

Reconstruction of Pinon-Juniper Forest Structure to Examine Historic Wildlife Habitat Characteristics in the Davis Mountains, USA

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Abstract

Changes in pinon-juniper (*Pinus* spp., *Juniperus* spp.) communities across the southwestern United States have often decreased ecological diversity of the understory and increases of exotic species. Reconstructing age and establishment patterns provides essential understanding to guide treatments and management for anthropogenically-altered forests. The goal of this study was to determine how patterns of pinon and juniper growth in the Davis Mountains, Texas, varied over time and how this pattern influenced wildlife habitat of several indicator species. Establishment patterns and basal area growth progression were identified, canopy cover estimates regressed from pre-developed canopy regression equations to re-construct historic forest stand structure and canopy characteristics in twenty-year intervals and applied to known wildlife habitat requirements of Montezuma quail (*Cyrtonyx montezumae*), black bear (*Ursus americanus*) and White-tailed deer/Mule deer (*Odocoileus virginianus*/*O. hemionus*). The sites provided habitat for these wildlife species, but the specific habitat provided changed over time. Prescribed burning could promote better forage for black bear while fire exclusion could improve dense cover for escape and denning cover. Montezuma quail would use thinner, less-dense habitats for forage, loafing and escape cover and the denser stand dynamics for cover and shelter. If forage habitat for Montezuma quail is required, the more open habitats found in the early 1900's could be re-established by prescribed burning and tree removal. Habitat for White-tailed deer transitioned from more open forage, loafing, fawning cover in the early 1900's to denser thermal, and escape cover in the later 1900's. Mule deer habitat transitioned from a preferred open habitat to a more dense cover habitat that would be utilized primarily for bedding. Prescribed burning and tree removal to open up the current habitat would benefit Mule deer and white-tailed deer to a lesser degree.

Keywords: David mountains; Stand dynamics; Wildlife; Habitat

Introduction

Pinon-juniper (*Pinus* spp., *Juniperus* spp.) forests were utilized for centuries by Euro-American settlers for firewood and other necessities. During the nineteenth century, timber was cut heavily to provide fuel and lumber for mining and ranching. Much of the woodlands, converted to rangelands, were subsequently overgrazed and then considered an insignificant natural resource. Pinon-juniper woodlands are now recognized as a unique and valuable natural resource to be managed [1], and the need to restore pinon-juniper communities to more historic and sustainable conditions have been emphasized [2,3].

Large changes in pinon-juniper communities across the southwestern United States have been reported, including decreased diversity and increases of exotic species, increased soil erosion and concomitant decreased site productivity. Modification of pinon-juniper communities for livestock grazing, fuelwood harvesting and industrial land use have also degraded portions of the pinon-juniper forest type [2,3]. Due to the natural aridity of the sites, pinon-juniper forests typically have low establishment success and biomass production. Expansion of pinon-juniper into adjacent ecotones, however, has been rapid. Areas of the Great Basin sagebrush communities have experienced up to ten times increase in pinon-juniper encroachment since the 1850's [4], and expansion of pinon-juniper into ponderosa pine and grassland ecotones in the Davis Mountains has been reported [5]. Pinon-juniper encroachment into ponderosa pine forest communities has also been noted with a subsequent reduction of understory plant biomass [6].

The contemporary status and long-term changes in structure, composition, and function of plant communities is needed to set and guide restoration goals, and age reconstruction studies can

provide a target point for restoration and management activities [5,7]. Reconstructing age, establishment and growth patterns provides essential understanding to guide treatments and management for anthropogenically-altered forests [3,8].

The Davis Mountains, part of a large cluster of sky islands, provides a unique ecosystem, full of biodiversity and genetic variation. The unique physiographic and climatic variations of sky islands allow layering of biological communities and altitudinal and aspect migration of species [7,9].

The Davis Mountains are characterized by a diverse group of endemic animal species from both the Madrean Archipelago and the Rocky Mountains [10]. White-tailed deer (*Odocoileus virginianus*) and Mule deer (*Odocoileus hemionus*) both utilize sympatric range in west Texas. Western Mule deer have historically exhibited unpredictable population fluctuations in west Texas. Preferred Mule deer habitat reduction has coincided with increased White-tailed deer habitat through the invasion of pinon and juniper into their habitats [11]. The

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Davis Mountains may provide quality habitat for Black Bear (*Ursus americanus*), an endangered species in the United States, as suitable habitat for foraging was found on the Davis Mountains Preserve [12]. Montezuma quail (*Cyrtonyx montezumae*) no, inhabits pinon-Juniper-oak woodland of west Texas [13,14]. Understanding historic forest stand structure may help provide a better understanding of pinon-Juniper woodland influence on all of these species of interest.

The overall goal of this study was to examine historical pinon-juniper woodland establishment and growth on The Texas Nature Conservancy Davis Mountains Preserve, and from there to infer historical wildlife habitat use.

The specific objectives of this study were to:

- Estimate establishment patterns and growth characteristics of pinon pine (*Pinus cembroides* var. *cembroides*) and Alligator juniper (*Juniperus deppeana*) in the Davis Mountains.
- Infer pinon-juniper establishment and growth patterns to management recommendations for four wildlife species identified as being of interest by researchers and managers of the Davis Mountains Preserve (Montezuma quail Black bear, White-tailed deer and Mule deer).

Methods

Site description

The Davis Mountains, located at the eastern edge of the Madrean Archipelago, are considered foothills between the Rocky and Sierra Madre Mountains of the United States and Mexico. The Madrean Archipelago encompasses two large and unique flora and fauna groups, and is located at the convergence of three major climatic zones: temperate, subtropical and tropical [10,15]. These sky islands, essentially island terrain created through the sequence of valleys and mountains, contain unique biotic communities separated by valleys which serve as bridges or blockades for new species.

The wide range of parent soil material (igneous extrusive, igneous intrusive, sedimentary and metamorphic) provide varying soil types. Mountains and slopes are characterized by shallow soils, while valleys have deep soils resulting from erosion of the mountains. The varieties of plant communities are largely influenced by the soil depths, structure, and texture [9,16]. Grasslands and ponderosa pine (*Pinus ponderosa*) are found in low and high elevations, respectively; while quaking aspen (*Populus tremuloides*) are found in the summits of the mountains. Mid-range elevations are dominated by pinon-juniper and oak (*Quercus* spp.) communities. Elevation is considered the primary determining factor for plant communities, but aspect, slope, and soil depth have created non-linear patterns [10,17].

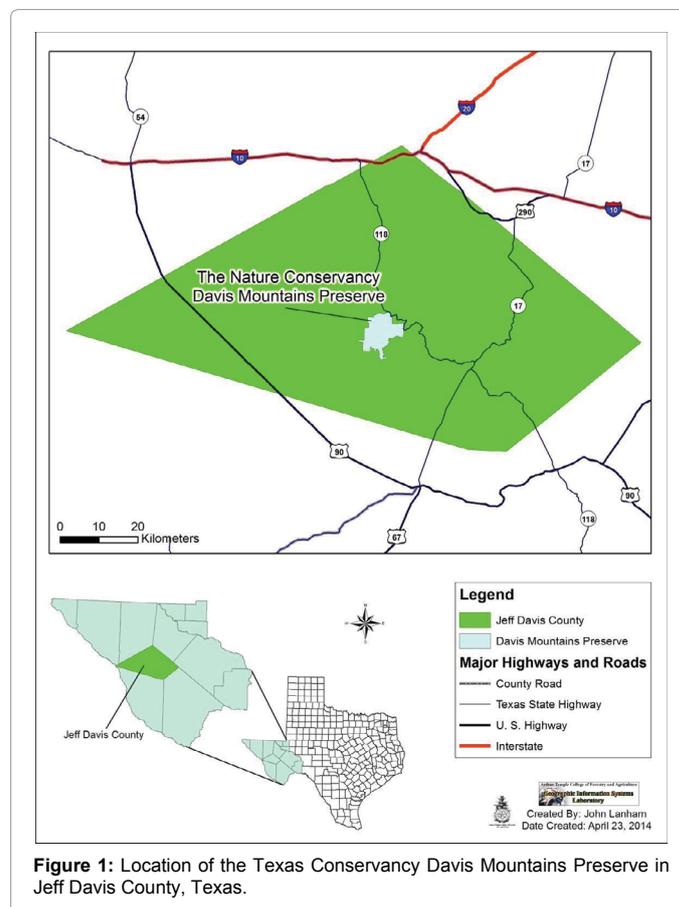
Three pertinent Rocky Mountain plant community designations have been assigned based on elevation and forest type: Encinal woodlands, pinon-juniper woodlands, and high elevation coniferous forests [17]. Encinal woodlands contain Emery oak (*Quercus emeryi*), gray oak (*Quercus grisea*), and silverleaf oak (*Quercus hypoleucoides*) and pine-oak woodlands of varying densities between 1,200 and 2,200 m above mean sea level (MSL). Closely associated pinon-juniper woodlands range from 1,370 - 2,290 m above MSL with Mexican pinon, Colorado pinon (*Pinus edulis*), single needle pinon (*Pinus californiarum*), Alligator juniper, red berry juniper (*Juniperus coahuilensis*), Utah juniper (*Juniperus osteosperma*), and rocky mountain juniper (*Juniperus scopulorum*).

The Nature Conservancy Davis Mountains Preserve was classified into 6 groupings: Ponderosa pine, oak-ponderosa pine, oak-pine, oak-Mexican pinon, Mexican pinon, and Alligator juniper [18]. Mexican pinon was found on moderate slopes and wetter sites, while Alligator juniper was found on dryer, steeper slopes. The difference in plant community classifications between [17] and [18] may be caused by the distance to source areas. The Rocky Mountains serve as a source area influencing the entire Madrean Archipelago, while the Davis Mountains sky islands are more influenced by the Sierra Madre Occidental [7].

Study sites

The Nature Conservancy (TNC) Davis Mountains Preserve (Figure 1) is in Jefferson County, TX, Temperatures are characterized by cool temperatures during the fall, winter and spring while summers are warm. Mean temperatures for the summer and winter are 27°C and 5°C, respectively, and mean annual rainfall for the area is 40.6 cm. Summer monsoons last from May-September and comprise two thirds of the annual rainfall per year [19]. Orographic lifting plays a large role on the precipitation in the mountains and influences location of vegetative communities.

The primary soil of the site is the Puerta-Madrone association, part of the Puerta soil series in the Alfic Lithic Argiustolls subgroup, and covers the greater portion of the study area [7]. Loghouse association soils, belonging to the loghouse soil series and Udic Haplustalfs subgroup, are found in the creek bottoms and stream channels. Other soils found in the area are MainstayBrewster, Rockhouse-Gageby, Liv-Mainstay-Rock outcrop, Sproul-Mainstay, Hurds-Friends, and Musquiz [19]. The resulting vegetation is diverse, with



overstory often consisting of ponderosa pine, Mexican pinon, Emory oak, gray oak, silverleaf oak, and alligator juniper. Sideoats grama (*Bouteloua curtipendula*), bulb panic grass (*Panicum bulbosum*), pinon ricegrass (*Piptochaetium fimbriatum*), longleaf cologania (*Cologania angustifolia*), and Catclaw mimosa (*Mimosa aculeaticarpa*) can be found in the herbaceous understory [18].

Sampling sites were selected randomly from within a collection of suitable locations, chosen subjectively but without preconceived bias based on vegetation, slope, elevation and aspect [20]. Four sites (Figures 2 and 3), were chosen with separate characteristics (slope, elevation and aspect) so as to best represent the breadth of the site characteristics within the Davis Mountain Preserve.

Field sampling

Overstory vegetation was identified to species level and diameter at breast height (1.37 m) measured to the nearest 0.1 cm, and any trees greater than 15.0 cm dbh were cored at the base of the tree and root collar diameter (RCD) (nearest 0.1 cm) and total height (nearest 0.1 m) measured. A sub-sample of 15 trees (less than 15.0 cm dbh) per species per diameter class (0.1-1.0, 1.1-2.0, cm etc.) was taken, cross sections were collected from trees less than or equal to 5.0 cm at dbh and cores obtained on all trees greater than 5.0 cm. Similar to the large tree samples, RCD, total height and bark thickness were recorded for each tree in the sub-sample. GPS was used to mark all tree locations.

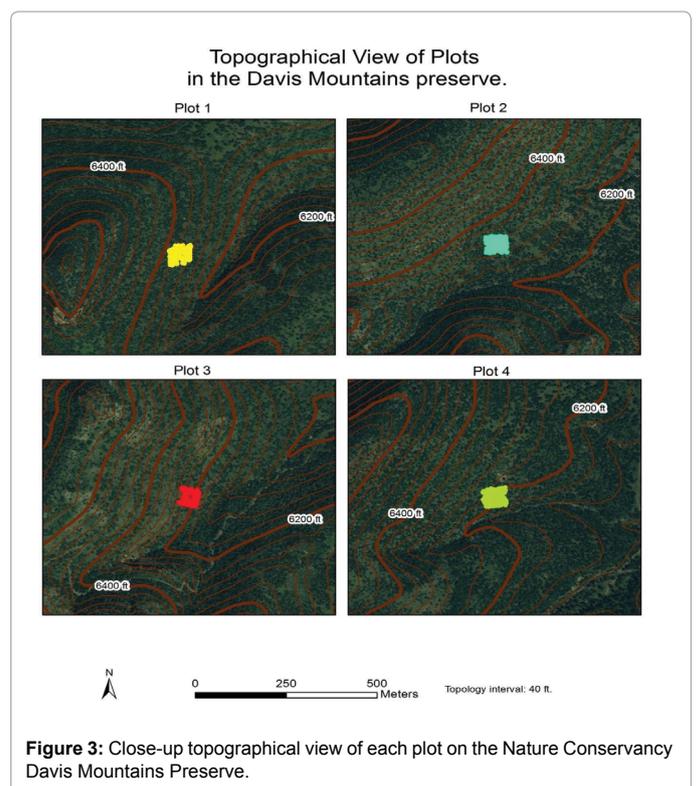
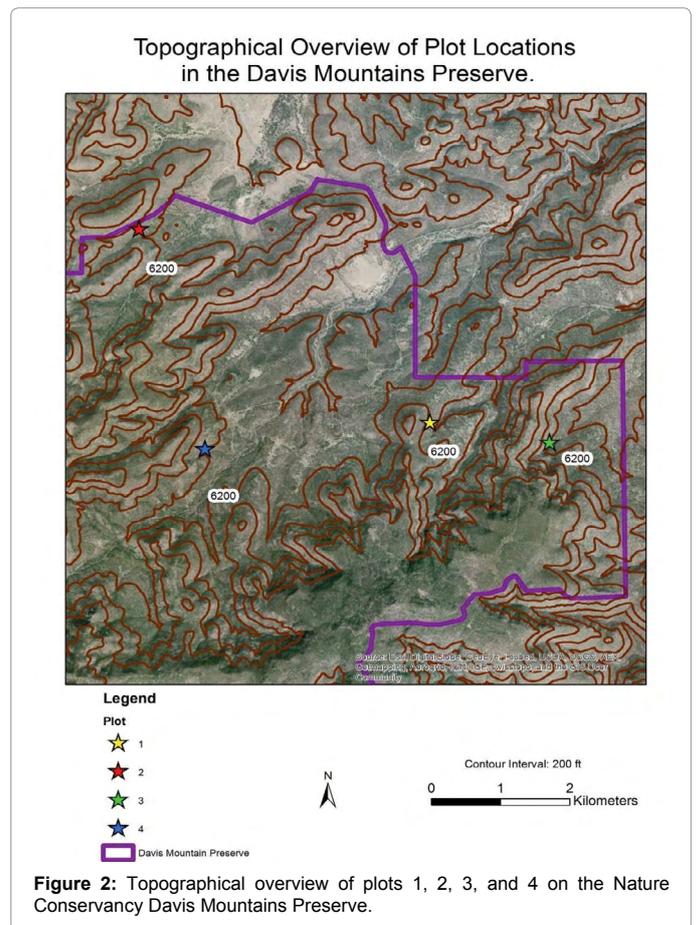
Dendrochronology

Annual growth of the pinon and juniper were measured to the nearest 0.001 mm using WinDENDRO and Velmex TA System[®]. Two plots were processed through dendrochronology software and analyzed using the measure J2X software in conjunction with a Velmex TA measuring system. Two more plots were processed and analyzed using WinDENDRO. As a result of the species' tendency to have too many false and missing rings [21], junipers were visually compared by two lab technicians instead of being crossdated. Oak trees were not cored due to frequent heart rot found within the oak species. A list of species used in tree-ring research and a suitability ranking for crossdating and research showed that the pinon pine was suitable to compare between sites within one region while the juniper has no previous crossdating information recorded or no crossdating suitability was expressed during previous investigations [22].

Pinon pine cores processed with WinDENDRO were crossdated to confirm correct dating within each plot using a cross dating feature. WinDendro uses the "Gleichlaufigkeit sign test" to measure the growth correlation coefficient. Due to the slow growth habits and tendency to form missing rings in pinon pines, the minimum targeted correlation coefficient was set at 60%. Trees were divided into 10 cm diameter classes for "group" comparison. The three clearest growth cores from each group were then averaged to create the reference data line that each core from that group was compared to. For any dead trees or stumps within the plots, the outermost ring on the sample was considered the death or cut date.

On the trees less than 15 cm basal diameter that were not sampled, a regression equation was created based on the growth of all the other trees to simulate and fill in the growth for them based on their diameter.

Crown diameter regression estimations utilizing root collar diameter (RCD) were used to calculate historical canopy estimations. Diameter at breast height has shown a higher correlation than RCD with crown canopy [23]; however, historical growth data for this study



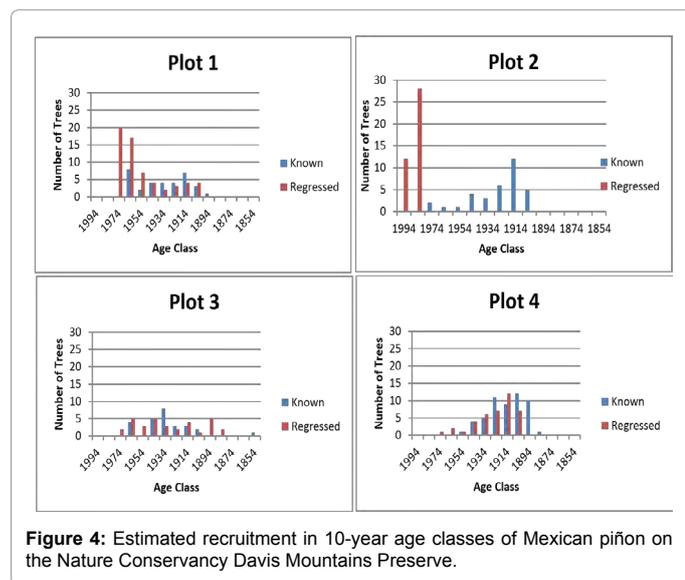


Figure 4: Estimated recruitment in 10-year age classes of Mexican piñon on the Nature Conservancy Davis Mountains Preserve.

is based on RCD as both equations used for canopy cover utilized RCD. Canopy cover for the Juniper was estimated using regression derived from a pinon-juniper woodland in Arizona [21] with a similar forest species makeup.

$$\text{Crown area} = (0.68 + 0.96 \text{ RCD} - 0.01 \text{ RCD}^2)^2$$

Canopy cover for the pinon was estimated using a regression was derived from a pinon-juniper woodland in Los Alamos, New Mexico with similar forest species characteristics [24].

$$\text{Crown Radius} = 0.065 \text{ DAB} + 0.10$$

These equations do not take into account the canopy overlap of trees that are near each other, overtopped or suppressed, but estimates the canopy area of each tree without effects of other canopies nearby.

GIS analysis

Arc GIS 10.1 with Python 2.6 coding to program a loop was used to create a time lapse of the diameter growth and regressed canopy growth of all the trees within each of the plots. Estimated canopy cover was examined with the time lapse data to estimate wildlife habitat availability and characteristics on the sites.

Simple Kriging was used to analyse spatial pattern diameter distribution to identify potential gaps and gap sizes for wildlife use based on the known and estimated diameters of the trees on the plot. Based on the assumption that larger trees have larger canopies, potential area of dense canopy or gaps, as well as the identification of areas with lower height canopies based on clusters of smaller diameter trees was identified.

Results

Density, growth and establishment

Plot 4 had the highest total number of trees (Table 1). Juniper comprised nearly 50% of the trees on plot 4 and 2 while plots 1 and 3 only had 15 to 20% junipers. Pinon was more evenly distributed, comprising about 30% in each of the plots. Oak trees ranged from 50% of the trees in plot 1 to 24% of the trees in plot 4.

The establishment dates and growth data gaps for the >15 cm

diameter trees were filled using regression equations created from the known growth data of the sites by species. Relationships between yearly growth, DBH and RCD were examined similarly [17], establishment equations for each species were created and then tree growth estimates were developed by dividing the age by the growth constant (Table 2). Plot 3 growth did not match the other plots close enough to use the same regression formulas. Pinon known growth exhibited very fast growth in the smaller diameter trees and very slow growth in the larger diameter trees. The regressed smaller diameter pinon trees exhibited extremely slow growth, while the larger diameters were extremely fast growing; causing inaccurate predictions with the regression formula. To correct this, a special regression equation for plot 3 was created (Table 2).

Regression equation accuracy could not be assessed by the R^2 value because the linear regression lines were forced across the X-Y point of origin to conform to zero root collar diameters at year zero. A visual bar graph was used to compare the regression predicted ages to known ages of similar diameter classes. While trees do not exhibit exactly even yearly growth, the examination periods were expanded into 20 years periods and a mean yearly growth increment was applied to an estimate of tree growth.

A wide variety of establishment trends for each species within different plots were identified, reflecting both site conditions and possible climatic conditions over time that influenced the species differently (Figures 4 and 5).

Canopy

Canopy estimates for both known and regressed pinon and juniper data expanded from the early 1900's to 2004 (Table 3; Figures 6-9). Plot 1 had the least estimated canopy cover while plot 4 contained the most. Plots 2 and 3 had similar estimated canopy cover.

Spatial autocorrelation and spatial interpolation

All plots exhibited non-random clustering in 2004 (Tables 4 and 5). Plot 1 was evenly spaced from 1904 to 1964, and then switched to a clustered classification in 1984. Plot 2 switched from evenly spaced in 1904 and 1924 to clustered from 1944 to 1984. Plot 3 transformed from evenly spaced (1904-1944) to clustered in 1984. Plot 4 has remained clustered since 1924.

The spatial interpolation of historic and contemporary stand basal tree diameters indicates a steady growth and expansion of the trees into the open spaces across all plots (Figures 10-18). Plots 1 and 3 maintain the most open stands throughout the study. Of the four plots, plot 4 appears to have the most even tree diameter distribution across the plot.

Stand structure

Trees in plots 3 and 4 (Table 2) showed a hump-like diameter distribution of two diameter classes. The height of the pinon juniper also indicated a minimum of two cohorts, the short trees being the younger cohort and the larger trees the older cohort. The tree density of plots 3 and 4 were comparable to other sites in northern Arizona and east central Mexico [7,8,25]. Plots 3 and 4 were located on a south-east facing slopes of 15.1-30 degrees. Lower elevations, steeper slopes inclination, and a south-east aspect provide less favourable conditions for tree establishment and growth than compared to other aspects, slopes and elevations.

Plots 3 and 4 showed a presence of at least two cohorts: an initial or

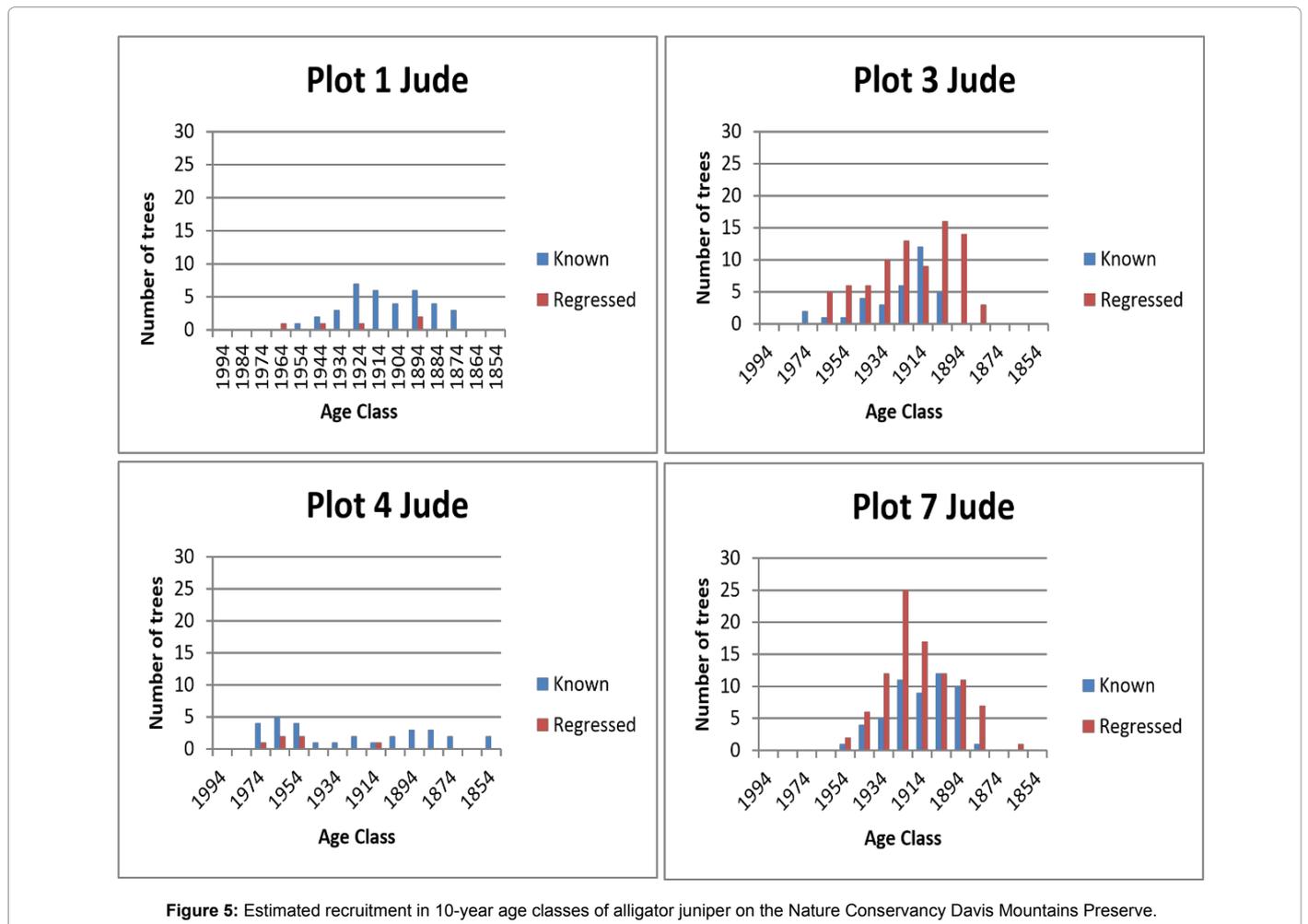
	Plot 1			Plot 3			Plot 4			Plot 7		
	Count	Percent	Trees/HA									
Juniper	41	14.49	114	116	43.77	322	38	22.89	106	166	48.12	461
Piñon	98	34.63	272	79	29.81	219	60	36.14	167	96	27.83	267
Oak (combined)	144	50.88	400	70	26.42	194	68	40.96	189	83	24.06	231
Dead count	18	6.36	50	29	10.94	81	12	7.23	33	27	7.83	75
Total trees	283		786	265		736	166		461	345		958

Table 1: Tree count and tree percentage of trees by species in the Nature Conservancy Davis Mountains Preserve.

Plot	Species	Age since Establishment	Growth Rate (cm)
1	Piñon	$RCD \times 4.9350$	Age $\div 4.9350$
	Juniper	$RCD \times 5.4023$	Age $\div 5.4023$
2	Piñon	$RCD \times 4.9350$	Age $\div 4.9350$
	Juniper	$RCD \times 5.4023$	Age $\div 5.4023$
3	Piñon*	$RCD \times 5.9337$	Age $\div 5.9337$
	Juniper*	$RCD \times 4.4384$	Age $\div 4.4384$
4	Piñon	$RCD \times 4.9350$	Age $\div 4.9350$
	Juniper	$RCD \times 5.4023$	Age $\div 5.4023$

*Based on individual plot data for equation.

Table 2: Establishment year regression equations and annual growth rate calculations for Piñon and Juniper on The Nature Conservancy Davis Mountains Preserve.



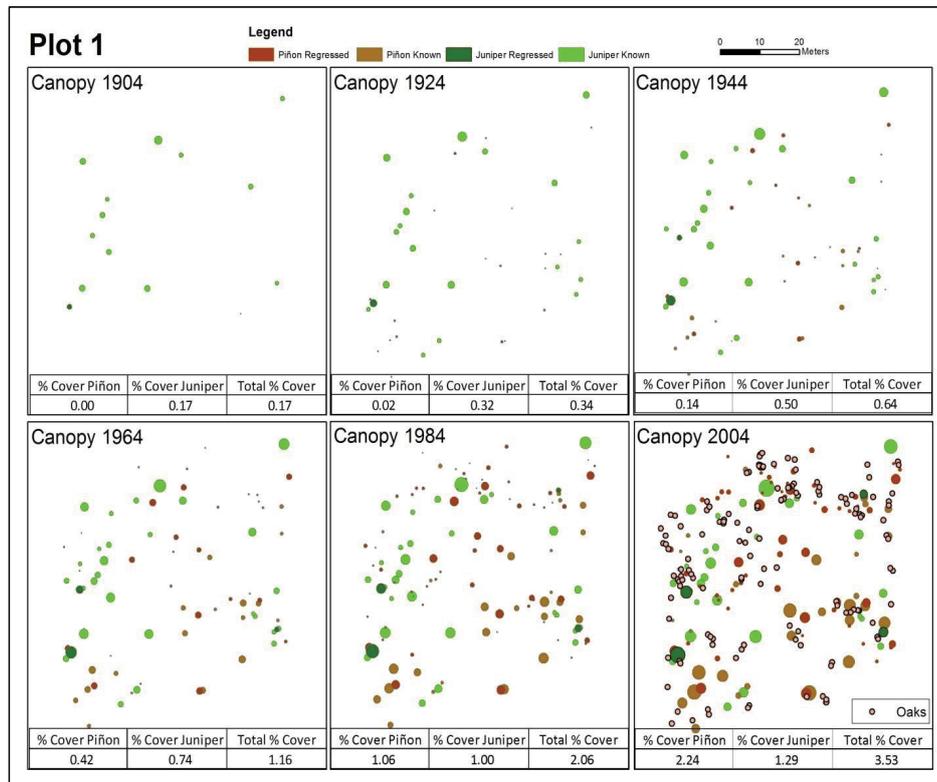


Figure 6: Plot 1-time lapse of the estimated canopy cover of alligator juniper and Mexican piñon from of 1904 to 2004 with oak tree locations included in 2004 on the Nature Conservancy Davis Mountains Preserve.

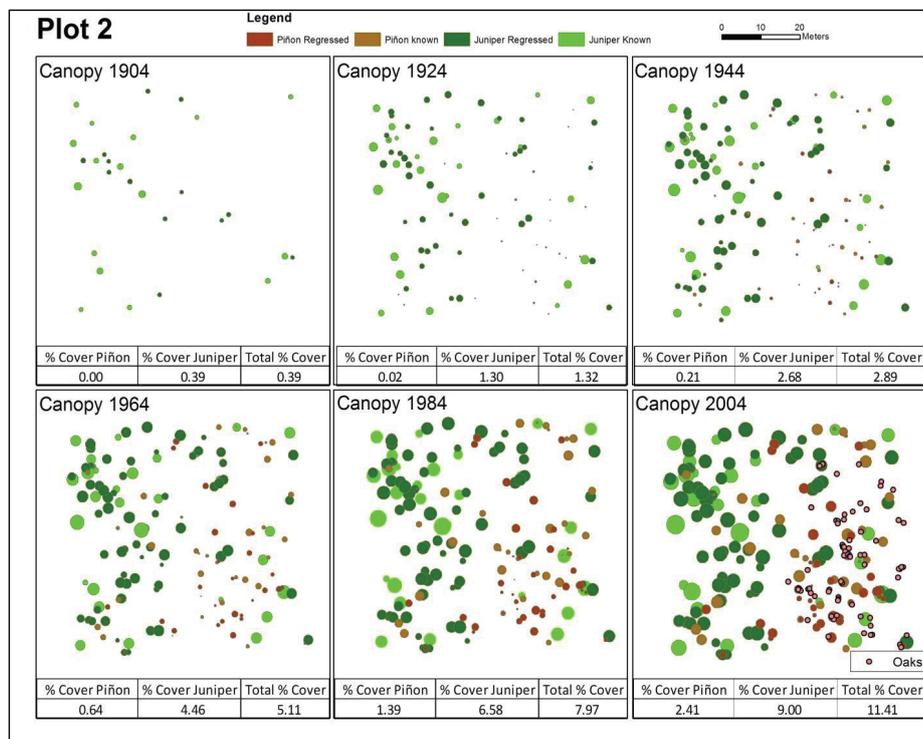


Figure 7: Plot 2-time lapse of the estimated canopy cover of alligator juniper and Mexican piñon from of 1904 to 2004 with oak tree locations included in 2004 on the Nature Conservancy Davis Mountains Preserve

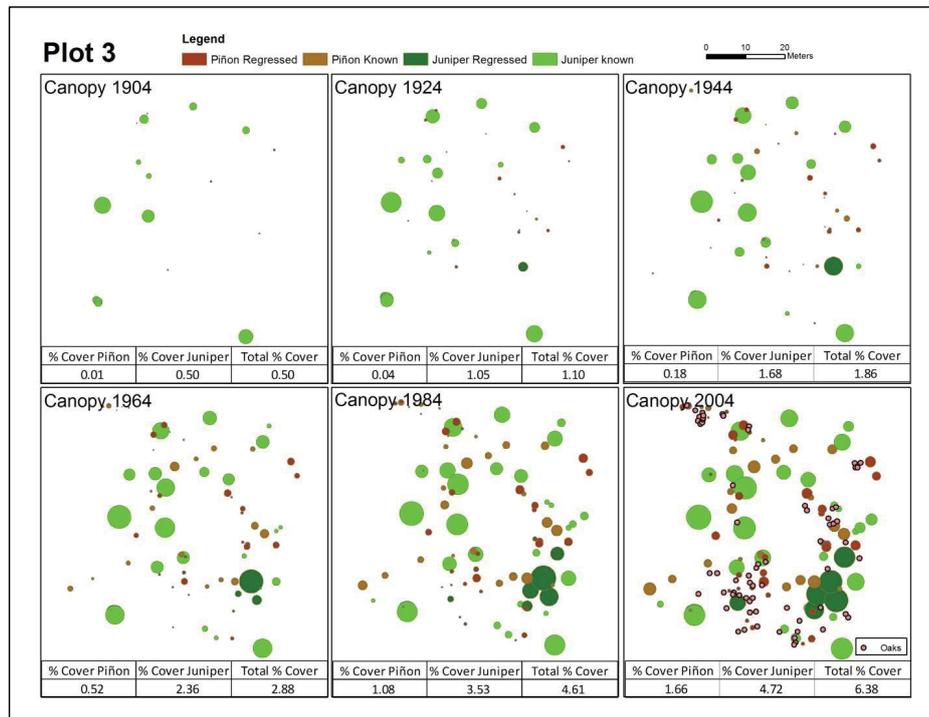


Figure 8: Plot 3-time lapse of the estimated canopy cover of alligator juniper and Mexican piñon from 1904 to 2004 with oak tree locations included in 2004 on the Nature Conservancy Davis Mountains Preserve.

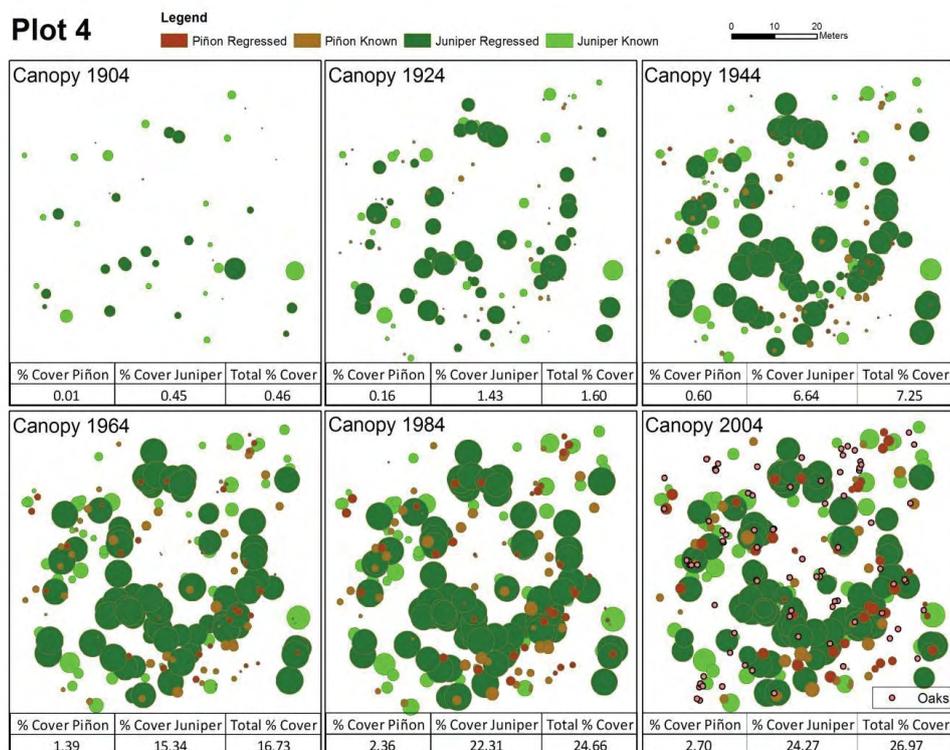


Figure 9: Plot 4-time lapse of the estimated canopy cover the alligator juniper and Mexican piñon of 1904 to 2004 oak tree location included in 2004 on the Nature Conservancy Davis Mountain Preserve.

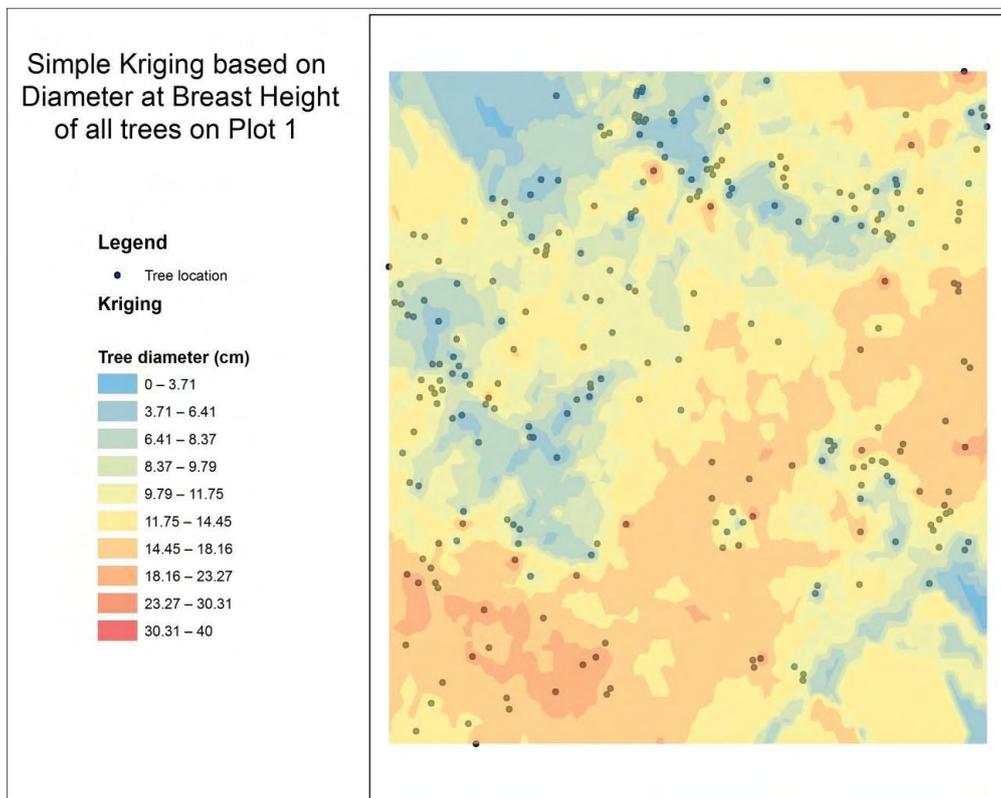


Figure 10: Simple Kriging of estimated and contemporary Mexican piñon, alligator juniper and oak diameters (DBH) on Plot 1 in 2004

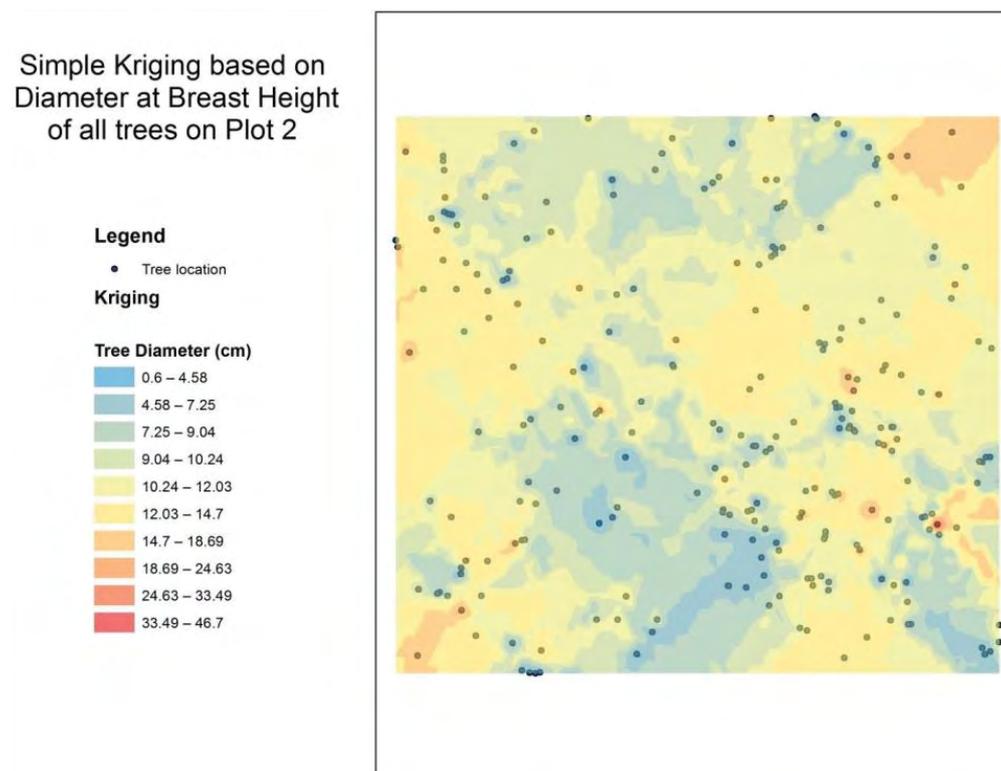
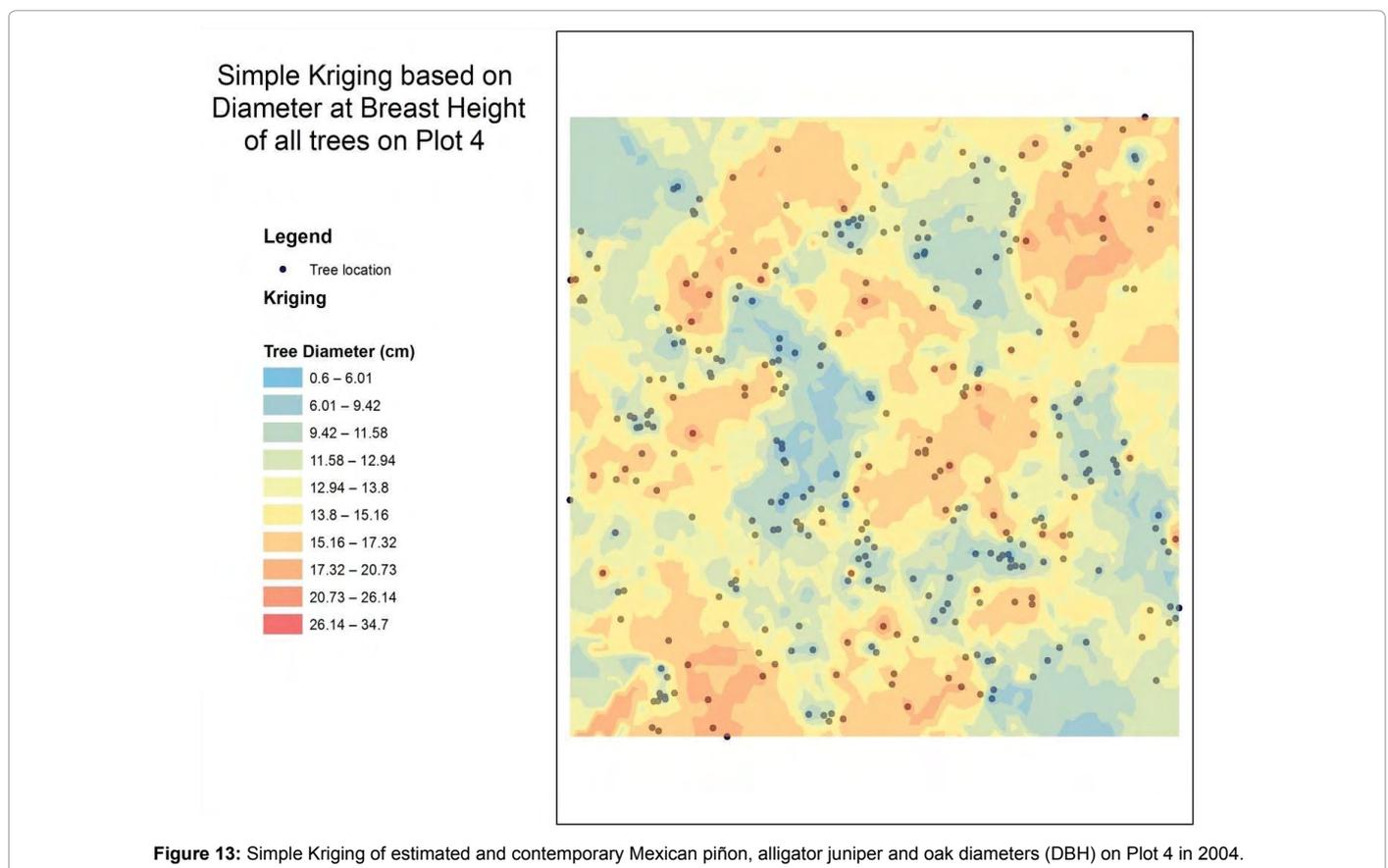
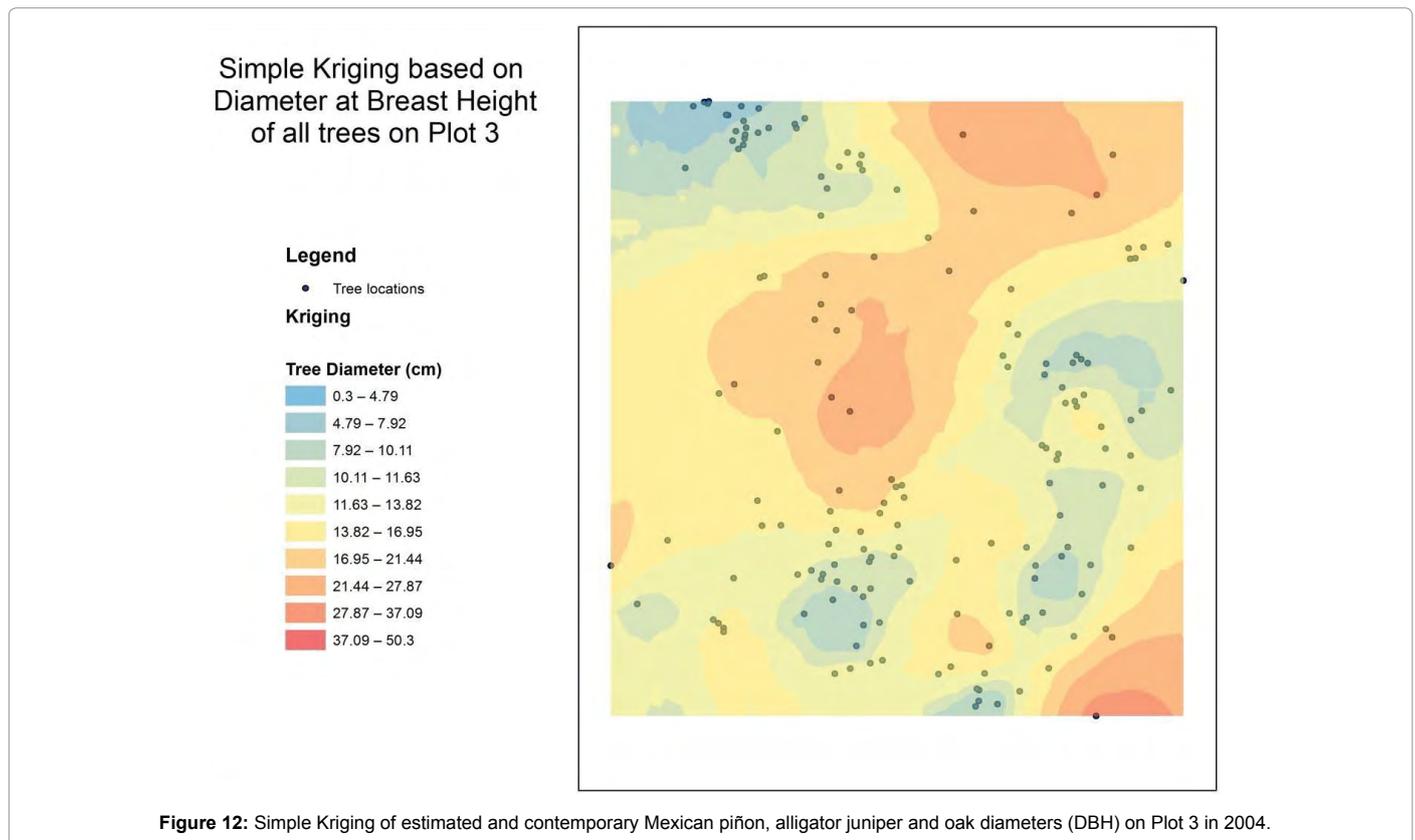


Figure 11: Simple Kriging of estimated and contemporary Mexican piñon, alligator juniper and oak diameters (DBH) on Plot 2 in 2004.



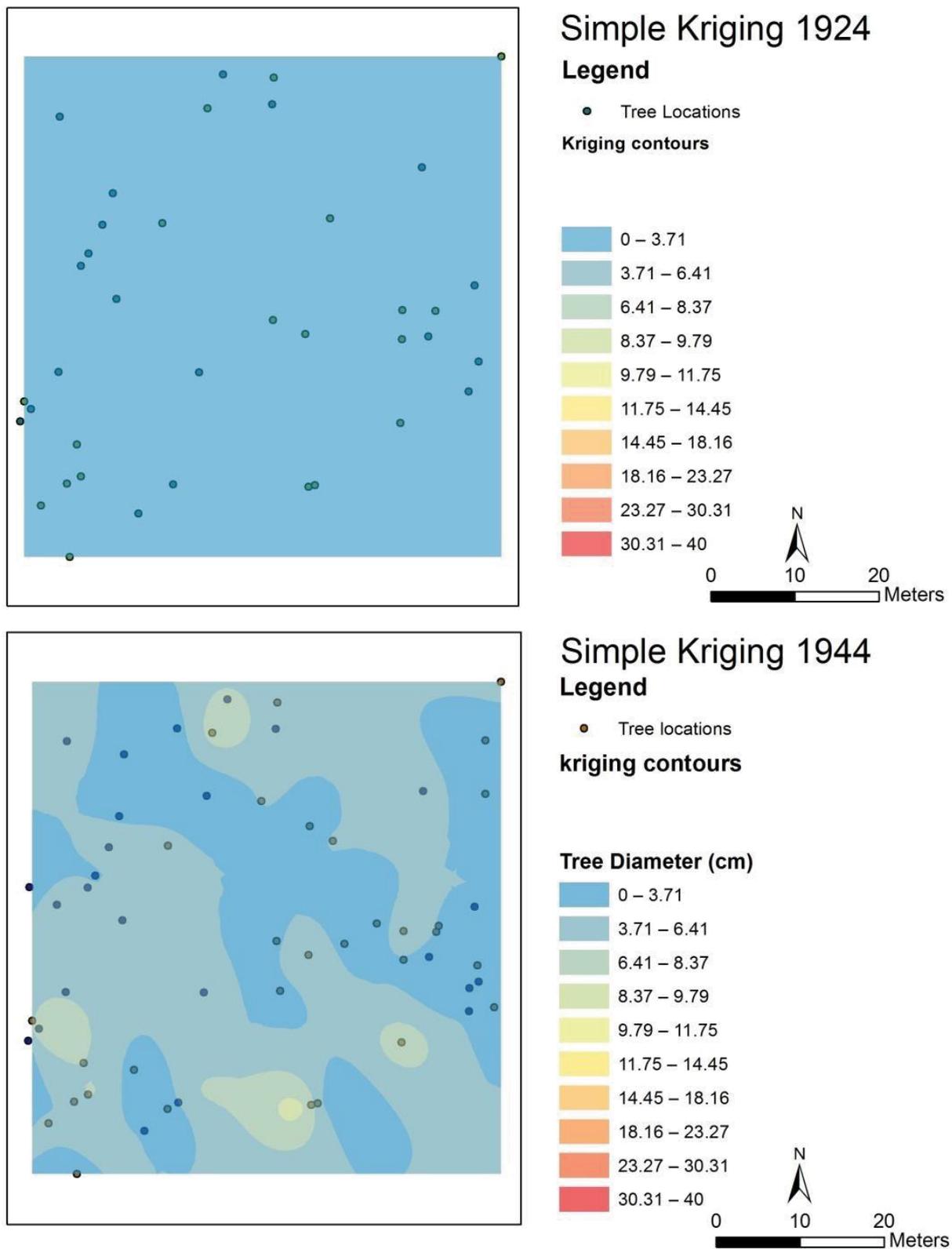
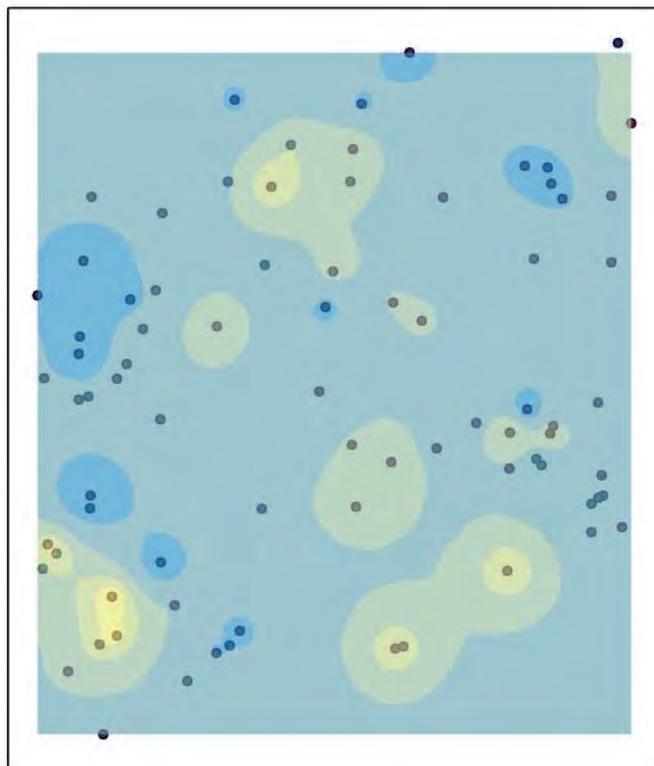


Figure 14: Simple Kriging of estimated and historical Mexican piñon and alligator juniper diameters (DBH) on Plot 1 in 1924 and 1944.



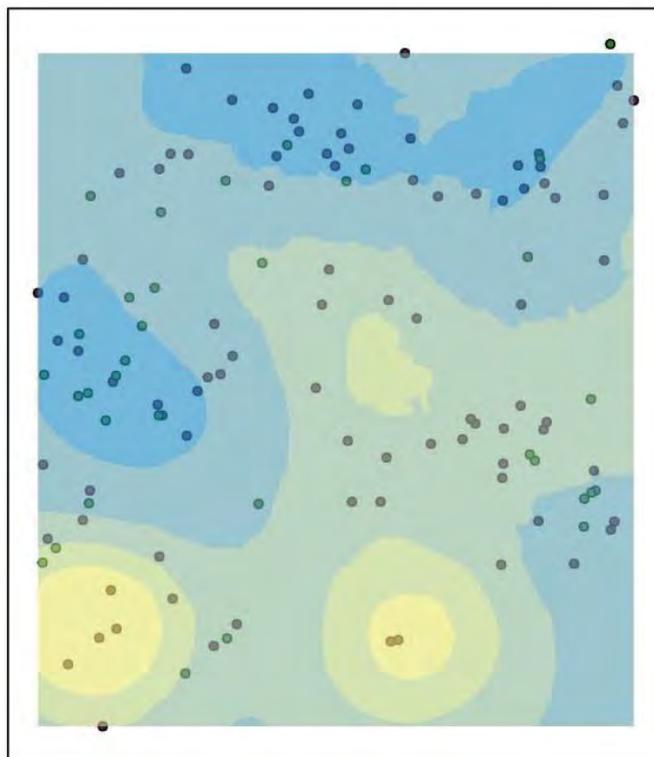
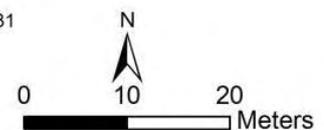
Simple Kriging 1964

Legend

• Tree location

Kriging Contours

Tree Diameter (cm)



Simple Kriging 1984

Legend

• Tree Location

kriging contours

Tree Diameter (cm)

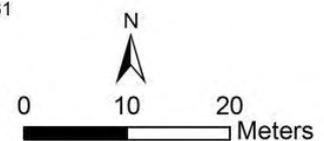
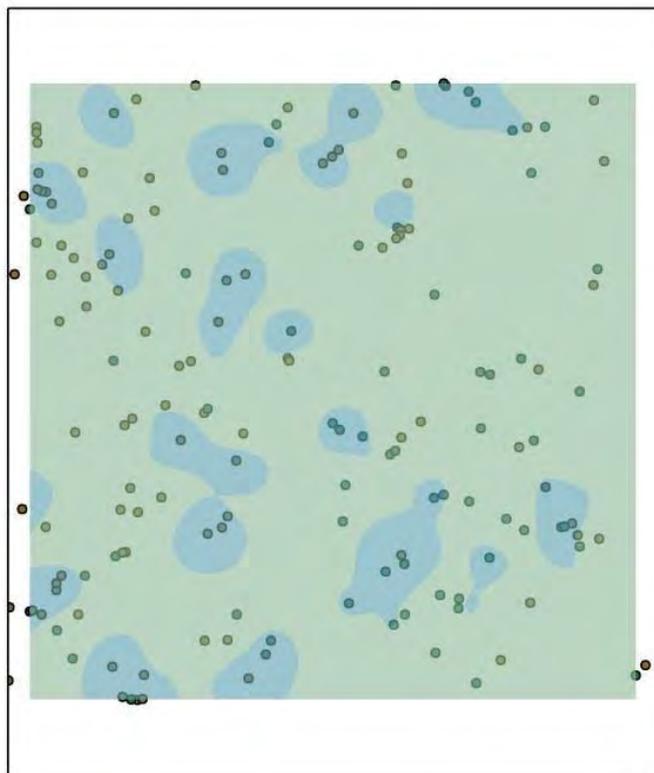


Figure 15: Simple Kriging of estimated and historical Mexican piñon and alligator juniper diameters (DBH) on Plot 1 in 1964 and 1984.



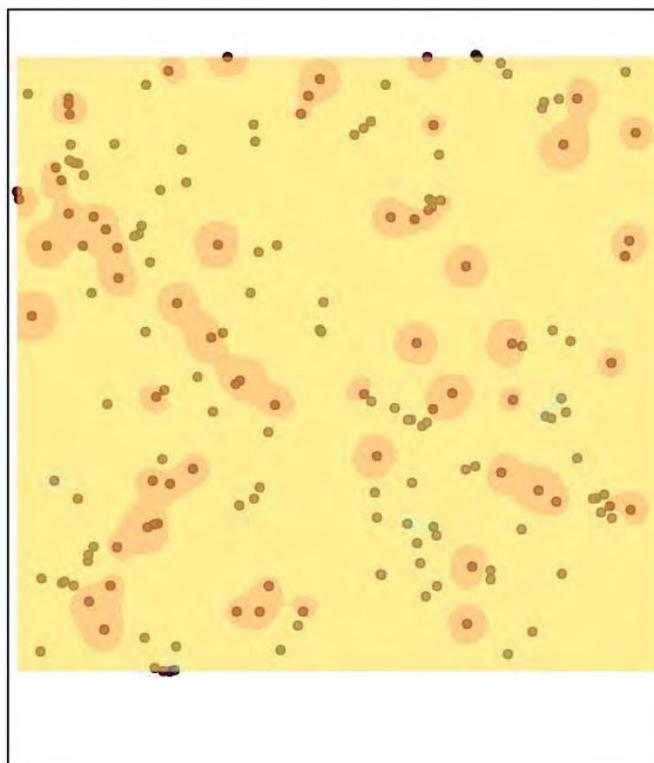
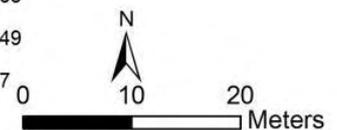
Simple Kriging 1964

Legend

- Tree location

Kriging contours

Tree Diameter (cm)



Simple Kriging 1984

Legend

- Tree location

Kriging contours

Tree Diameter (cm)

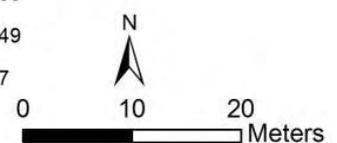
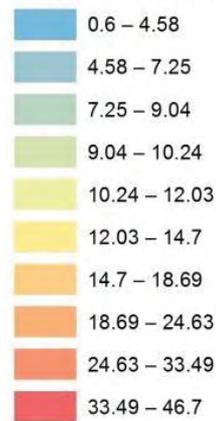


Figure 16: Simple Kriging of estimated and historical Mexican piñon and alligator juniper diameters (DBH) on Plot 2 in 1964 and 1984.



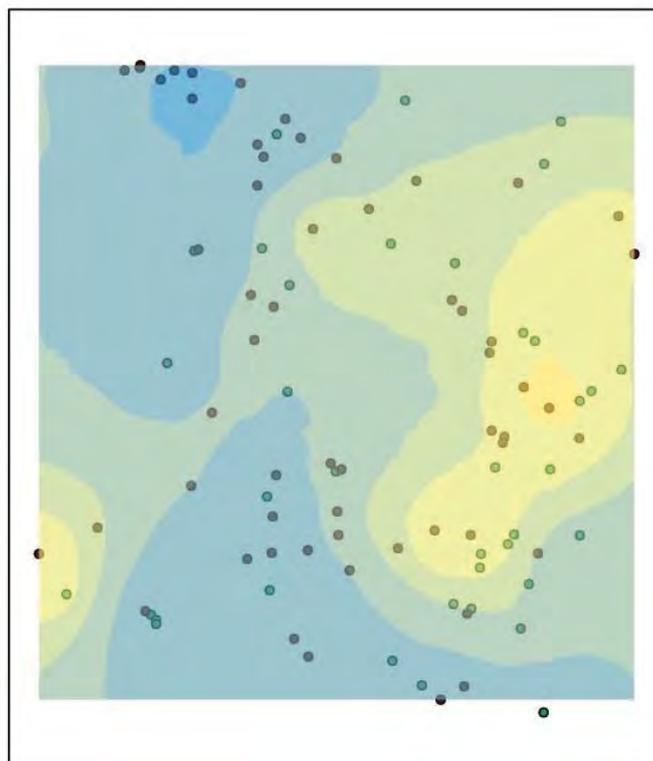
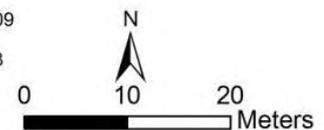
Simple Kriging 1964

Legend

● Tree location

Kriging contours

Tree Diameter (cm)



Simple Kriging 1984

Legend

● Tree location

Kriging Contours

Filled Contours (cm)

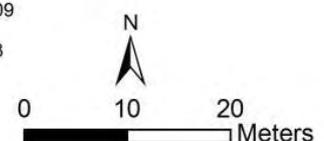


Figure 17: Simple Kriging of estimated and historical, Mexican piñon and alligator juniper diameters (DBH) on Plot 3 in 1964 and 1984.

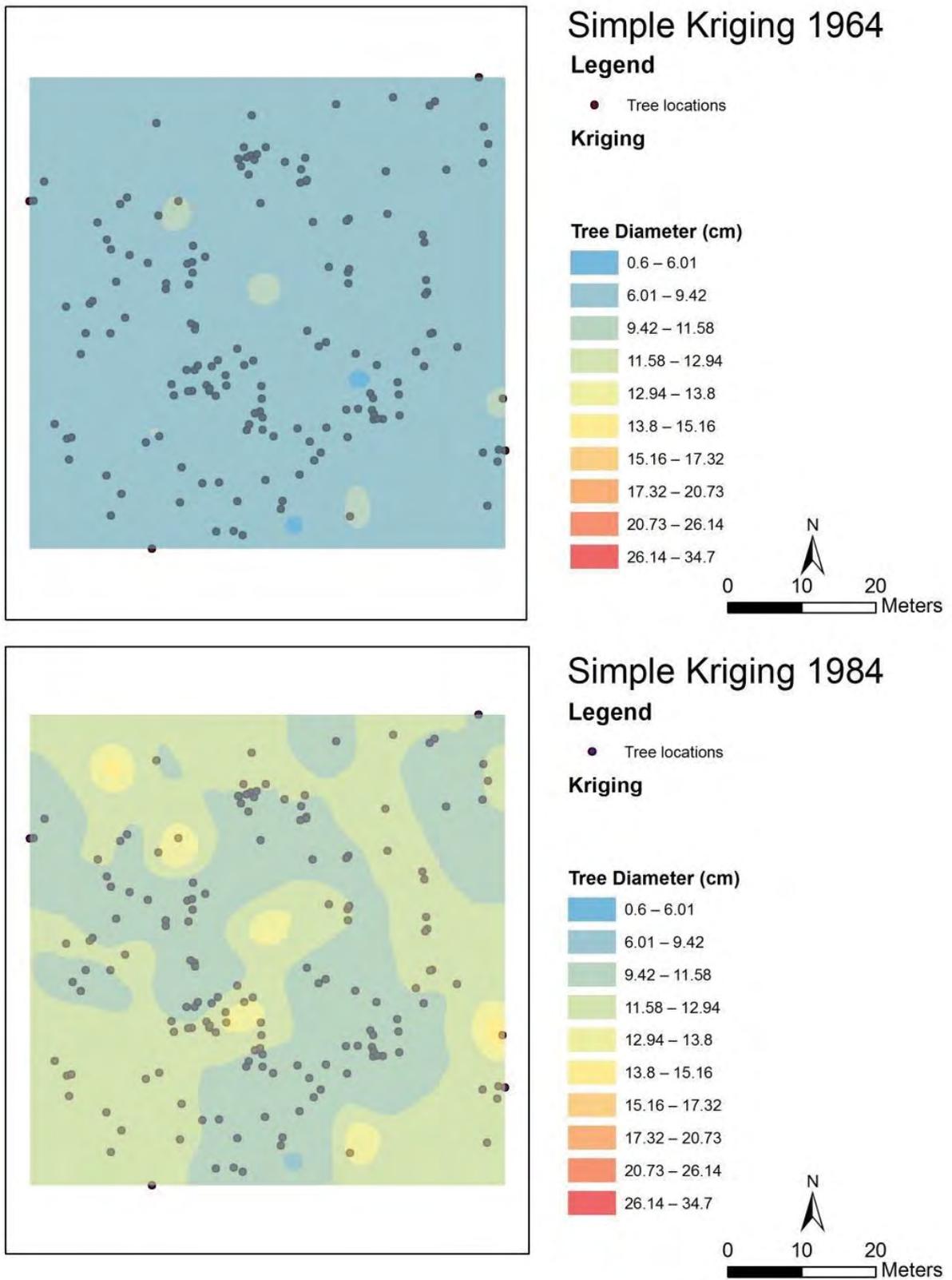


Figure 18: Simple Kriging of estimated and historical Mexican piñon and alligator juniper diameters (DBH) on Plot 4 in 1964 and 1984.

remnant alligator juniper cohort followed up by a mixed pinon juniper secondary cohort. Two cohort scenarios may exist: the initial scenario where the encroachment of alligator juniper in an open area, and the remnant scenario as a result of regeneration through disturbance. The initial scenario would be successful with greater seed longevity, better drought stress tolerance, and use of shallow soil moisture by pinon and juniper. The remnant cohort scenario would best fit with a disturbance regime that coincides with the establishment of nearby Fort Davis in 1854. The pinon juniper would be used by the fort for lumber and fuel wood. The secondary cohort responds to substantial recruitment between 1890-1949. Recruitment for both pinon and juniper were seen, however, alligator juniper recruitment extended longer than pinon by 20 years.

Discussion

Vegetation establishment and growth

One issue that influenced estimating establishment and yearly growth and canopy was false or missing rings, and including or not including either effected the estimations of both establishment and yearly growth. Another was even growth/circular growth rings, including out-of-centre pith where the tree exhibits greater growth on one side of the tree than the other, creating an oval shaped ring. Both pinon and juniper were found to have abnormal growth rings while performing the dendrochronology analysis.

Tree recruitment in plots 1 and 2 peaked between 1910 and 1920. The juniper regression estimates for plots 1, 2 and 4 when compared to the known growth data appear to simulate the diameter growth for plots 1 and 2 but plot 4 juniper diameter growth estimates appear to slightly overestimate the diameter growth. Using the growth regression equation based on all sites on plot 3 resulted in the small diameter trees to be significantly older than the larger diameter. Because the RCD growth for the canopy estimates was based on age, it would have also of overestimated the canopy cover of the trees, resulting in a separate growth estimation equation based solely on plot 3 known growth data.

Variation in growth may have been caused by a host of natural influences. A maximum of 4.8 km (3 mi) separates the four sites. Within this separation, soils vary greatly in soil type and soil depth, which may influence tree growth. Precipitation often vary within this distance as the monsoonal rains summer thunderstorms release greatly varying rain amounts over small areas. While elevation and slope are similar for all plots, the distance to the peak above the plot will affect the amount of precipitation run-off and overland flow the plot receives (Figures 1 and 2). The plots located lower or midway up a slope (plots 2, 3 and 4) are going to receive more overland flow than a plot located nearer the top of a slope (plot 1). The surrounding stand structure, especially above the plots, may also affect the stand structure within the plots. The more forested landscape above plots 1 and 4 will likely absorb more moisture than the areas above plots 2 and 3, while also, during heavy rains, seeds may also be washed down slope, influencing the plant stand structure below. The low mean yearly rainfall and rocky and sandy loam soils combine to make micro-aspect an important factor.

Canopy

Juniper exhibited almost double the canopy cover of pinon in 2004 across all plots except plot 1, which was about even (Table 5). This is likely a result that plot 1 initially started with a higher ratio of pinon to juniper, whereas plots 2 and 4 started with a significantly larger amount of juniper than pinon. The estimated canopy diameters for

pinon in this study were similar to pinon canopy diameters previously reported [24]. Plots 1 and 2 average juniper crown diameters were more similar than plots 3 and 4 average crown diameters. This is likely because of the originally overestimated growth diameters during the growth regression. Oak tree canopy estimations cannot be estimated as dendrochronology could not be utilized and no canopy estimation equations were found. Alligator juniper and grey oak were responsible for the highest canopy cover in similar cover types on the Davis Mountains Preserve [12]. As oak trees make up from 24% to 50% of the trees on the plots, it is important to remember that pinon and juniper trees do not provide the only canopy cover.

Wildlife

Black bear

During the spring and summer grasses and soft mast producers may be utilized by bears, especially where there is less canopy cover. Pinon juniper may be utilized by bears for forage, especially during the autumn [26,27] as hard mast is mostly available then, as well as the [27] as acorns play a large role in providing energy rich starch that enable wildlife to survive through winter.

Bears consider several ecological factors when selecting a denning site. Canopy cover, slope aspect, and available forage all play a role in den sites. The steeper slopes among the four selected sites among the Davis Mountains Preserve fall within the slope range selected by bears in similar habitat in Arizona [26], where bears selected slopes primarily ranging between 20 and 40% slopes, but selected pine-oak woodlands for den sites in Arizona only 5% of the time, preferring chaparral cover types between 1,000 and 1,800 m elevation 90% of the time. This denning preference may primarily be a result of spring forage availability. In pine oak woodlands green up occurs later and bears must travel, upon exit from the den, for forage.

Montezuma quail

The elevation of the plots within this study (1,900 to 2,000 m above MSL), are above the elevation range where Montezuma Quail were found (between 1,738 and 1,838 m) in the Davis Mountains [14], similar to results in Arizona [28,29]. Canopy cover for Montezuma quail has been considered a fundamental habitat requirement [30-32]. Plots 1, 2 and 4 may fit optimum habitat recommendation of 30% canopy cover if the oak trees are taken into account [31], as [30] reported that Montezuma quail selected areas ranging from 26-50% tree canopy cover and used areas with up to 50% cover when available, so recommended a minimum of 26% canopy cover be maintained in pinon-juniper oak communities in the Madrean Archipelago.

Montezuma quail rely on their cryptic coloration to avoid detection by staying motionless when predators are near, so there has to be enough horizontal cover as well as vertical cover for the birds to hide. It has been recommended a visual obstruction of up to 50 cm might improve non-detection from aerial predator's 51%-75% grass canopy to ensure optimum cover availability for Montezuma quail a height of 20 cm [30]. All plots provide the grass canopy recommended; however, the earlier years of the time lapse (1904 to 1964) would potentially have much more grass canopy than later years.

Montezuma quail are dependent upon perennial bunch grasses for escape and thermal cover. In ungrazed habitats, Montezuma quail select areas with tall bunch grasses on north facing hillsides for day use and roosted on southeast facing slopes at night [28]. All four plots were on southeast facing slopes, and these sites may primarily be utilized

Juniper						
Plots	Canopy cover (m ²) for Known Basal Diameter		Canopy cover (m ²) for Regressed Basal Diameter		Total Estimated Canopy (m ²)	Total Estimated Canopy (m ²)/Ha
	1884*	2004	1884*	2004	2004	2004
1	75.4	299.1	3.0	105.8	404.9	1124.7
2	16.7	31.4	30.0	1852.0	1883.4	5231.7
3	57.3	1069.3	0.3	14.3	1083.6	3010.0
4	57.4	1829.8	90.9	4064.6	5894.4	16373.3

Piñon						
Plots	Canopy cover (m ²) for Known Basal Diameter		Canopy cover (m ²) for Regressed Basal Diameter		Total Estimated Canopy (m ²)	Total Estimated Canopy (m ²)/Ha
	1904**	2004	1904**	2004	2004	2004
1	1.7	191.6	1.5	242.7	434.3	1206.4
2	1.5	211.0	6.7	216.8	427.8	1188.3
3	2.9	151.5	4.0	159.1	310.6	862.8
4	0.7	262.6	0.7	262.6	525.2	1458.9

*Five of the eight plots were base year 1884, plots 1 and 2 juniper regressed base year was 1904, plot 4 juniper regressed base year was 1924.

**Five of the eight plots were base year 1904, Plot 3 piñon known base year was 1924 and plot 4 piñon known base year was 1884. Plot 3 piñon regressed base year was 1924

Table 3: Estimated canopy cover of piñon and juniper trees based on known and regressed basal diameter on 60 by 60 m plots on the Nature Conservancy Davis Mountains Preserve.

Plot	Species	Of tree	Observed mean**	Expected Mean***	r ²	Z Score
1.	Oaks	144	1.46	2.64	0.00	-9.96
	Pinon	98	2.80	3.18	0.03	-2.24
	Juniper	41	4.46	4.50	0.92	-0.10
	Cumulative	283	1.46	2.64	0.00	-9.96
2.	Oaks	70	1.54	2.22	0.00	-4.92
	Pinon	79	2.86	3.07	0.25	-1.15
	Juniper	116	2.48	2.75	0.05	-2.00
	Cumulative	265	1.42	1.81	0.00	-6.46
3.	Oaks	68	2.13	3.18	0.00	-5.20
	Pinon	60	3.32	3.35	0.88	-0.15
	Juniper	38	4.93	4.39	0.15	-1.44
	Cumulative	156	1.85	2.14	0.00	-3.33
4.	Oaks	83	2.87	3.17	0.10	-1.65
	Pinon	96	2.98	3.10	0.46	-0.75
	Juniper	166	1.98	2.37	0.00	-3.97
	Cumulative	345	1.68	0.79	0.00	-7.25

*Indicates a calculated Z outside the range of critical Z values (-1.96 Z critical \geq 1.96) for an Alpha level of 0.05 and thus a spatial pattern that is significantly different from that expected by an independent random process.

**The actual calculated distance between the trees

***The expected distance between trees if they were non-randomly clustered

Table 4: The observed, expected, r square, and Z score for mean nearest neighbour distance of trees for contemporary Mexican piñon, alligator juniper, oak and cumulative.

as roost sites by Montezuma quail. The open spots within the plots may provide the bunch grasses preferred by Montezuma quail. Since perennial bunch grasses that Montezuma quail use for cover are warm-season species, hiding cover is most limited during the spring.

Montezuma quail feed on subterranean bulbs and tubers of several forb species, sedges (*Cyprus* sp.), wood sorrels (*Oxalis* sp.), acorns, cultivated grains, and insects [13,14]. The lower slopes within these plots where sediment deposits and deeper soils remain may provide the softer soils for digging and scratching for tubers. If oak trees influence the use of a site [28], plots 1 and 3 provide the most oak trees. While all plots provide areas of patchy, very dense cover, plots 2 and 4 provide the most dense semi-even cover of the plots.

Montezuma quail select areas near larger trees, with greater canopy cover and tree species richness [30]. While all four plots contain oak trees, plots 1 and 3 may be preferred by Montezuma quail if nesting

sites are influenced by larger oak trees [29].

White-tailed deer and mule deer

The historic (1904-1944) open forest / canopy estimation of this study suits Mule deer habitat better than White-tailed deer. The contemporary denser canopied forest of modern times (1964 to present) suits Carmen Mountain Whitetailed deer better. Carmen Mountain White-tailed deer have been found distributed, near areas with free standing water, and areas of dense juniper oak vegetation [11,33]. In the Chisos Mountains, Carmen Mountain White-tailed deer were plentiful over 1,400 m above MSL; our study site ranged from 1,900 m-2,000 m above MSL). Non-spatial distribution of Mule deer has been attributed to forage and microclimatic factors. Habitat use may also depend on the diversity of plants and bed sites within the nearby wash systems [34,35].

Plot	Year	Number of trees(n)	Observed mean**	Expected Mean***	r ²	Z Score
1.	1904	14	9.40	6.89	1.36	2.61
	1924	39	4.69	5.64	1.01	0.13
	1944	57	3.99	3.84	1.04	0.56
	1964	79	3.52	3.42	1.03	0.48
	1984	123	2.55	2.78	0.92	-1.76
2.	1904	29	5.87	5.09	1.15	1.58
	1924	90	3.38	3.01	1.12	2.26
	1944	140	2.34	2.41	0.97	-0.68
	1964	169	1.89	2.20	0.86	-3.52
	1984	182	1.77	2.12	0.84	-4.21
3.	1904	17	8.38	5.84	1.43	3.42
	1924	33	4.45	4.22	1.05	0.60
	1944	50	4.06	3.75	1.08	1.13
	1964	75	3.13	3.12	1.00	0.03
	1984	95	2.69	2.81	0.96	-0.75
4.	1904	44	4.82	4.37	1.10	1.30
	1924	129	2.49	2.68	0.93	-1.56
	1944	219	1.79	2.08	0.86	-3.94
	1964	246	1.63	1.97	0.83	-5.17
	1984	250	1.62	1.95	0.83	-5.17

*Indicates a calculated Z outside the range of critical Z values (-1.96 Z critical \geq 1.96) for an Alpha level of 0.05 and thus a spatial pattern that is significantly different from that expected by an independent random process.

**The actual calculated distance between the trees

***The expected distance between trees if they were non-randomly clustered.

Table 5: The observed, expected, r square, and Z score for mean nearest neighbour distance of trees for estimated historic Mexican piñon, alligator juniper by plot.

Deer activity is dependent on many factors such as season, temperature, forage availability, microclimate and physiological factors [34]. While Carmen Mountain White-tailed deer don't truly migrate; they were found to use lower elevations in winter and higher elevations in summer. This may be in response to the distribution of browse and forbs during the winter and summer months [36]. All four plots have sufficient wooded and open areas for annual forb growth to provide browse and mast that deer could utilize.

The probability of summer use of the plots as bedding sites by both Mule deer and Carmen Mountain White-tailed deer is low because both species utilize north, east and west facing slopes due to the cooler temperatures and less thermal heat absorbed during the day [33,36]. During winter, the plots may have a little better chance to be utilized as bedding sites because the southeast facing slope may provide better wind protection from cold north winds and be warmer during the daytime.

The slopes of the research plots (15.1° to 30°) fall within the range found to be utilized by Carmen Mountain White-tailed deer [33,36]. Mule deer were found to prefer low slopes and dry washes [34], so the lower slopes or wash areas of the study sites in the Davis Mountains may be utilized by Mule deer for bedding. Plots 2 and 4 provide the densest pinon-juniper cover and may be utilized for winter bedding. Plots 1 and 3 are more open, yet have tree clusters which may provide the best summer shade cover but still allow a cool breeze to pass through. All four plots in this study have oak trees. Plots 1 and 3 have the highest percentage of oak trees on their plots and therefore may see the most use by both Mule deer and Carmen Mountain White-tailed deer in the fall. Both Mule deer and Carmen Mountain White-tailed deer will browse on the leaves and buds of oak trees and therefor also provide needed forage during the spring and winter when available forage is reduced.

Deer are abundant in regions where forage species density and diversity is high (especially high plant diversity for Mule deer), cover from afternoon sun is available, perennial springs are present and daytime temperatures are not severe [34,36]. Woody browse

and buds could be found on all four sites. Plot 4 should provide the highest amount of woody browse based on the density of trees on the site; however, plots 1 and 3 may provide more preferred browse due to their higher oak tree percentages. This is an important as browse makes up for 35% of a Carmen Mountain White-tailed average yearly diet and 50% of a Mule deer's yearly diet [33,34,36]. In August and September, plots 1,2, and 3 may become more important than plot 4, as a pronounced dietary switch to forbs occurs after the summer rains [36].

During late June and early July, does nearing term will seek brushy mountainous habitat with slopes ranging from 15% to 30%. All four plots qualify for fawning ground based on slope, but lacked the cover needed for cover and shelter in the 1904 and 1924 canopy estimates. Starting in the 1944 canopy estimation through current conditions, plot 4 provided dense pockets of cover required for safe hiding and escape cover from predators for fawn survival. Plot 2 lacked multiple pockets of dense cover for fawns until 1964 and should have provided suitable cover through the 2004 estimation. Plot 1 canopy estimations show the pinon juniper stand to be open with few pockets of trees through all estimations causing this location to most likely not be utilized for fawning habitat. Plot 3 lacked the cover needed for fawns until 1984 and 2004.

Conclusions

All plots changed from being primarily open canopy in 1904 with large space between trees to a much denser forested landscape in 2004. Large variability among plots, possibly due to high microsite variability and total number of trees and percent trees by species varied greatly between plots. Due to this, canopy cover estimations also varied.

While the sites may be utilized by bear as foraging areas, denning by bears is less likely to occur. While the steeper sloped plots fit the slopes found to be utilized by bears, they have been found to prefer a lower elevation (1,000 to 1,800 m above MSL) to den. Soft mast production may be increased by performing some prescribed burns in the area to encourage and increase forb and low level soft mass production. Prescribed burns would also increase grass and forb production

which are important food sources for bears exiting hibernation in spring. Increasing tree thickets for summer and winter thermal shelter would also be beneficial. Fire exclusion of patches or clumps of trees, especially, clusters of young or smaller trees will encourage the growth of the thickets for shelter. While Montezuma quail are typically found in the forest types and habitats similar to those found in this study, they have been found to prefer lower elevations (1,700 to 1,800 m above sea level) than where these plots occur (1,900 to 2,000 m above sea level). All sites may be utilized by both species of deer; however, the current thick timber lends itself to the dense cover preferred by Carmen Mountain White-tailed deer. Prescribed burning will improve forb production for forage, maintain a more open understory and prevent encroachment of woody species into the open pockets within the plots providing better open understory summer thermal cover. Maintaining a more open understory would be preferred by Mule deer. Maintaining and increasing the number of denser pockets of timber is important for providing winter thermal cover and escape cover for both species of deer, while allowing the plots to be denser would be more beneficial to the Carmen Mountain White-tailed deer.

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