. Within these lands lie four sacred mountains: Sierra Blanca, Guadalupe Mountains, Three Sisters Mountains, and Oscura Mountain Peak. These mountains represent the four directions of everyday life for the Mescalero Apache. Mescalero lore also speaks of White Mountain; it was on this mountain that White Painted Woman gave birth to two sons, which in later years would bring peace and prosperity to the Mescalero ("Mescalero Apache Tribe 'Our Culture,'" 2018).

One of the most precious and sacred gift from White Painted Woman to this date is the Mescalero Apache Puberty Rite Ceremony. White Painted Woman reared sons that destroyed the evils of earth and brought peace to the Mescalero. It is for this reason the Mescalero conduct this ceremony for White Painted Woman. They believe that an Apache woman should strive to be like White Painted Woman. This 12-day rite of passage ceremony marks the transition of an individual from girlhood into womanhood. For the duration of the rite, the young girl dresses and act like White Painted Woman ("Mescalero Apache Tribe 'Our Culture,'" 2018). The following discussion is drawn from Mescalero Apache Tribe 'Our Culture,' (2018) and conversations with medicine men (J. Padilla, A. Comanche, personal communications 2015 and 2016).

The ceremony is a major commitment for the family of the maiden. Preparation often begins as much as a year in advance with the gathering of sacred items such as roasted mescal heart and pollen from water plants. A medicine man and medicine woman must participate and lead certain ceremonies. Dancers and singers must be arranged. Finding a ceremonial dress, either from a relative who previously went through the ceremony or one that has been made for the occasion is important, as it is a symbolic part of the ceremony. A major part of the family's responsibility is to prepare a feast for 4 days of the ceremony where friends and family attend ("Mescalero Apache Tribe 'Our Culture,'" 2018).

The girl is dressed in the buckskin attire that she wears for the 12 day ceremony (Figure 4). Her attendants supply her with a length of reed that she must drink from. The maiden is also forbidden to touch her lips with water, as well as to scratch herself with her fingernails, so a wooden scratcher is provided. The girl is urged to talk little, to pay full attention to the lessons being told to her, and to carry herself in a dignified manner.

On the first day of the ceremony the maiden along with male family members wander into the forest at sunrise to collect teepee poles. These poles, 12 per teepee, are collected strictly from Douglas-fir trees. The 3-7 inch diameter poles collected must not contain any sort of defects, no scars, forks, or diseases. Each teepee pole is carefully selected and blessed with pollen and named by the medicine man. The trees are felled in each of the cardinal directions following the four stages of life, and ensuring to fell the last tree in the same direction of the first tree. The teepee poles are then brought back to the ceremonial grounds where then, the teepees can be erected (Figure 1). Each teepee has a specific use ranging from storage, cooking, and living (Figure 2, 3). A ceremony can have 3-4 teepees. One medicine man stated that in one summer he can conduct 9 ceremonies. This equated to 324 teepee poles cut for this one medicine man.

The maiden sleeps in the big teepee for the duration of the ceremony this teepee is unlike the others, where the bark is left on, and the last 3-5 feet of brush is life on as well. There is a path of fir trees to the entrance of the big teepee organized from tall trees on the outer path to shorter trees closer to the teepee. The floor of the big teepee is lined with reeds on which the maiden will sleep for the duration of the ceremony.

By the end of the fourth day, every possible experience, even sleep and the old age stick, has been mentioned in the songs and prayers. The songs sang and prayers said performed ensure that the maiden experiences a long life and good fortune in her future. For four more days after the completion of the ceremony, the maiden must continue to wear her ceremonial buckskins and must not wash or come in contact with water. She must continue to use her drinking tube and scratcher. At the end of this period the medicine woman washes her hair and body with suds from the yucca root. Then she changes into her ordinary clothing, furnished for her new her role in the community, and the next stages in her life as a Mescalero Apache woman ("Mescalero Apache Tribe 'Our Culture,'" 2018).

Mixed Conifer Stands in the Southwest

An assessment of southwestern mixed conifer forests in the later 2000s led to the classifications of 2 mixed conifer forest types, warm/dry and cool/moist mixed conifer forests (Romme et al., 2009). Warm/dry mixed conifer forests are typically found in lower elevations on mainly southerly aspects and are dominated by ponderosa pine (*Pinus ponderosa* var. *scopulorum* Englm.) and Rocky Mountain Douglas-fir (*Pseudotsuga menziesii var. glauca* (Beissn.) Franco) but also includes species adapted to mesic environments such as white fir (*Abies concolor* (Gord. & Glend.) and aspen (*Populus tremuloides* Michx.) and sometimes southwestern white pine (*Pinus strobiformis* Engelm.). Warm/dry mixed conifer forests are generally located higher in elevation than pure ponderosa pine stands. Moisture and temperature are the primary drivers that influence the species composition and fire regimes both warm/dry and cool/moist mixed conifer forest types. The dominant forest type on MATL is warm/dry mixed conifer (Figure 3). Fires are the main ecological disturbance; surface fires burned with sub- to multi-decadal frequency prior to Euro-American settlement (late 1800s) but fire have been excluded for over a century (Azpeleta et al. in review), leading to several large, uncharacteristically severe crownfires in the 20th century (Historical Research Associates, 1981).

Over a century of fire suppression in southwestern mixed conifer forests has shifted species composition toward more mesic, shade tolerant species such as white fir and Douglas-fir, increased tree density, and increased surface and ladder fuels (Cocke, Fulé, & Crouse, 2005; Fulé et al., 2009), making them more susceptible to stand-replacing fires which can lead to novel ecosystems (Seastedt, Hobbs, & Suding, 2008). There has also been increased continuity of vertical and horizontal fuels (Cocke et al., 2005; Margolis & Balmat, 2009) as a result of these changes, there is a push in focus for scientists and land managers is to restore forest stand structure to similar historically adapted to frequent surface fires (Falk, 2006; Fulé et al., 2003; Heinlein, 2005). Understanding forest stand structure and characteristics is essential when planning for future desired conditions.

Southwestern Forests and Climate Change

The effects of global climate change during the last 50 years have begun to alter natural ecosystems (Soja et al., 2007). Southwestern tree species distributions are being affected by dieback and mortality in *Populus tremuloides* (Michaelain et al.,2011; Rehfeldt et al., 2009) *Pinus ponderosa* (Gitlin et al., 2006), and *Pinus edulis* (Breshears et al., 2005; Shaw, Steed, & DeBlander, 2005), and for an additional 88 tree species worldwide (Allen et al., 2010). On top of large amounts of tree mortality in the southwest, the largest spreading climatic-induced ecosystem shifts involve insect outbreaks, either directly in response to climate abnormalities (Candau & Fleming, 2011; Raffa et al., 2008) or indirectly by weakened trees from drought stress (Negrón et al., 2009) . Such climate-induced impacts on forests when combined with altered wildfire frequencies (Flannigan et al., 2009) are expected to shift vegetation species composition and create novel ecosystems.

Climate change is altering forest fire regimes by shifting vegetation distributions (Lenoir et al., 2008) creating hotter, drier, and longer fire seasons (Westerling, 2006), and burning uncharacteristically high fuel loads due to fire suppression in the last century. The interactions between high fuel loads and hotter, drier, and longer fire seasons produced fires of record size, severity, and cost in dry mixed coniferous forests of North America and Europe (Miller et al., 2009). Following increased disturbances there is also a shift in dominance by sprouting species and a loss of the formerly dominant seeding species such as ponderosa pine in the western and southwest United States. This suggests that there are long-term changes in vegetation characteristics with conversions from forest to shrublands or grasslands for a number of decades (Haire & McGarigal, 2010) or indefinitely (Savage & Mast, 2005). There are new tools such as Climate-Forest Vegetation Simulator (C-FVS) to help forest managers explore the potential effects of climate change. Using C-FVS help forest managers make informed decisions on management of forest in efforts on mitigation the future effects of climate change. Model simulations are a helpful tool for climate scientists, and being that these are models, there are uncertainties that users should take into consideration when using climate model simulations (Crookston et al., 2010).

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FIGURES

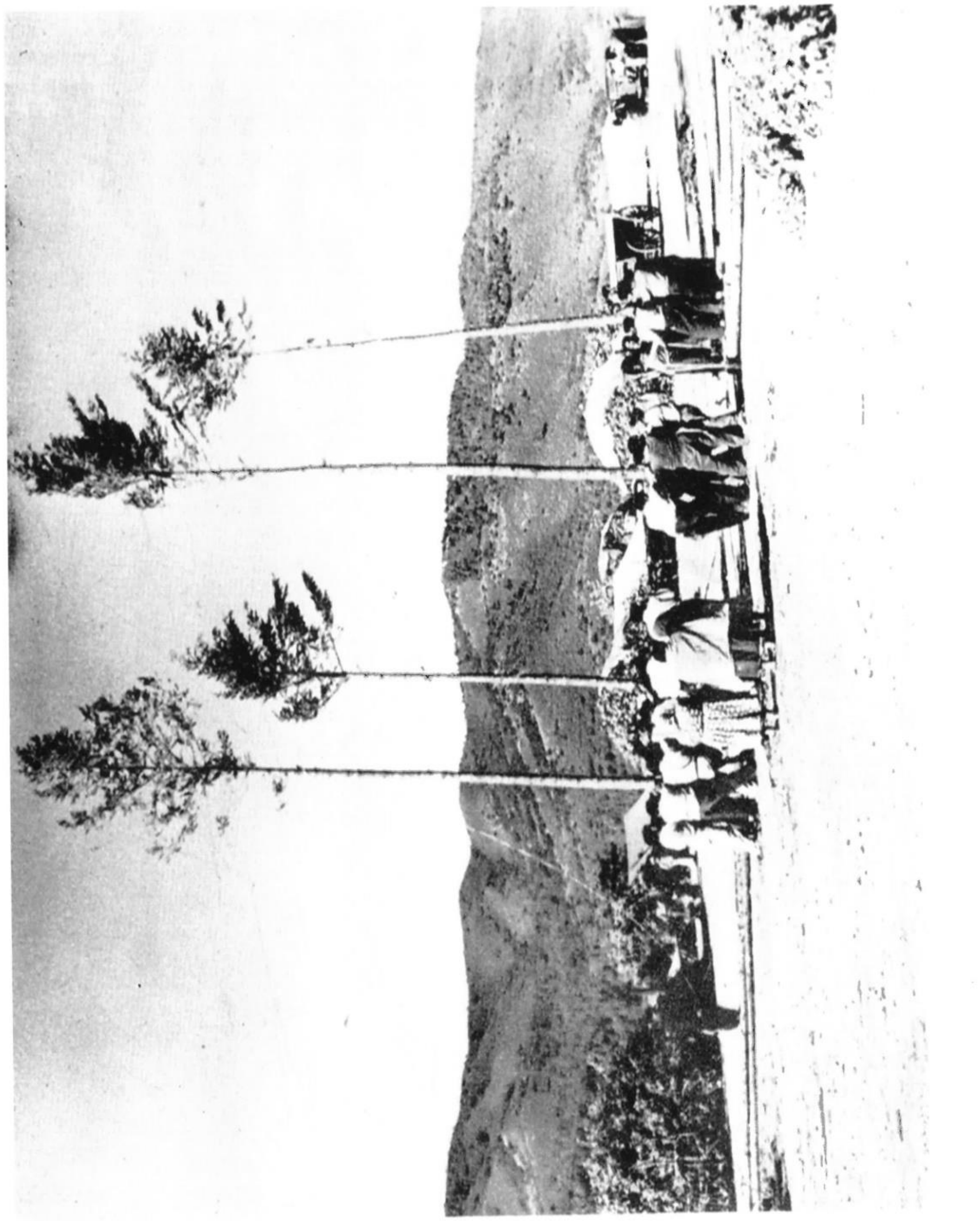

Figure 1. Mescalero tribal members erecting a teepee for female's rite of passage ceremony. The teepee being erected is the "big teepee" distinguishable from the bark and top of needles remaining on the poles.

Figure 2. Each teepee has a specific use. Teepee can be used for cooking, storage, and living. Arbors are also constructed out of Gambel oak or Douglas-fir saplings. Arbors are used for cooking and seating guests who attend the ceremony.

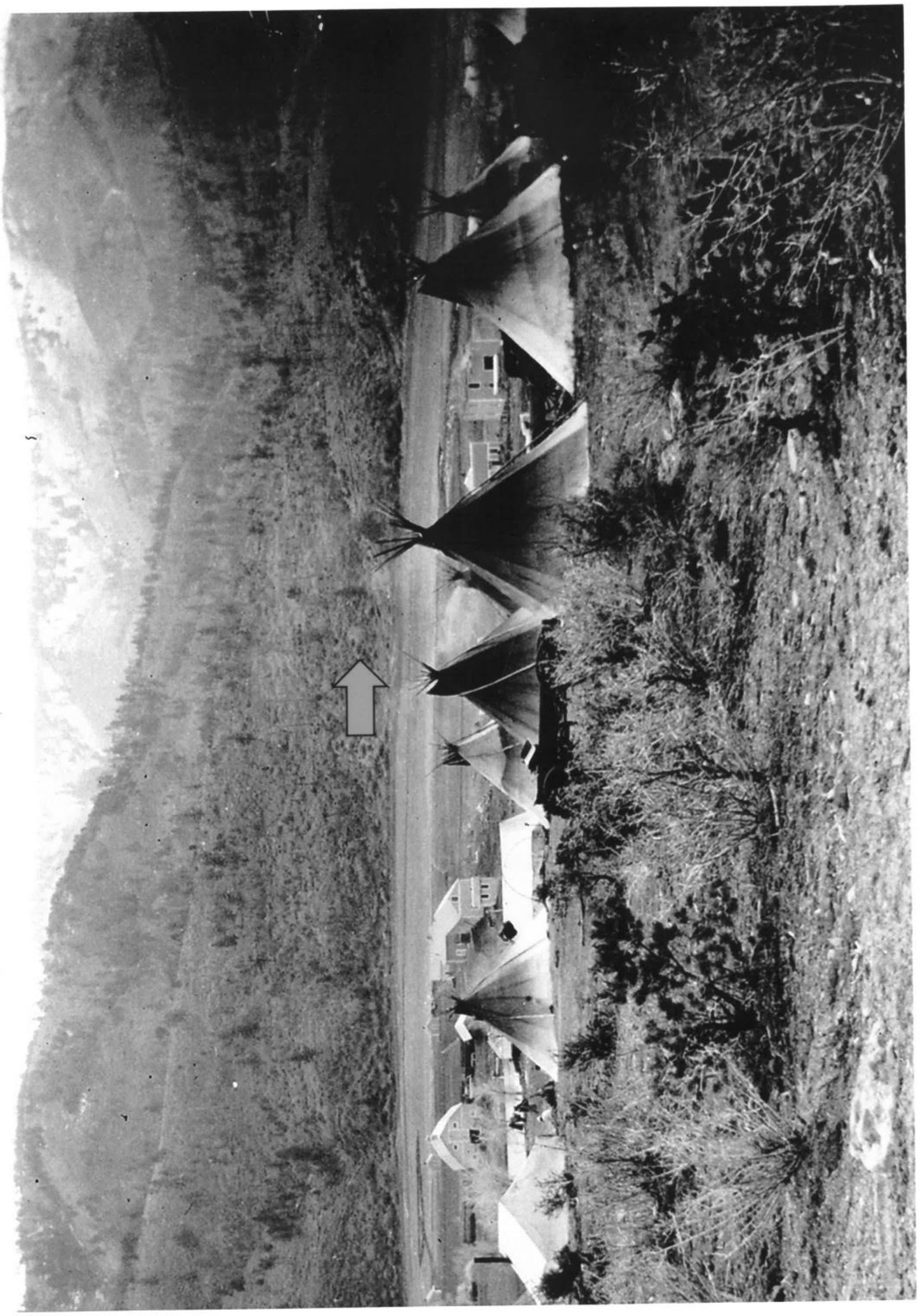

Figure 3. Historical use of teepees on Mescalero Apache Tribal Lands. Traditionally the Mescalero were nomadic people who erected teepees for various ceremonial uses.

CHAPTER 2:

SUSTAINABILITY OF TEEPEE POLE STANDS ON MESCALERO APACHE TRIBAL LANDS: CHARACTERISTICS AND CLIMATE CHANGE EFFECTS

ABSTRACT

The Mescalero Apache tribe conduct a coming of age ceremony for young women who follow a traditional way of life. In order to conduct this ceremony, tall, thin teepee poles made from Douglas-fir trees are needed. Douglas-fir trees capable of producing teepee poles are a culturally important resource for the Mescalero Apache tribe. We interacted with tribal members, medicine men, and tribal foresters to gain insight on characteristics of teepee pole stands. We established thirty, 0.1 acre (400 m^2) circular plots with nested 0.025 acre (100 m^2) regeneration plots in teepee pole producing stands to characterize composition, structure, age, growth rates, and fuels. Teepee pole producing stands occupy elevation ranges from 6,600 to 8,400 ft (2012 to 2561 m), slopes of 3%-43%, and aspects from NW to NE. The stands consist of dense, relatively old trees dominated by Douglas-fir, with other species of trees, namely white fir, southwestern white pine, ponderosa pine, Gambel oak, and juniper usually present as a minor component. Douglas-firs in teepee pole producing stands averaged 508 ± 40 trees per acre (TPA) (1255 ± 99 trees per ha (TPH)), 138.1 ± 6.5 ft^2/ac basal area (31.7 ± 1.5 m^2/ha), and 7.3 ± 0.2 in (18.5 ± 0.5 cm) quadratic mean diameters (QMD). Douglas-fir trees in teepee pole producing stands were most commonly 75-100 years old with diameters at breast height (DBH) ranging from 2-10 in (5.1-25.4 cm). In order to assess future trajectories of teepee pole stands, we applied the model Climate-Forest Vegetation Simulator (C-FVS) which incorporates the effects of climate change scenarios over the next 100 years. We compared three standard scenarios ranging from moderate to severe climate change, Representative Concentration Pathways (RCP) 4.5, 6.0, and 8.5. Simulated future forests at the current plot locations did not contain Douglas-fir after a century of modeling, even under the mildest climate scenario, RCP 4.5. Ninety-seven percent of plots failed to maintain a minimum basal area of 5 ft^2/ac (1.1 m^2/ha) of any species. Complete forest mortality was predicted under RCP 6.0 and RCP 8.5. Comparing bioclimatic niche modeling of Douglas-fir with downscaled future climate scenarios indicated that the species would have to be planted at least 1000 ft (305 m) higher to maintain 21st century viability under RCP 4.5 and 6.0, or at least 2000 ft (610 m) higher under RCP 8.0. The characterization of current teepee pole producing stands and simulations of future effects of climate change provide useful information to the Mescalero Apache Tribe to support management decisions on how they would like to preserve this cultural important resource.

Keywords: Douglas-fir, New Mexico, Assisted Migration, Climate-Forest Vegetation Simulator, C-FVS, Traditional Ecological Knowledge .

INTRODUCTION

Forests provide a wide variety of ecosystem services, including cultural niceties supported by traditional ecological knowledge (TEK) based on forest materials. In south-central New Mexico, USA, the Mescalero Apache Tribe conduct a Coming-of-Age Ceremony for girls who follow a traditional way of life. This 12-day rite of passage ceremony marks the transition from girlhood into womanhood (Mescalero Apache Tribe 2018). The maiden goes through a series of ceremonies led by medicine men and women to ensure that she lives a prosperous life. Teepees and other structures constructed from forest trees are built for the maiden. Teepees are constructed for storage, cooking and living and remain erected before, during, and after the ceremony. A ceremony can have 3-4 teepees and one medicine man stated that in one summer he can conduct 9 ceremonies. This equated to 324 teepee poles cut for this one medicine man.

Teepee poles are essential forest products for Mescalero ceremonies. Poles are made exclusively from Rocky Mountain Douglas-fir (*Pseudotsuga menziesii var. glauca* (Beissn.) Franco). This species can grow up to 115-150 feet tall (35- 46 m), reach about 3 feet (.9 m) DBH and can be found on cool, dry, interior mountain ranges from New Mexico up into Canada (Hermann & Lavender, 1999). It is smaller than the coastal variety (*Pseudotsuga menziesii* (Mirb.) Franco *var. menziesii*), which can reach 250 feet tall (76 m) and is found from California to British Columbia. Douglas-fir trees in the Southwest are found in warm/dry mixed conifer forests (Romme et al., 2009) which are vulnerable to warming climate and associated disturbances (Craig D. Allen et al., 2010; Flatley & Fulé, 2016).

The Mescalero Apache Tribal Lands (MATL) are located in the Sacramento Mountain Range of New Mexico. The dominant forest type on MATL is warm/dry mixed conifer. Surface fires burned with sub- to multi-decadal frequency prior to Euro-American settlement (late 1800s) but fires have been excluded for over a century (Azpeleta et al. in review), leading to several large, uncharacteristically severe crownfires in the 20th century (Historical Research Associates, 1981). Mescalero Forest Management is conducted jointly between the Bureau of Indian Affairs and the Tribe's Division of Resource Management and Protection. Silvicultural treatment, fuels reduction operations, and prescribed burning are carried out on over 5,000 acres (2,023 ha) annually. Much of the commercial forest area is managed for low-density, crownfire-resistant, efficient wood fiber production featuring Douglas-fir and ponderosa pine (Hoyt et al., 2016). However, an important core objective for Mescalero forest management includes the incorporation of traditional, religious, and cultural forest values. In the specific case of teepee pole production, the incorporation of traditional values creates a paradox for forest management. Contemporary forest management aims to restore and maintain open forests similar to historical conditions, but simultaneously the Mescalero Apache Tribe seeks to sustain areas of high-density Douglas-fir stands for teepee pole production. Recently, people who follow a traditional Mescalero Apache way of life have expressed concerns with silvicultural treatments such as thinning in teepee pole stands, leading the Tribal Council to identify teepee poles as a resource of concern in tribal government resolutions (13-20) and to seek research on sustaining them for the future.

We interacted with foresters, medicine men, and tribal members who conduct ceremonies to develop insight into the ecological, cultural, and management issues surrounding teepee pole producing stands. Based on this information, we sampled teepee pole stands across Mescalero's forested lands with the following objectives: (1) characterize the composition, structure, age, growth rates, and fuels of current teepee pole stands; (2) apply forest simulation modeling to forecast teepee pole stand development and sustainability under alternative management and climate scenarios; and (3) provide the data to the tribe so they can consider developing plans for future management of this important cultural resource.

METHODS

Study area

Mescalero Apache Tribal Lands, in south-central New Mexico is 460,678 acres (186,429.8 ha) and is 85% forested with 150,000 acres (60,702.8 ha) classified as commercial forest (Hoagland 2016) (Figure 1). The forest is managed conjointly between the Bureau of Indian Affairs (BIA) (Breuninger, 2014) and Mescalero's Division of Resource Management and Protection (DRMP). Mescalero's Tribal Council also influences forest management by including cultural values and philosophies that protect Mescalero's natural resources. The western areas of MATL include elevations ranging from 6,000 ft (1828 m) to 12,003 ft (3658 m) while the eastern areas of MATL is lower in elevation, and has a more arid climate and is dominated by woodlands (Hornsby, 2001; Hoagland, 2016) climate is semi-arid to subhumid at high elevation. Soils in the Sacramento Mountains are classified as mostly Argiborolls, derived from limestone and siltstone parent material (Kaufmann, 1998) Average annual high temperatures are 65.3°F (18.5° C) while average low temperatures are 35.4°F (1.9° C). Average annual precipitation is 21.8 in. (55.5 cm), with average annual snowfall of 78.7 cm (Ruidoso Weather Station, https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?nmmesc).

Desert-grassland vegetation types dominated by shrubs and grasses are found in the eastern portions of MATL and overstory vegetation types include pinyon pine (*Pinus edulis* Engelm), Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), alligator juniper (*Juniperus deppeana* Steud.), in mid elevations sites from 5,500 ft. (1676 m) -7,000 ft. (2133 m) Pine forests occur around 7,000ft. (2133 m) elevational zone with ponderosa pine (*Pinus ponderosa* var. *scopulorum* Englm.) and Gambel oak (*Quercus gambelii* Nutt) as the dominant tree species. Mixed conifer forests occur on north facing aspects between 7,500 ft. (2286 m) - 9,000 ft (2743 m) and are dominated by Douglas-fir (*Pseudotsuga menziesii* var. *glauca*

(Besissn.) Franco), white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr), southwestern white pine (*Pinus strobiformis* Engelm.), aspen (*Populus tremuloides* Michx.) as well as ponderosa pine and Gambel oak. At the higher elevations above 8,500 ft. (2591 m) spruce-fir and alpine meadows dominate the landscape.

Interactions with Tribal Members, Medicine Men, and Foresters

To gain insight on the characteristics of teepee pole producing stands we met with Mescalero Apache medicine men who explained the process of selecting teepee poles. Their recurring theme was respect for what was being taken from the land. (J. Padilla and A. Comanche, personal communication, 2016-2017). Teepee poles are selected from dense patches of Douglas-fir trees ranging from 3-5 in. (7-12 cm) in diameter (8-10 in. (20-25 cm) for "big teepee"). The collection of teepee poles must be accessible by road because collection of poles must be completed by noon on the teepee construction day. Teepee pole trees should be free of any deformities such as crook, sweep, or fork, or illnesses or wounds visible on the trees. When a teepee pole is selected, it is first named by the medicine man and blessed with pollen. Then the teepee poles are felled in each of the cardinal directions with an axe. Once felled, poles are measured from the top of the tree 8-10 axe handles down (approximately 18–23 ft (5.5-7 m)).

Field Methods

We sampled thirty teepee pole stands using 0.1 ac (400 m^2) plots within teepee pole/producing stands identified by medicine men and tribal foresters. We sampled three pilot plots in 2015. In 2016 we divided Mescalero Apache Tribal Lands into 4 quadrants to establish an additional 27 plots spread across the landscape. Within each quadrant, we randomly selected plots from a map of teepee pole stands provided by the Bureau of Indian Affairs (BIA) Branch of

Forestry. Each point was verified on the ground based on the presence of teepee pole-size Douglas-fir trees as well as the stumps of cut teepee poles.

We took measurements in the plots of tree species, condition class (live; declining; recent snag; loose bark snag; clean snag; snag broken above breast height; snag broken below breast height; dead and down tree; cut stump; and cut teepee pole), diameter at breast height (DBH), diameter at stump height (DSH), total height, crown base height, live crown ratio and dwarf mistletoe rating (0-6). Tree condition classes were assigned based on a tree, snag, and log classification system (Thomas, 1979), with the exception of the category “cut teepee pole” which is unique for the purpose of this study. Trees with damage or deformities that could affect selection as a teepee pole were noted. In the three preliminary plots collected in 2015, all trees within the 4305.56 ft^2 (400 m^2) circular plot were cored with an increment borer at ≈ 11.8 in (30 cm) because it is an appropriate location for simultaneously dating tree age and measuring radial growth. After analysis of the preliminary plot data in 2016 the coring intensity was reduced to the first 20 live trees of each species with a DBH $\geq$ 2.8 in (7 cm) starting clockwise from due north. Samples were stored in paper straws. Seedlings or sprouts of tree species shorter than breast height 4.5 ft, (1.37 m) were tallied on with nested 0.025 ac (100 m^2) subplots by species and condition in three height classes: (1) ≤ 15.7 in (38 cm); (2) 15.8–31.5 in (38- 80 cm); and (3) 31.5– 53.9 in (80-134 cm). Downed woody biomass and forest floor depth were measured in a randomly selected direction from the center of the circular plots along a 50ft. (15.2 m) planar transect (Brown 1974) in each plot.

Laboratory Methods

Dendrochronology

Tree cores were air dried, glued to slotted wooden mounts, and sanded until wood cells and ring boundaries were clearly visible under magnification(Stokes & Smiley, 1968). Cores were visually crossdated with the chronology NM 573.RWL developed by Margot Kaye et al., 1997 and a local unpublished chronology that we developed. For cores that missed the pith, additional years to the center were estimated with a pith locator consisting of concentric circles matched to the curvature and density of the inner rings to the estimated pith (Applequist, 1958). Ring widths of all samples were measured using a Velmex stage and the Measure J2X software, and quality control of crossdating was done with the COFECHA program (Grissino-Mayer, 2001). Ring width measurements were converted to diameter growth increment for the simulation modeling.

Climate Forest Vegetation Simulator (Climate-FVS, C-FVS)

To model future conditions of teepee pole producing stands we used the Climate-Forest Vegetation Simulator (Crookston et al., 2010). Climate-FVS is an extension to the base Forest Vegetation Model Simulator (FVS), which is a deterministic, individual-tree growth model (Dixon, 2013). FVS is a semi-distant-independent growth model, meaning that tree growth and mortality rates are adjusted based on stand density.

We initialized C-FVS with data from the 30 field plots, using the Mixed Conifer model in the Central Rockies Variant of FVS. Site Index (SI) values were applied from the nearest continuous forest inventory (CFI) plots. Plot-specific growth data from increment cores were used to adjust simulated tree growth based on observed growth in the period 2000-2016.

The effects of changing climate are simulated in C-FVS through species viability scores (Crookston et al., 2010) which are based on bioclimatic relationships of species´ known environmental envelopes compared to climate scenario conditions (Rehfeldt, 2006). Species viability scores are used in C-FVS to modify species-specific tree-growth rates, site-index, and mortality rates of the base FVS model as a function of climate scenario selection. The species viability scores values are standardized from 0-1, where 1 indicates that a species is within its observed climatic envelope. As conditions increasingly depart from those suitable for the species, the species viability scores declines. When it goes below the (arbitrary) level of 0.4, the species can no longer regenerate at the site. Meanwhile, as other species encounter increasingly favorable conditions their species viability scores values increase and they can appear on the site through the Autoestablishment feature of C-FVS (Crookston et al., 2010). A maximum of four species were selected from the available species based on viability score. As a result, most of the trees to be established were those with increasing species viability scores, inserted by Climate-FVS as best suited for the future climate of the site based on local availability, climate scenario, latitude, longitude and elevation.

We used Representative Concentration Pathways (RCPs) scenarios developed by the Intergovernmental Panel on Climate Change (IPCC, 2014) to represent a range of potential future climates. The four RCP scenarios represent conditions in which radiative forcings increase by 2.6, 4.5, 6.0, or 8.5 Watts per square meter (W/m^2) by the year 2100 (van Vuuren et al., 2011) Three of the four RCP scenarios are included in the current version of Climate-FVS, excluding the RCP 2.6 scenario which is considered to be unrealistically low in impact. We uploaded plot coordinates to the C-FVS website and received downscaled projections for climate variables and species viability scores in historical (1990) times and the dates 2030, 2060, and 2090 for the three available RCP scenarios. We also used a “no climate change scenario” consisting of the standard FVS model without the climate module. We carried out forest simulations for 100 years after plot establishment. We planned to test alternative management strategies such as effects of tree thinning or fire use. However, early results showed that the species viability scores for

Douglas-fir at the plot locations rapidly dropped below the level of sustaining or regenerating the species even under the mildest climate scenario, RCP 4.5. Therefore we revised the modeling component to assess the elevational thresholds at which Douglas-fir could still persist by the end of the century. We did this by adding hypothetical elevation gains of 1000 ft (305 m) and 2000 ft (610 m) to the plot elevations and assessing the Douglas-fir species viability scores under these altered conditions.

RESULTS

Teepee Pole Stand Characteristics

Teepee pole producing stands were found over a range of elevations from the lowest plot at 6765 ft (2062 m) to the highest plot at 8438 ft. (2572 m). The average elevation for all 30 plots was 7890 ft. (2405 m) (see Supplementary Information, Table S1). Slopes ranged from 4% to 43%, averaging 18%. Twenty-five out of 30 plots (83%) had northerly (WNW to ENE) aspects while only 5 plots (17%) had southerly aspects in the ESE to SSW range (Table S1.).

A total of nine species were encountered but forest structure was dominated by Douglas-fir, which comprised 70% of all trees (Table 1). Douglas-fir averaged 508.3 trees per acre (TPA) (1256 trees per ha (TPH)), out of an overall average of 833.4 TPA (2,059.3 TPH). One-seed juniper and southwestern white pine were the distant second- and third-most common species. Douglas fir accounted for 74% (138.1 ft^2/ac, 31.7 m^2/ha) of the total basal area of 186.6 ft^2/ac (42.8 m^2/ha). The second-highest species in basal area, white fir, only averaged 8% (15.1 ft^2/ac, 3.5 m^2/ha) of the total. Quadratic mean diameters (QMD) were below 10 in (25.4 cm) for all species. Douglas-fir has a QMD of 7.3 in (18.5 cm).

We found 109 cut teepee pole stumps (36.3 TPA/90 TPH) on the 30 plots. The average diameter of cut teepee poles measured at stump height was 4.8 in (12.2 cm). Separating out the Douglas-fir trees potentially capable of being used as teepee poles based on DBH from 3 to 7 in for smaller teepees and 7-11 in for a “big teepee” (7.7–17.8 cm, 17.9–27.9 cm). We found a total of 1041 potential teepee poles, corresponding to an average density of 347 TPA (858 TPH). Removing individuals with defects, deformities, damage, pests or illnesses, the total number of usable smaller teepee poles was 518 and 358 larger poles. The total usable poles was reduced to 876 poles (292 TPA/721 TPH), a reduction of approximately 16% in usable poles. Note that these estimates apply to teepee pole densities within isolated teepee pole stands, not across the forest in general. The estimates are based on the characteristics of teepee poles as described by medicine men, but in actual practice the medicine men select the poles themselves. We found 12 of the 30 teepee pole plots were infested with Dwarf mistletoe. Douglas-fir on average has a mistletoe rating of 2.6 out of 6, while ponderosa pine had an infection rating of 3.7 our of 6.

The average diameter distribution was strongly reverse-J shaped (Figure 2), dominated by the smallest size classes of trees. Douglas-fir was the predominant species in all size classes except the largest diameter class 22 in. In contrast to the uneven distribution of tree sizes, the tree age distribution showed that most of the trees established in the early 20th century primarily in the two decades of the 1920s and 1930s (Figure 3). The oldest tree encountered was a ponderosa pine with a center date of 1874 (144 years old). The youngest trees established in the 1960s, but note that the minimum size for sampling was 2.8 in (7 cm) so smaller and younger trees were also present on some plots.

Tree diameter of Douglas-fir was linearly but weakly related to age with very high variability in the range of 70-100 years old, the ages of most of the trees (Figure 4). Diameter growth in the period 2000-2016, the time period used to calibrate the C-FVS growth model, tended to be higher in larger Douglas-fir trees but high variability was also present (Figure 5). Growth was slow: a 6 in (15.2 cm) Douglas-fir tree in the size range for use as a teepee pole grew an average of only 0.44 in (1.1 cm) over the past 16 years.

Forest fuels were relatively low (Figure 6), averaging 14.1 tons/ac (31.6 tonnes/ha). Distributed by moisture timelag and soundness categories, the highest individual category was the 1000-hr rotten woody biomass, averaging 3.6 tons/ac (5.8 tonnes/ha). Forest floor depth averaged 0.45 in (1.1 cm) for litter and 1.22 in (3.1 cm) for duff, for an overall forest floor depth averaging 1.67 in (4.2 cm).

Forest Simulation Modeling

Simulated future forests at the current plot locations did not contain Douglas-fir after a century of modeling, even under the mildest climate scenario, RCP 4.5. Ninety-seven percent of plots failed to maintain a minimum basal area of 5 ft^2/ac (1.1 m^2/ha) of any forest species. Complete forest mortality was predicted under RCP 6.0 and RCP 8.5. Comparing bioclimatic niche modeling of Douglas-fir with downscaled future climate scenarios indicated that the species would have to be planted at least 1000 ft (305 m) higher to maintain 21st century viability under RCP 4.5 and 6.0, or at least 2000 ft (610 m) higher under RCP 8.0 (Figure 6).

DISCUSSION

Teepee Pole Producing Stand Characteristics

Teepee pole producing stands excluded from silivicultural treatments are scattered throughout the forested areas of Mescalero. When searching for teepee pole stands, the Mescalero Apache can identify them visually as dense patches of tall and “skinny” Douglas-fir trees. In terms of quantitative characteristics of teepee pole producing stands, what do the numbers say when describing these stands? From the 30 teepee pole plots established in the study we can say that stands range in elevations from 6,600 ft. (2012 m) to 8,500 ft. (2591 m), grow on a range of slopes but tend to have mostly NW to NE aspects, with the exception of 3 plots that were on south facing aspects. Stands have on average ≈ 500 Douglas-fir TPA (≈ 1240 TPH) with the occasional presence of white fir, southwestern white pine, ponderosa pine, Gambel oak, and junipers. These stands average 140 ft^2/ac (32 m^2/ha) BA with average diameters ranging from 7-10 in (17.8-25.4 cm).

Despite being relatively small, teepee pole stands were not young. The average tree age was ≈ 80 years old. Teepee pole growth rates averaged less than 0.03 in/year (0.07 cm/year), nearly an order of magnitude less than average growth rates for Douglas-fir across the general Mescalero forest of 0.1-0.2 in/year (0.3-0.6 cm/year) (Blanford, 2014).

The potential for severe wildfire is a key motivation for thinning treatments at Mescalero, so the fuel loading is an important issue. Forest floor fuel loading averaging 14.1 tons/ac (31.6 tonnes/ha) falls within the optimal range suggested for management of coarse woody debris balancing fire risks with ecosystem benefits (Brown et al., 2003). However, the high density of trees in teepee pole stands and the potential for ladder fuels associated with the reverse-J diameter distribution does suggest that fire could reach the canopy relatively easily under severe fire weather conditions (Honig & Fule, 2012). Since the teepee pole stands are isolated points in a matrix of thinned, managed forest they likely do not contribute substantially to landscape-level fuel hazard.

How Will Climate Change Affect Teepee Pole Producing Stands?

Climate-Forest Vegetation Simulator runs showed near-complete tree mortality of Douglas-fir in teepee pole stands by 2116. Some stands maintained low forest basal area but with a shift in species composition to junipers, Gambel oak, and southwestern white pine as early as 2065. These results are broadly consistent with the findings of other studies using C-FVS primarily in ponderosa pine stands in northern Arizona (Bagdon & Huang, 2014) and eastern Arizona (Azpeleta et al. 2014), including the White Mountain Apache Tribal lands (Shive et al. 2014). These studies found that climate simulations regardless of treatment led to large decreases in forest basal area by the mid-century. Fewer studies have been done in mixed conifer forests with a substantial Douglas-fir component, but these simulations have also shown forest decline and compositional shift (Stoddard et al. 2015; Yazzie et al., in review). Landscape-level simulations in the Southwest U.S. using the Landis-II and/or Fire-BGC models have had more varied results but broadly coincide with our findings in terms of basal area reduction and compositional shift (Flatley & Fulé, 2016; Hurteau et al., 2016; Loehman et al., 2018).

Additional evidence from other lines of research supports the projection of substantial loss of southwestern tree species in the 21st century, including dieback and mortality in *Populus tremuloides* (Michaelain et al.,2011; Rehfeldt et al., 2009) *Pinus ponderosa* (Gitlin et al., 2006), and *Pinus edulis* (Breshears et al., 2005; Shaw et al., 2005), and for an additional 88 tree species worldwide (Craig D. Allen et al., 2010). Independent tracks of research in tree physiological responses to drying conditions (McDowell et al., 2016) and plant community traits related to climate (Laughlin et al., 2012) are also consistent in forecasting high mortality as climate warms.

Climate change scenarios are continually under revision as new information is gained by climate scientists and as greenhouse gas emissions by human societies fluctuate (IPCC 2014). Any particular model, such as C-FVS, has many limitations and specific predictions made today about forests 50-100 years in the future should be treated with caution. However, the fact that numerous independent lines of research are broadly consistent in predicting substantial forest decline should be taken into consideration by the Mescalero Apache community and resource managers.

Traditional Ecological Knowledge and Forest Management

Traditional Ecological Knowledge is defined by as Berkes, 1999 as "a cumulative body of knowledge, practice, and belief, evolving by adaptive process and handed down through generations by cultural transmission, about the relationship of living being (including humans) with one another and with their environment." (Berkes, 1999). Traditional Ecological Knowledge is based upon the view that humans should not view themselves as separate from nature but should view themselves as one with nature (Pierrotti & Wildcat, 2000). Native people realized through observation that all things are connected and these connections are reciprocal (Pierrotti & Wildcat, 2000).

These observations allowed Native Americans and Indigenous people worldwide to adapt land management techniques and use tools such as fire on the landscape for millennia. In some regions of North America, Native people ignited low intensity fires regularly which helped sustain key natural resources for the people (Anderson, 2006; Charnley, 2007). The low intensity burns also promoted understory biodiversity as well as increased resilience to trees to droughts and fires (Long et al., 2017). In the southwestern mountains, a semi-arid region with high lightning density, it is not clear what mix of human- and lightning-ignited fires occurred in the past (Allen, 1999; Kaye & Swetnam, 1999) However, there is abundant evidence of ecological as well as cultural adaptation to the frequent-fire environment (Fulé,et al., 2011)(Fulé et al. 2011).

Teepee pole conservation in the case of the Mescalero Apache presents certain unique features. First, modern conservation efforts often focus on large trees because they provide numerous ecosystem services and can take centuries to regrow and are vital to forest ecosystem resilience (Franklin et al., 2008). However, small (albeit relatively old) Douglas-fir trees are a critical resource for the Mescalero Apache Tribe due to the use of teepee poles for ceremonial and spiritual use. Small diameter teepee poles may have equal or higher value as large diameter trees in the eyes of the Mescalero Apache, fitting the definition in TEK of Culture Component, "species that significantly shape the cultural identity of a people, as reflected in diet, materials, medicine, and/or spiritual practice" (Duraiappah et al., 2005). The use of teepees by the Mescalero has greatly shaped their culture. Additional resources used in the ceremony include: reeds, cattails, mescal, and Gambel oak. The sustainability of Douglas-fir trees into the future is important. The Tribe understand the sensitivity of the trees and the impacts that could happen to these stands, this has lead them to look for ways to use their culture to guide the sustainability of this resource for many generations. Second, despite the high historical frequency of fire on the Mescalero landscape (Azpeleta et al. in review), the dense teepee pole stands likely require some level of fire protection. Integrating TEK related to teepee poles into contemporary management requires complexity and collaboration in developing silvicultural and fire management prescriptions.

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

Teepee pole producing Douglas-fir stands are an important cultural resource for the Mescalero Apache Tribe. Management and sustainability are of high priority for these stands and tribal members, foresters, and traditional leaders have come together to explore options on how to preserve and maintain this resource. From conducting interviews and attending ceremonies, we gained insight on the current issues surrounding teepee pole stands. Using these issues to guide our research we have come to learn that teepee pole stands are quite dense compared to the surrounding forested areas of Mescalero, contain relatively low understory regeneration, and moderate levels of fuel loading.

What are the options for sustaining traditional use of Douglas-fir teepee poles? Current management of teepee pole producing stands include marking currently known sites, and excluding these stands from silvicultural treatment. These practices should be continued. Across the Mescalero landscape there are some additional areas of dense Douglas-fir regeneration; these areas should also be marked and be excluded from treatment as well. Exclusion from treatment and survival of regeneration will increase the amount of possible usable poles in the future.

Reuse of poles, rather than collection of new poles for ceremonies, is a possible strategy for extending pole availability that came up in discussion with medicine men. This might be an option to discuss within the appropriate cultural context. Proper storage of collected teepee poles above ground, in a well-ventilated area can reduce the chances of warping, insect infestation, and growth of mold. The application of proper storage of teepee poles can prolong the use of these poles.

There is much uncertainty involving the future effects of climate change on forests in the Southwest but the Climate-FVS simulations tested under RCP 4.5, 6.0, and 8.5 suggested high to complete mortality of Douglas-fir at the elevations of the current teepee pole plots on Mescalero Apache Tribal Lands. In order to sustain teepee pole stands in the future, the simulation runs indicated that at 1000 ft (305 m) to 2000 ft (610 m) higher than current teepee pole plots Douglas-fir trees capable of producing teepee remained viable to grow under the simulated RCP scenarios. This suggests that if the Mescalero Apache Tribe would like to sustain teepee pole producing stands 100 years into the future planting of some nature could be helpful. A possible strategy to consider is planting Douglas-fir saplings at high densities on shaded aspects of Sierra Blanca. The portion of Sierra Blanca within the tribal boundary is largely southerly in aspect, but it might be useful to search for favorable microsites with non-southerly aspect and perhaps locally moist conditions. Experimental planting with different varieties of Douglas-fir from across tribal lands or perhaps elsewhere in the Southwest might be helpful to assess drought tolerance. Given that the current trees used for teepee poles are 70-90 years old, staggered plantings on a decadal basis in 1000 ft (305 m) increments might be sufficient to sustain ceremonial needs. As described above, climate predictions and modeling of future climate effects have considerable uncertainty. These models are meant for forest managers to gain some insight into possible future forest conditions, rather than as an exact guide to future conditions.

Following the management suggestions above will insure that this important ceremony can carry on. Collection of teepee poles may have to be conducted earlier than current times and at higher elevations, for the viability of teepee poles at current elevations decreases even by mid-century. We also recommend that there should be a prioritization of harvest where stands are closer to reaching mortality than others. This will allow better utilization of teepee pole producing stands thought MATL.

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TABLES

Table 1. Average teepee pole producing stand structural characteristics by species. Values are mean (± SEM).

SPECIES	Code	TPA	BA (ft^2/ac)	QMD (in)
Douglas-fir	DF	508.3 (40.3)	138.08 (6.46)	7.33 (0.23)
White fir	WF	37.9 (6.9)	15.10 (3.65)	7.22 (0.62)
Southwestern white pine	SW	56.1 (8.1)	9.22 (1.22)	5.78 (0.46)
Ponderosa pine	PP	24.7 (4.7)	9.19 (1.19)	9.30 (0.72)
Pinyon	PI	10.1 (N/A)	0.23 (0.055)	1.72 (0.25)
Gambel oak	GO	29.7 (5.7)	5.84 (1.93)	4.58 (0.43)
Alligator juniper	AJ	40.5 (6.6)	1.66 (0.471)	2.24 (0.37)
Rocky Mountain juniper	RM	55.3 (9.5)	6.28 (1.3)	4.20 (0.38)
One-seed juniper	OJ	70.8 (N/A)	1.03 (N/A)	1.63 (N/A)

SPECIES	Code	TPA	BA (m^2/ha)	QMD (cm)
Douglas-fir	DF	1,255.9 (99.6)	31.7 (1.5)	18.62 (0.58)
White fir	WF	93.7 (17.2)	3.5 (.84)	18.34 (1.57)
Southwestern white pine	SW	138.7 (20.0)	2.1 (.28)	14.68 (1.17)
Ponderosa pine	PP	61.1 (11.5)	2.1 (.27)	23.62 (1.83)
Pinyon	PI	25.0 (N/A)	0.05 (0.01)	4.37 (0.64)
Gambel oak	GO	73.3 (14.1)	1.3 (.44)	11.63 (1.09)
Alligator juniper	AJ	100.0 (16.3)	.38 (0.11)	5.69 (0.94)
Rocky Mountain juniper	RM	136.5 (23.5)	1.4 (.29)	10.67 (0.96)
One-seed juniper	OJ	175.0 (N/A)	.24 (N/A)	4.14 (N/A)

FIGURES

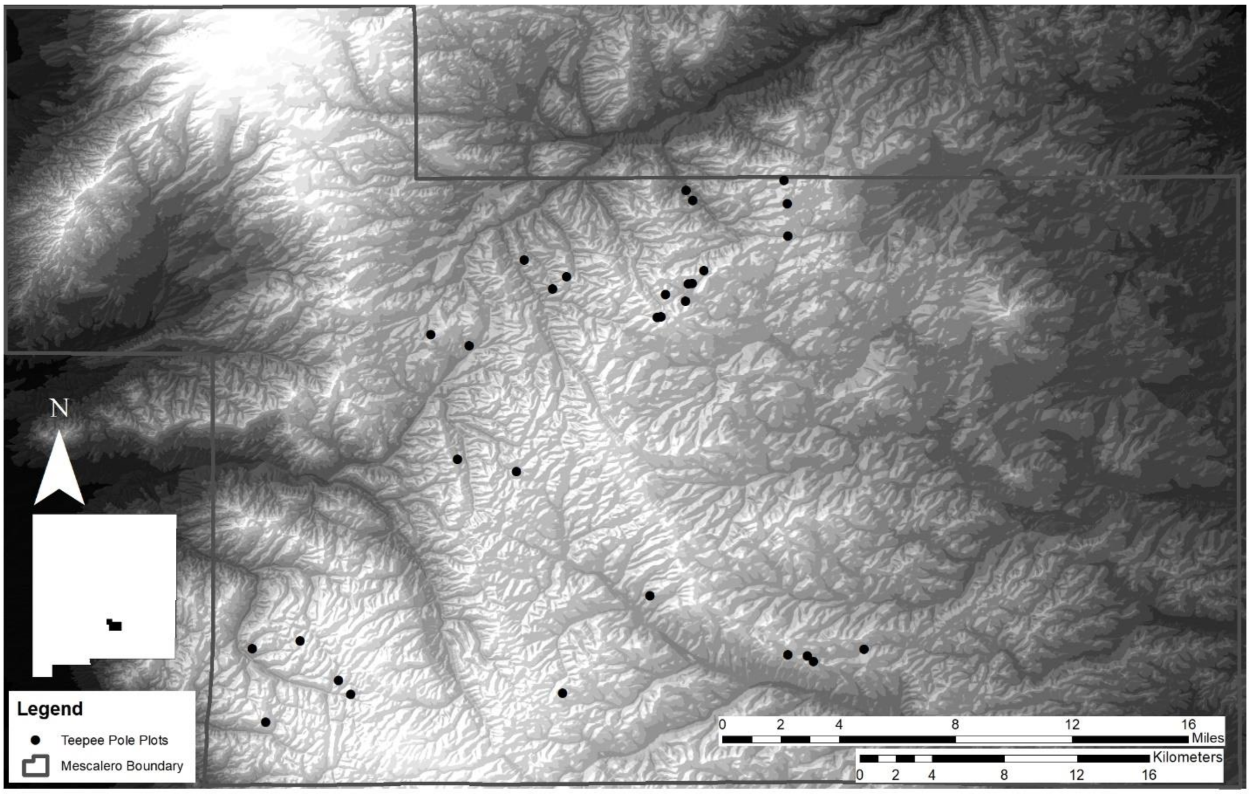

Figure 1. Mescalero Apache Tribal Lands reference map in New Mexico. Mixed-conifer forests are found in the central region of the MATL. The highest elevation of the landscape, Sierra Blanca (11,981 ft/3,652 m), is at the northwest corner of the map.

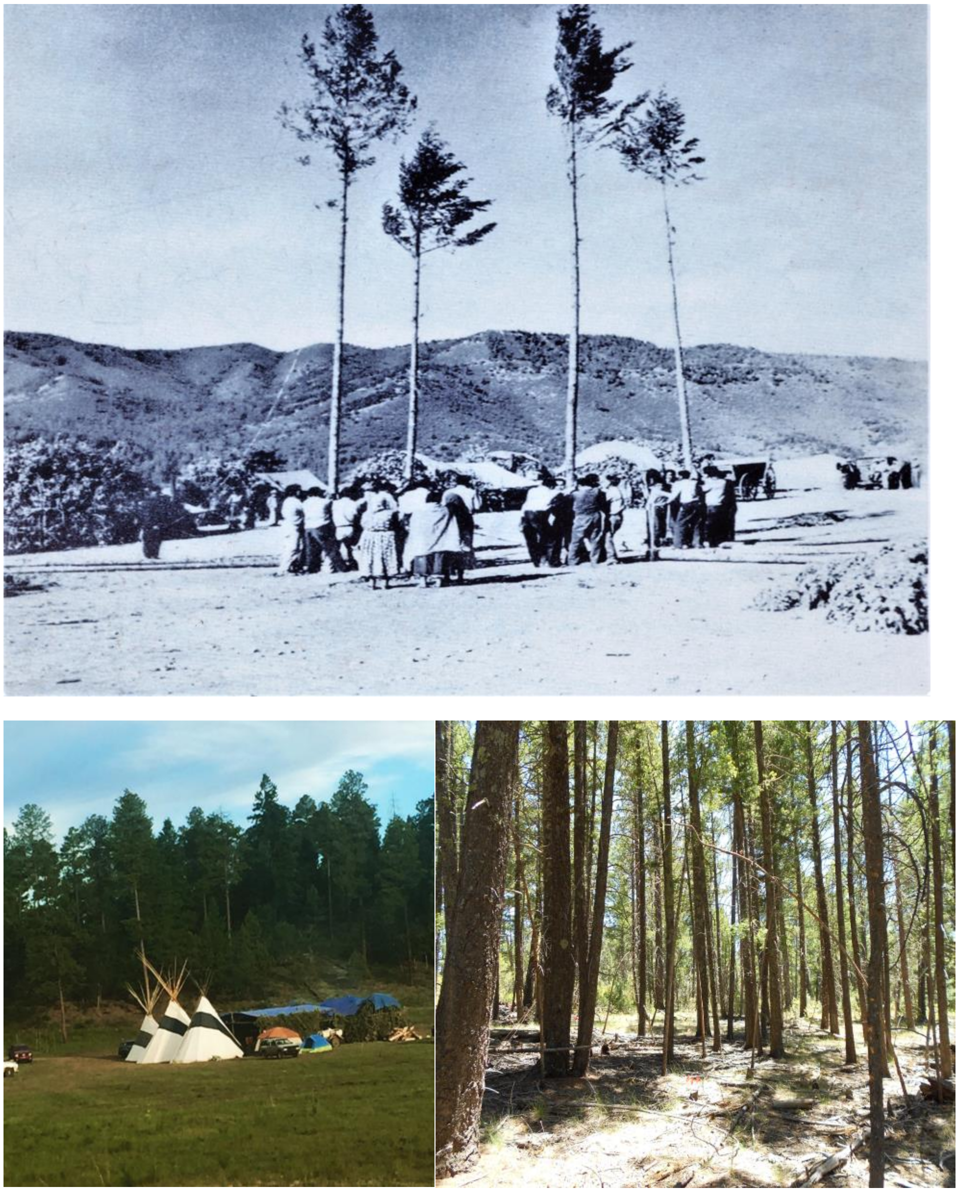

Figure 2. Top: Historical photo of Mescalero Apache members constricting a “Big Teepee”. Bottom left: Pictures of constructed teepees and an arbor. Bottom right: teepee pole producing plots.

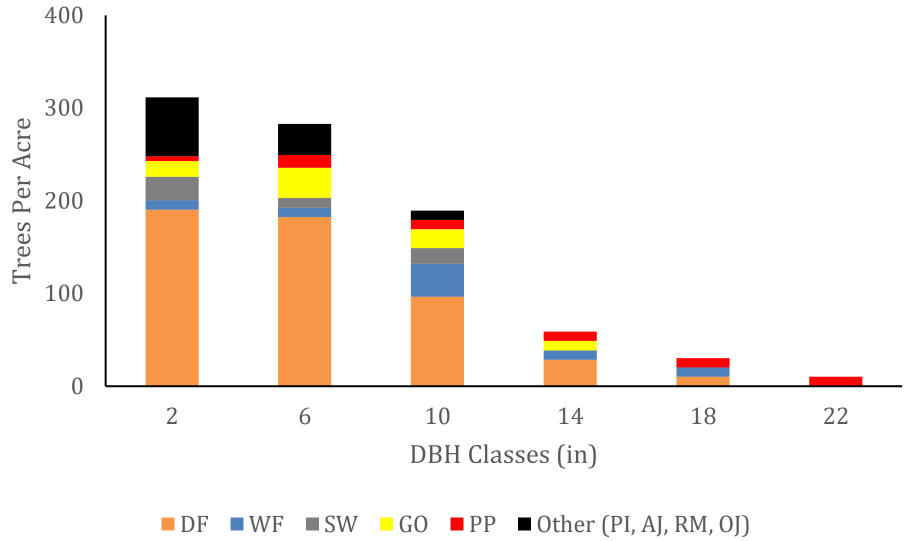

Figure 3a. Diameter distribution of trees in teepee pole producing stands. Labels are the midpoints of 4” diameter classes.

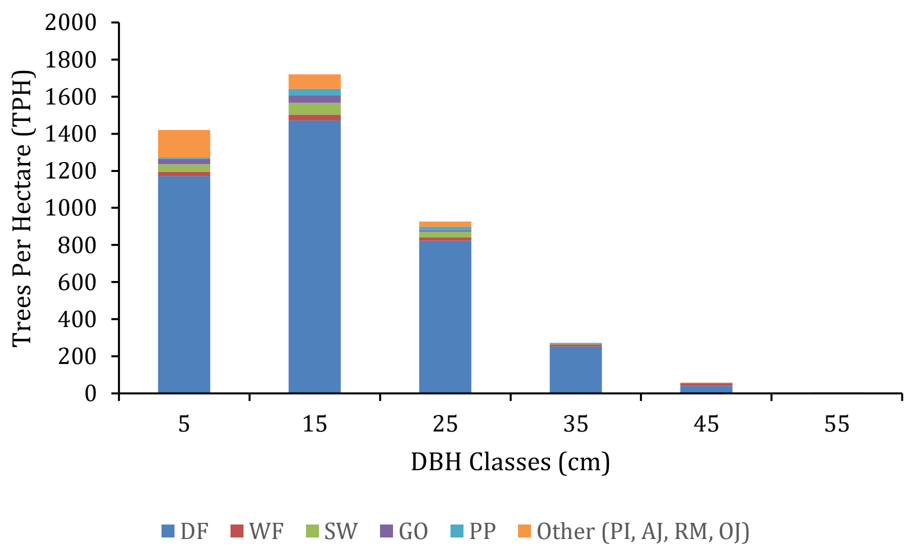

Figure 3b. Diameter distribution of trees in teepee pole producing stands. Labels are the midpoints of 10 cm diameter classes.

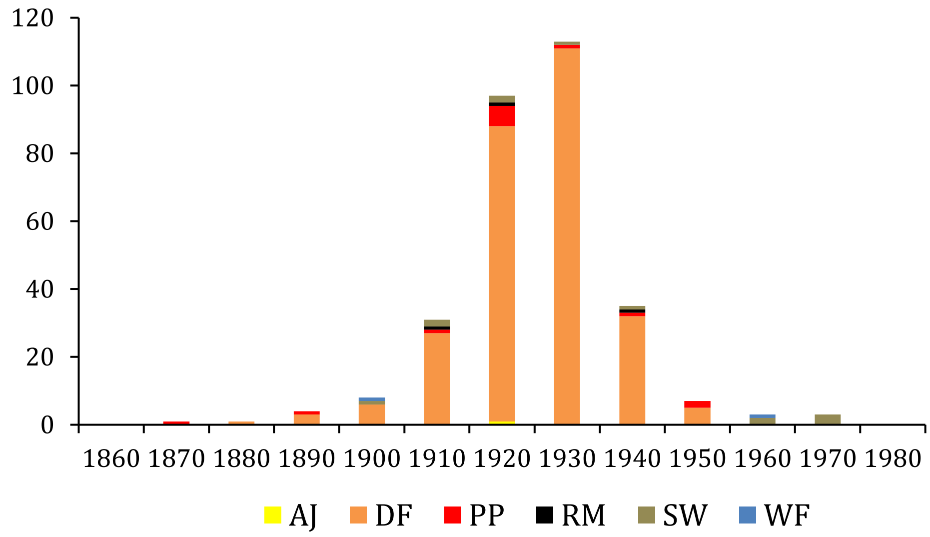

Figure 4. Tree age distribution, showing center date at the coring height (1.2 ft, 31 cm). X-axis labels are the starting dates of decades.

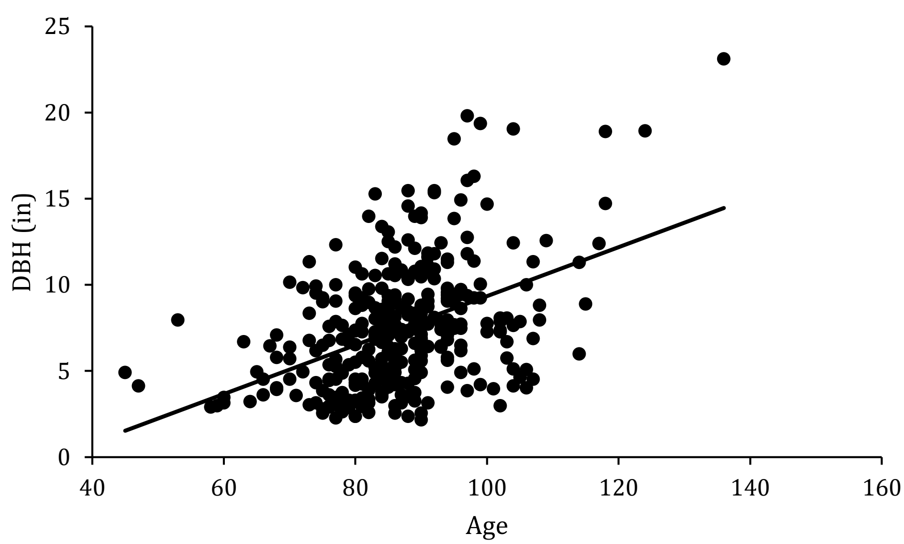

Figure 5a. Relationship between DBH in inches and age for Douglas-fir trees (R^2= .195, Y= -5.059 + 0.144 X AGE)

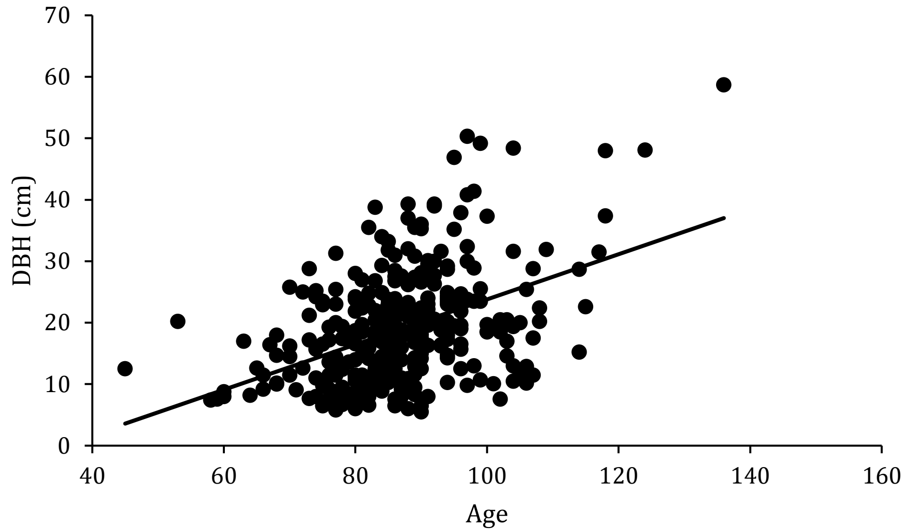

Figure 5b. Relationship between DBH in centimeters and age for Douglas-fir trees (R^2= .196, Y= -12.94 + 0.367 X AGE)

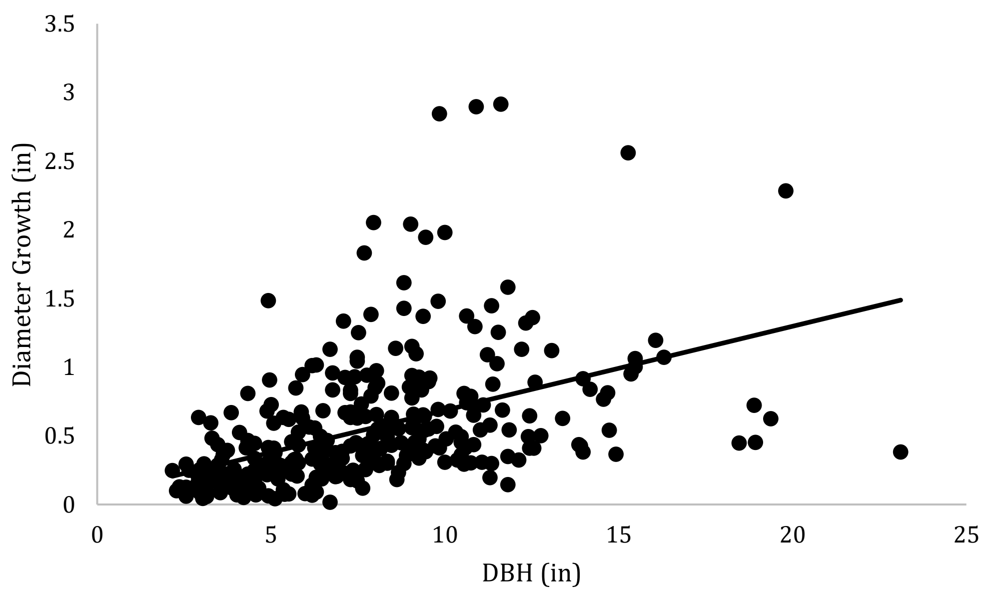

Figure 6a. Diameter growth of Douglas-fir (inches) in teepee pole stands between 2000-2016. (R^2= .22, Y= 0.073 + 0.061 X DBH)

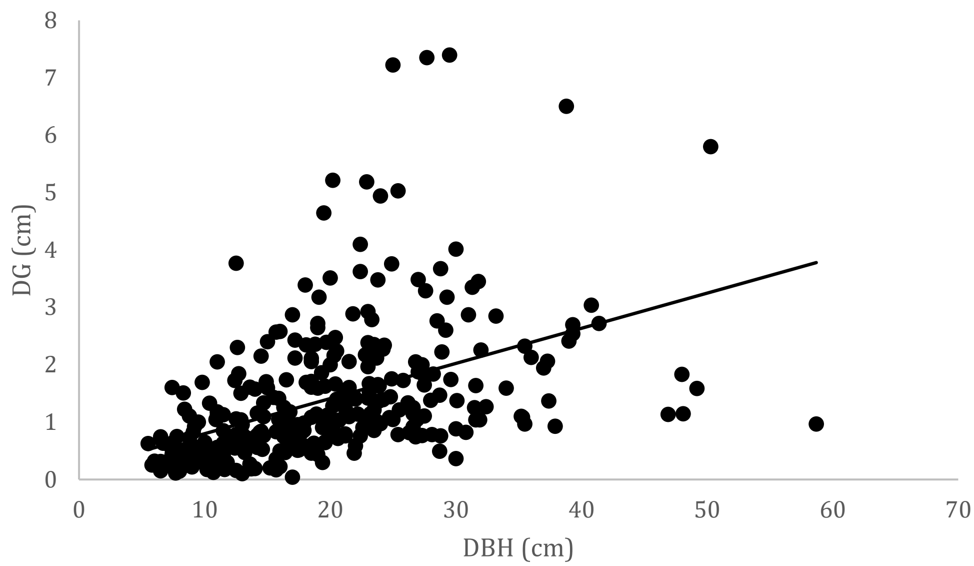

Figure 6b. Diameter growth of Douglas-fir (centimeters) in teepee pole stands between 2000-2016. (R^2= .22, Y= 0.19 + 0.061 X DBH)

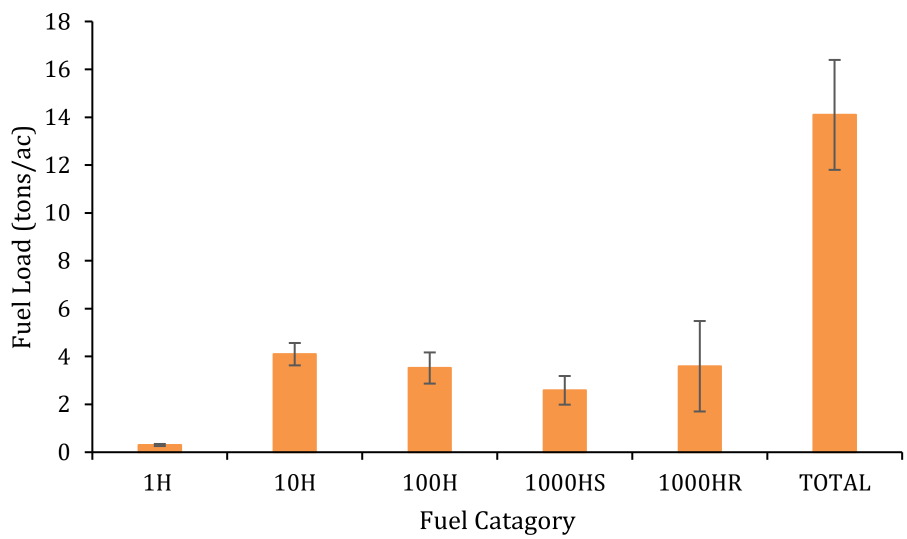

Figure 7a. Fuel loading of downed woody material divided by moisture timelag class (1 hr, 10 hr, 100 hr, 1000 hr sound, 1000 hr rotten) and the total fuel loading (ton/ac).

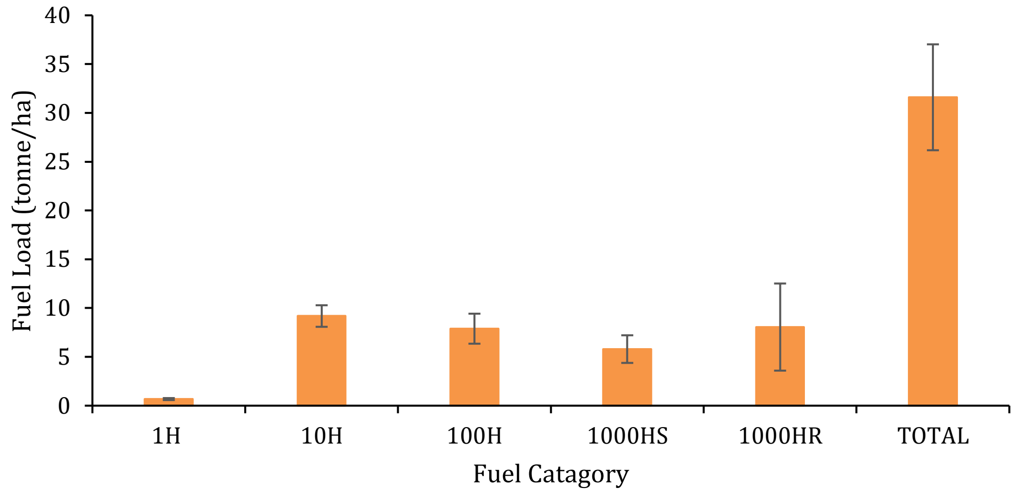

Figure 7b. Fuel loading of downed woody material divided by moisture timelag class (1 hr, 10 hr, 100 hr, 1000 hr sound, 1000 hr rotten) and the total fuel loading (tonne/ha).

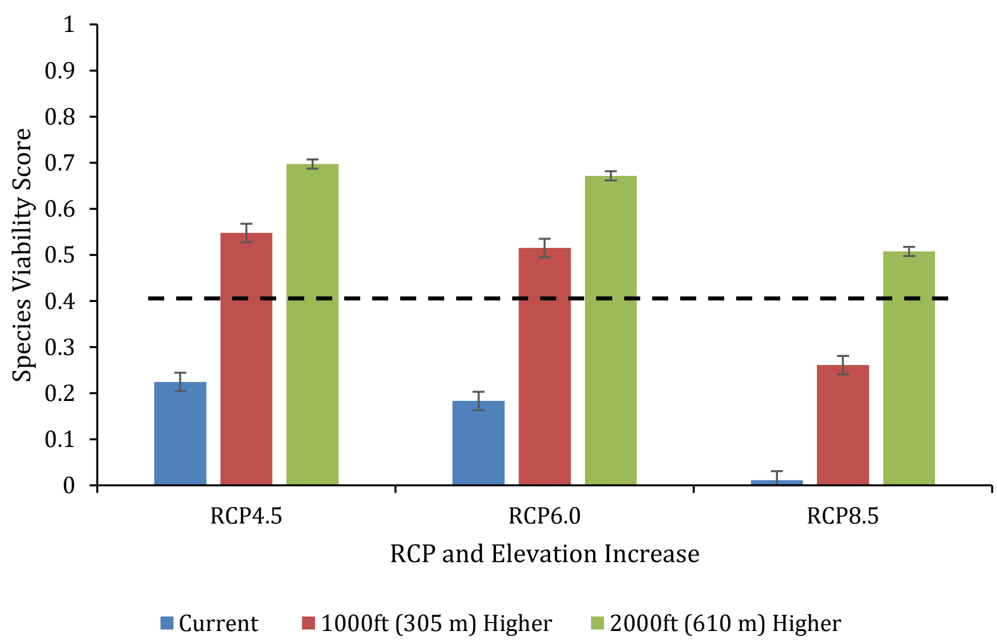

Figure 8. Average species viability scores based on downscaled ensemble climate models for Douglas-fir trees under RCP 4.5, 6.0, and 8.5 climate scenarios at the end of the 2116 cycle on

Mescalero Apache Tribal lands. The dashed line represent the viability threshold for species in the C-FVS model. When species viability scores fall below the threshold, the species cannot persist in the modeled scenario.

SUPPLEMENTAL INFORMATION

Table S1a. Site characteristics for all 30 teepee pole inventory plots. Teepee pole plots ranged in elevation from 6765 – 8425 ft. Twenty-five of the 30 plots were on NWN to NEN aspects with slopes ranging from 4-43%.

Plot	Elevation (ft)	Slope (%)	Aspect(°)
TPP_1	7742	8	370 NNW
TPP_2	7559	15	346 NNW
TPP_3	8395	19	78 ENE
TPP_4	7910	6	303 NNW
TPP_5	8061	11	20 NNE
TPP_6	8018	4	276 NNW
TPP_7	8025	13	6 NNE
TPP_8	8176	16	96 ESE
TPP_9	8022	14	304 WNW
TPP_10	8425	26	350 NNW
TPP_11	8218	15	2 NNE
TPP_12	7897	16	43 NNE
TPP_13	8251	18	218 SSW
TPP_14	7621	27	300 WNW
TPP_15	8113	43	190 SSW
TPP_16	8353	19	76 NEN
TPP_17	8339	12	0 N
TPP_18	7641	17	340 NNW
TPP_19	7848	11	158 SSE
TPP_20	7734	16	272 WNW
TPP_21	7877	7	276 WNW
TPP_22	8048	7	2 N
TPP_23	7096	32	326 NNW
TPP_24	6765	26	21 NNE
TPP_25	7667	13	216 SSW
TPP_26	7415	17	322 NNW
TPP_27	7454	43	341NNW
TPP_28	7539	15	22 NNE
TPP_29	8051	41	304 NW
TPP_30	8438	21	334 NNW

Table S1b. Site characteristics for all 30 teepee pole inventory plots. Teepee pole plots ranged in elevation from 2062 – 2572 ft. Twenty-five of the 30 plots were on NWN to NEN aspects with slopes ranging from 4-43%.

Plot	Elevation (m)	Slope (%)	Aspect(°)
TPP_1	2360	8	370 NNW
TPP_2	2304	15	346 NNW
TPP_3	2559	19	78 ENE
TPP_4	2411	6	303 NNW
TPP_5	2457	11	20 NNE
TPP_6	2444	4	276 NNW
TPP_7	2446	13	6 NNE
TPP_8	2492	16	96 ESE
TPP_9	2445	14	304 WNW
TPP_10	2568	26	350 NNW
TPP_11	2505	15	2 NNE
TPP_12	2407	16	43 NNE
TPP_13	2515	18	218 SSW
TPP_14	2323	27	300 WNW
TPP_15	2473	43	190 SSW
TPP_16	2546	19	76 NEN
TPP_17	2542	12	0 N
TPP_18	2329	17	340 NNW
TPP_19	2392	11	158 SSE
TPP_20	2453	16	272 WNW
TPP_21	2163	7	276 WNW
TPP_22	2062	7	2 N
TPP_23	2337	32	326 NNW
TPP_24	2260	26	21 NNE
TPP_25	2272	13	216 SSW
TPP_26	2298	17	322 NNW
TPP_27	2357	43	341NNW
TPP_28	2401	15	22 NNE
TPP_29	2454	41	304 NW
TPP_30	2572	21	334 NNW

Figure S1. Teepee Pole & Teepee Pole Stands Fact Sheet.

Teepee Pole Characteristics

- Teepee poles come from Douglas-fir trees with diameters ranging from 3”-11”.
- The average height of teepee poles are about 35-40 feet.
- Although they are small, it takes 75-100 years for a Douglas-fir tree to be a usable pole.
- Medicine people say that teepee poles must not contain any deformities or illnessess visible on the tree in order to be selected for a ceremony.
- Teepee poles must be cut with an axe and not a saw.
- With proper storage, poles can be reused.

Historical photo of Mescalero Apache teepee construction

Teepee pole producing stand

Teepee Pole Stand Characteristics

- Teepee pole stands are scattered across forested areas of Mescalero.
- Teepee pole stands range in size from less than one acre to multiple acres.
- The dominant tree species in teepee pole stands is Douglas-fir but other species include:
  - Southwestern white pine
  - White fir
  - Ponderosa pine
  - Gambel oak
  - Junipers
- Teepee pole stands grow at elevations of 6,600 to 8,400 ft.
- Most teepee pole stands grow on northern aspects with slopes of 3 - 43%.

Climate Change

Climate change is expeccted to greatly impact the Southwest. This poses a threat to Douglas-fir forests that produce teepee poles. Sustainable use of teepees poles now will improve the chances of maintaining teepee pole stands in the future.

CHAPTER 3:

USING NAIP IMAGERY AND REMOTE SENSING TO CLASSIFY TEEPEE POLE PRODUCING STANDS ON MESCALERO APACHE TRIBAL LANDS

ABSTRACT

The Mescalero Apache Tribe of south-central New Mexico, USA conduct a Coming-of-Age Ceremony for young girls who follow a traditional way of life. In order to conduct this ceremony, tall, thin teepee poles made from Douglas-fir trees are needed. We interacted with tribal members, medicine men, and tribal foresters to gain insight on characteristics of teepee pole stands. We learned that teepee poles come from dense patches of Douglas-fir stands isolated from surrounding mixed conifer forest across the landscape. Douglas-fir trees capable of producing teepee poles are a culturally important resource for the Mescalero Apache Tribe, and concerns for this resource have increased with future effects of climate change expected to shift vegetation composition in the southwest. We used GIS and remote sensing data to identify teepee pole stands. We found that there are 122 GPS located teepee pole stands and 76 treatment exclusions throughout MATL. Using the known locations of teepee pole stands as training sites. We attempted to use remote sensing techniques to classify all possible areas of teepee pole producing stands throughout the forested areas of Mescalero. The classification proved to be inadequate for management due to insufficient training sites to accurately detect teepee pole stands.

INTRODUCTION

Mescalero Apache Tribal Lands cover 460,000-acres located in south-central New Mexico, primarily in Otero County. MATLs are 85% forested with a commercial forest base of approximately 150,000 acres. Within the forested landscape of Mescalero there are areas of dense stands of Douglas-fir. These dense stands are important to the Mescalero Apache Tribe for these stands are areas that can be teepee pole producing stands. The Mescalero Apache conduct a young girls Coming-of-Age rite of passage ceremony. One key feature about this ceremony is erecting a ceremonial teepee, which the maiden will stay in for the duration of the ceremony. There is now a concern for Douglas-fir trees capable of producing teepee poles, and the Tribe has listed these trees as a species of concern. This concern has led the Tribe to explore management alternative to manage and sustain this culturally important natural resource. One management action the tribe is conducting for these teepee pole stands is having Tribal members search for teepee pole stands and marking them with GPS points and polygons.

Remote sensing (RS) and geographical information systems (GIS) are one of the most common techniques for analyzing natural resources (Ozyavuz et al., 2015). Remote sensing is an effective tool for extracting and mapping spatial information of land use and cover at different scales (Chen et al., 2017). Forest cover maps are one of the many products that can be made using remotely sensed data and are essential for providing forest managers the information needed to make forest management decisions at spatial and temporal scales (SH, 2015). The classification of forest cover type is an important element of forest resource management, for both practical purposes and for scientific research (Lennartz & Congalton, 2004) .

There are many different multispectral data at different resolutions and scales to conduct remote sensing: coarse-resolution imagery such as MODIS (Moderate-Resolution Imaging

Spectroradiometer) (Hansen et al., 2003; Savage et al., 2015), moderate-resolution imagery such as Landsat (i.e. multispectral scanner (MSS), and thematic mapper (TM)) (Ahmed et al.,2014; Carreiras et al.,2006), ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) (Falkowski et al., 2005), and high-resolution aerial imagery such as NAIP (National Agriculture Imagery Program) (Coulston et al., 2013).

This study explores a combination of remote sensing techniques using imagery from the National Agricultural Imagery Program (NAIP) to classify forest stand structure on the Mescalero Apache Tribal Lands. More specifically this study aims to 1) use currently known silvicultural treatment exclusions and GPS located teepee pole stands to characterize all potential areas of teepee pole producing areas across the forested areas of Mescalero Apache Tribal Lands, and 2) provide the information gained to the Tribe so they can consider developing plans for future management of this important cultural resource.

METHODS

Study Area

Mescalero Apache Tribal Lands, in south-central New Mexico covers 460,678 acres and is 85% forested with 150,000 acres classified as commercial forest (Hoagland, 2016). The forest is managed conjointly between the Bureau of Indian Affairs (BIA) (Breuninger, 2014) and Mescalero's Division of Resource Management and Protection (DRMP). Mescalero's Tribal Council also influences forest management by including cultural values and philosophies that protects Mescalero's natural resources. The western areas of MATL include elevations ranging from 6,000ft to 12,003ft while the eastern part of MATL are lower in elevation, has a more arid climate and is dominated by woodlands (Hoagland, 2016) Desert-grassland vegetation types dominated by shrubs and grasses are found in the eastern portion of MATL and overstory vegetation types include pinyon pine (*Pinus edulis* Engelm), Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), alligator juniper (*Juniperus deppeana* Steud.), in mid elevation sites from 5,500 ft. (1676 m) -7,000 ft. (2133 m) Pine forests occur around 7,000ft (2133 m) elevational zone with ponderosa pine (*Pinus ponderosa* var. *scopulorum* Englm.) and Gambel oak (*Quercus gambelii* Nutt.) as the dominant tree species. Mixed conifer forests occur on north facing aspects between 7,500 ft. (2286 m) -9,000 ft (2743 m) and are dominated by Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Besissn.) Franco), white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr), southwestern white pine (*Pinus strobiformis* Engelm.), aspen (*Populus tremuloides* Michx.) as well as ponderosa pine and Gambel oak. At the higher elevations above 8,500 ft. (2591 m) spruce-fir and alpine meadows dominate the landscape.

Data Sources

GIS data primarily came from the Mescalero Apache Agency BIA Forestry Department. The Tribe and BIA have been collecting various data on tribal lands and converting them into

GIS compatible layers. Layers used in the remote sensing section of this projects were: Mescalero Tribal Land boundaries, roads (main & logging roads), forest cover type, current known teepee pole producing stands, and finally treated areas and exclusions (teepee pole producing stands). Additional data sources included Digital Elevation Models (DEMs) and National Agricultural Imagery Program (NAIP) raster layers from the Resource Geographic Information System (RGIS). Located at the University of New Mexico, REGIS gathers data from various organizations and compiles them in a webpage, making vector and raster layers easily accessible to the public.

Mapping currently known teepee pole stands

We obtained 122 GPS marked teepee pole stands and 76 treatment exclusions from the BIA forestry department on the MATL. Teepee pole stands were GPS located by tribal members, medicine men, and tribal foresters. Marking crews marked teepee pole producing stands with red paint and polygons were established from the marked areas. The areas that were marked with red are excluded from silvicultural treatment to preserve teepee pole. GPS locations of teepee pole stands and treatment exclusions were then mapped using ArcMap 10.4.1.

Teepee Pole Stand Classification

We obtained 4 band NAIP aerial imagery from REGIS, current as of 2010. The 4 band imagery is necessary to conduct this project because the first 3 bands are in the visible spectrum Red, Green, and Blue while the 4th band is in near infrared spectrum. This allows us to delineate between features on the landscape such as coniferous and deciduous trees. 4 band NAIP imagery also allows us to create a Normalized Difference Vegetation Index (NDVI) layer. The creation of this layer allows for the compensation for different amount of incoming light and produces numbers between -1 and 1.

By quantifying how much visible and near-infrared light is reflected off the surface of plants, one can measure the “greenness” of the vegetation, to which an index value can be assigned. For example, a value of 0.5 indicates dense vegetation, whereas values less than zero imply no vegetation (Sonwalkaret al., 2010)

We conducted a texture analysis which essentially allows us to distinguish the magnitude, pattern, color, and shape of variability within the image (Di Cataldo & Ficarra, 2017). This layer produces a good image of separation between forested areas with shadows and crowns to flat areas such as grass lands. From the 4th and 2nd bands we ran Focal Statistics and set our neighborhood settings to 7x7 pixels, which is about the average size of a mature tree in a 1 meter resolution image. We then used the raster calculator tool to find an average between the two layers.

With layers the 4 band imagery, NDVI, and texture, we then were able to run the following classification tools: Unsupervised ISO Cluster, Supervised ISO Cluster, and Maximum Likelihood. ArcMap grouped raster cells with similar multispectral values and created 50 classes. 50 for the purpose of this study is too fine scaled to distinguish teepee pole producing stands from the rest of Mescalero’s forested areas. We ran focal statistics using the treatment exclusions as training site. Running focal statistics on treatment exclusions allow us to see which cell values are most commonly found in teepee pole producing stands. Understanding which cells commonly found in teepee pole producing stands reduces allows us to reclassify our 50 classes and getting rid of unneeded cell values.

RESULTS AND DISCUSSION

The results from conducting the image classification can show us general areas of where teepee pole producing stands might be. Conducting the first ISO-Cluster classification using 50 classes (Figure 2) it can be seen that regions in the central portion of MTAL contained pink, purple, and red colors. These are the areas of mixed conifer forest on MTAL. Areas with the blue and green were found to be low elevation woodland types of forest found on the eastern part of MTAL. The high elevation subalpine forest was classified as yellow, and red. This is the area of Sierra Blanca and can be seen in the northwestern part of MATL. Although Figure 2 describes the general features of the landscape on Mescalero it is not sufficient to distinguish between the surrounding forested areas and individual teepee pole stands.

In order to narrow down the number of classes to more specify our classification, zonal statistics was used to see which classes made up the majority of teepee pole producing polygons. The result of zonal stats showed us that there were 11 notable classes found in each teepee pole producing polygon which reduced our class number from 50 classes to 11. Reducing the 50 classes to the 11 most common classes found in teepee pole producing polygons from the first ISO-Cluster analysis, the final map (Figure 4) illustrates were all potential teepee pole producing stands can be located throughout the forested areas of MATL. The 11 most common classes were found most mainly in the central portion of MATL where the mixed conifer forest lie, in the southwestern portion of MATL, and the areas near Sierra Blanca. Although the final map (Figure 4) shows a more narrow area of potential locations of where teepee pole stands may be, the map still fails to show is where individual locations of teepee pole producing stands may be. Further classifications would be needed to delineate individual stands from the rest of the forested areas.

This section of the study attempted to classify specific areas on MATL where there are dense stands of teepee pole producing Douglas-fir excluded from silivicultural treatments scattered throughout the forested landscape. With remote sensing there are effective tools for extracting and mapping spatial information of land use and cover at different scales (Chen et al., 2017). With adequate information from ground data and from images, remote sensing allows us to effectively characterize specific features on the landscape. Remote sensing image data sources for earth monitoring programs can be advantageous when analysis of large land areas is desired and where other data sources may not have information on (Nordberg & Evertson, 2003). For instance, imagery is easily obtainable which allows for the production of up to date vegetation inventories over large areas with the help of satellite imagery (Xie et al., 2008).

Although remote sensing technology has improved greatly in recent years and has tremendous advantages in traditional methods for vegetation mapping, there should be a clear understanding of its limitations. Before attempting to utilize remote sensing, the objectives of the study should be clearly defined and a well-fit vegetation classification system should be carefully designed. This will allow for a better representation of actual vegetation community compositions when attempting to use imagery to classify features on a landscape. When classifying a complex landscape such as Mescalero's forested areas it is advised to have in depth existing knowledge of the area. Utilizing on the ground data with imagery will greatly improve the classification of the desired feature. Lastly, we advise that when conducting vegetation classification on large areas to using the data acquired from the same sources and applying the same processing methods for the entire region. This will improve the quality of the map and provide more accurate representations of actual features on the landscape.

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FIGURES

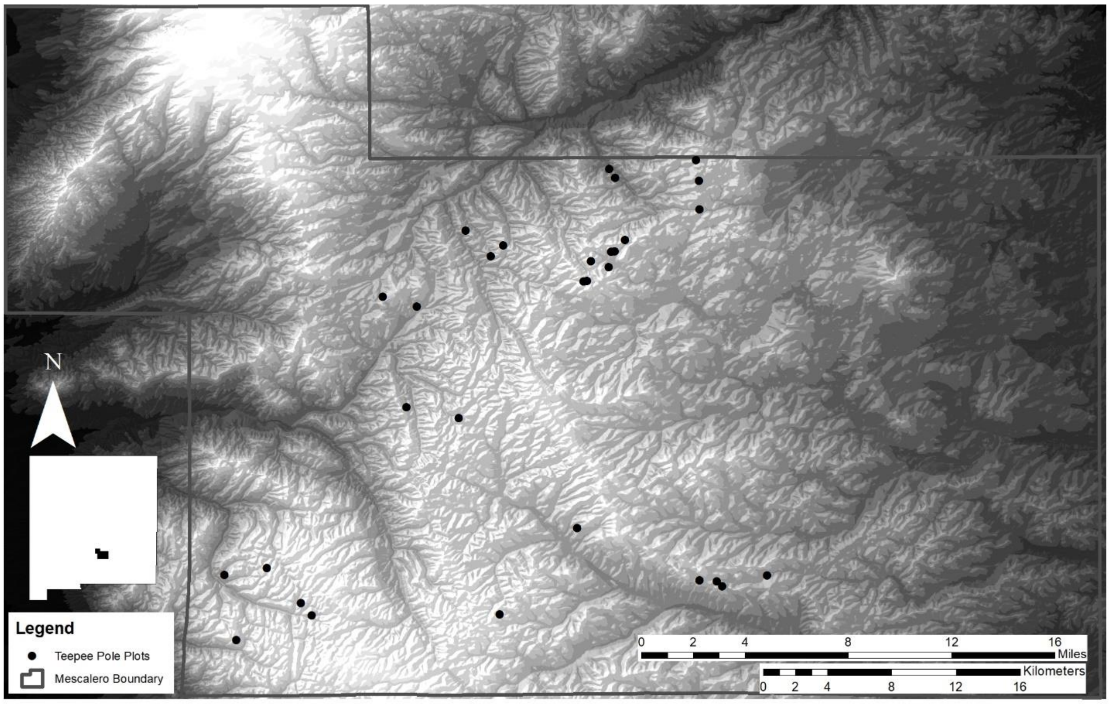

Figure 1. Mescalero Apache Tribal Lands reference map in New Mexico. Mixed-conifer forests are found in the central region of MATL. The highest elevation of the landscape, Sierra Blanca (11,981 ft/3,652 m), is at the northwest corner of the map.

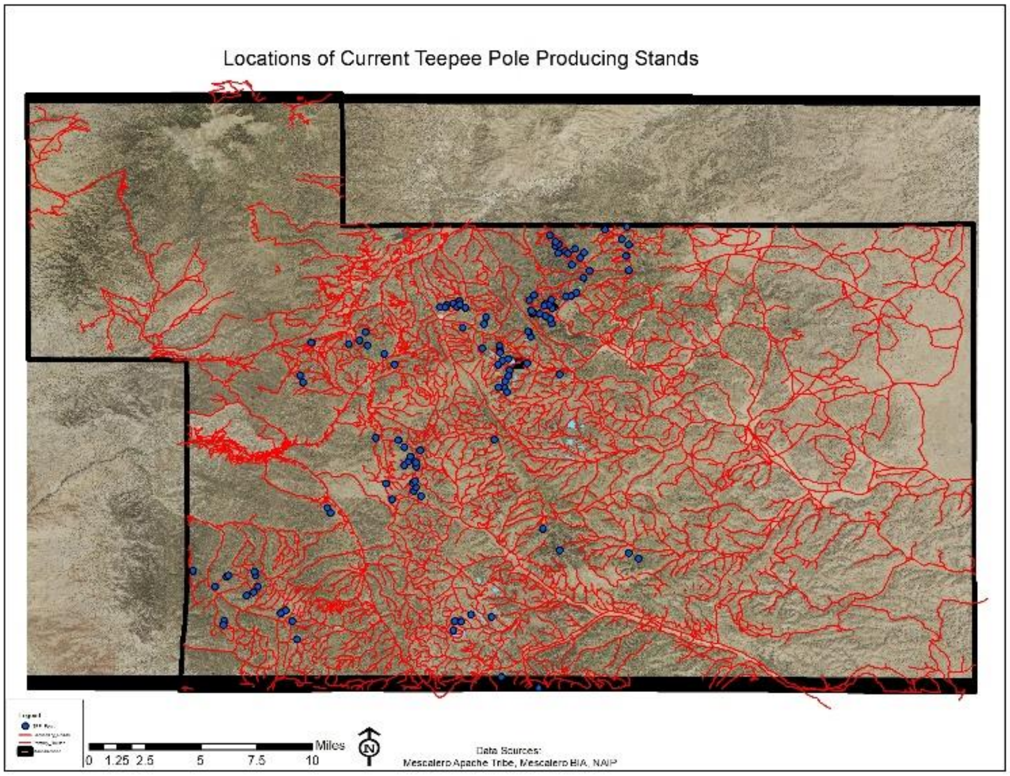

Figure 2. Map of 122 GPS points of teepee pole producing stands, 76 treatment exclusion zones for teepee pole producing stands.

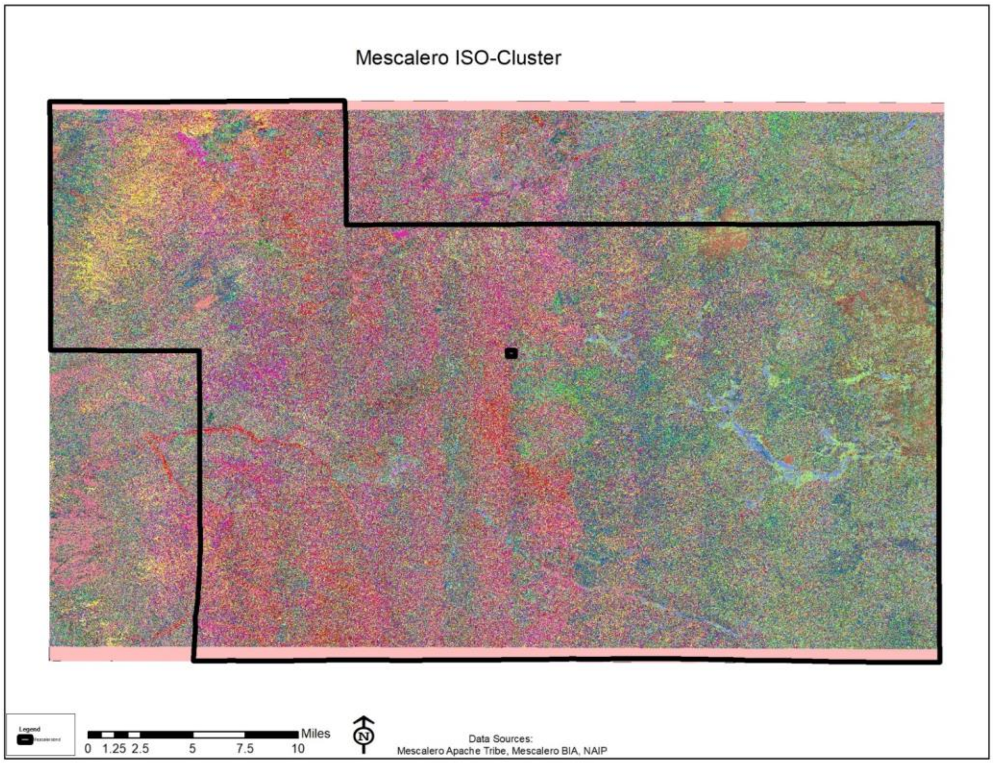

Figure 3. ISO-Cluster Analysis with 50 classes. The purpose of choosing 50 classes was because it best showed the amount of detail of the landscape while trying to minimize the amount of classes to be classified.

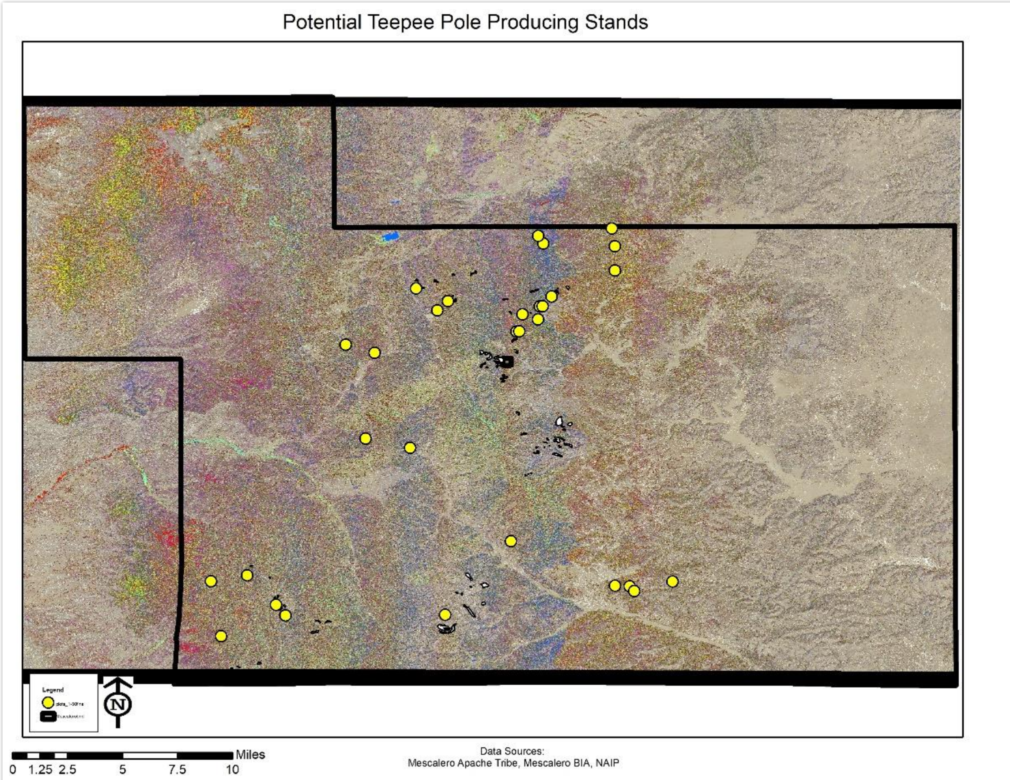

Figure 4. After reclassification of 50 classes with treatment exclusions as teepee pole stand training sites, from ISOCluster analysis, the final map shows 11 classes where all potential teepee pole producing sites. Product of this map is insufficient for determining where specific stands are located through MATL. Additional training sites are needed to produce a more accurate map of specific teepee pole stands.