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Journal of Arid Environments 69 (2007) 458–472

Journal of Arid Environments

www.elsevier.com/locate/jaridenv

Woody vegetation expansion in a desert grassland: Prehistoric human impact?

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Received 2 June 2006; received in revised form 24 October 2006; accepted 25 October 2006
Available online 12 December 2006

Abstract

Woody plant encroachment into grasslands and savannas is a global phenomenon with undisputed environmental and economic consequences. In central Arizona, the location of our study, it is well known that mesquite, juniper, and cacti account for the majority of the woody plant expansion into arid grasslands. Using aerial photographs (1940 and 2001), we quantified an increase in woody vegetation in this area. We estimated that from 1940 to 2001, the amount of woody vegetation at our study site increased from 559.7 ha (6.1% of the area) to 1326.6 ha (14.4%); an increase of 766.9 ha (8.3%). A GIS model which included two soil types (Rock Land and Springerville (fine montmorillonitic, thermic typic chromusterts)) with an elevation range from 1142 to 1183 m and slopes from 0° to 6° is able to account for 30.3% (234 ha) of the increase in woody vegetation at our study site between 1940 to 2001. We also examined the locations of woody vegetation in relation to archaeological sites (pueblos with over 40 rooms) and determined that human activities roughly 600 year ago continue to impact the distribution of woody plants on the modern day landscape.

Keywords: Desert-grasslands; Woody-cover; Prehistoric-humans; GIS; Aerial-photographs

1. Introduction

Woody plant encroachment into grasslands and savannas is a global phenomenon with undisputed environmental and economic consequences (Archer et al., 1995, 1988;

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0140-1963/$ - see front matter
doi:10.1016/j.jaridenv.2006.10.012

Bragg and Hulbert, 1976; Briggs et al., 2005; Brown and Carter, 1998; Dussart et al., 1998; Heisler et al., 2003; Hoch and Briggs, 1999; Hoch et al., 2002; Knight et al., 1994; Miller and Rose 1995; Moleele and Perkins, 1998; Schlesinger et al., 1990). Purported causes of increases in woody plant abundance and cover in grasslands are numerous, including alterations in fire and other disturbance regimes, climate change, increased N deposition, shifts in land use and management, rising CO_2 concentrations and landscape-level fragmentation (Archer et al., 1995; Briggs et al., 2002; Brown and Archer, 1999; Hoch et al. 2002; Schlesinger et al., 1990, Van Auken, 2000).

The large-scale mesquite/creosote bush invasion of arid and semi-arid grasslands is well-documented (Archer et al., 1988; Schlesinger et al., 1990). Most researchers agree that the woody shrub and cactus expansion in the West began around 1870, coincident with the introduction of large numbers of cattle and sheep into the region (Bahre and Shelton, 1993). However, Fredrickson et al. (2006) recently proposed that mesquite expansion may have ultimately occurred in the absence of widespread livestock grazing during the last 130 years because of removal of barriers to mesquite expansion created by indigenous peoples. They suggest that the ever-present potential for mesquite expansion was suppressed by chronic use of this plant by large browsers and indigenous peoples. Loss of these control mechanisms resulted in an expansion of mesquite dominance that was later accelerated by introduction of large herds of beef cattle that dispersed mesquite seed (Fredrickson et al., 2006). Additional studies on a variety of sites with varied land use histories are needed to test the hypothesis set forward by Fredrickson et al. (2006). The Agua Fria National Monument (AFNM) is an ideal location since there is a documented and visible prehistoric occupation and known record of historic grazing.

In central Arizona, the location of our study, it is believed that mesquite, juniper, and cactus account for the majority of the woody plant (for this paper we are combing cactus and woody plants), expansion into arid grasslands, though there have been few quantifiable studies of this phenomenon in this area. It is believed that the mechanisms behind the spread of mesquite and other woody vegetation in southern Arizona is primarily due to grazing and fire exclusion (Bahre and Shelton, 1993) both of which have occurred in our study site. The long-term land use history of AFNM includes occupation by a sizeable population that lived in dispersed hamlets of 1–10 rooms and villages of 10–150 rooms and farmed the surrounding mesa tops. People inhabited the mesa top from the late A.D. 1200s to the early 1400s (Briggs et al., 2006). To quantify any potential increases in woody vegetation in central Arizona, we conducted an analysis of aerial photographs spanning a 61-year period (1940–2001). We constructed a model that incorporated slope, aspect, elevation and soil types to help us understand where these changes, if present, have occurred. We used these variables in our model as they have been important in other studies looking at the expansion of woody vegetation (Knight et al., 1994) and they were available for the entire area. Other variables that are also known to be important in the expansion of woody plants into grasslands including fire history, grazing pressure and land use were not available for this area. Finally, we examined the location of woody vegetation in relation to archaeological sites (40 rooms or more in size) to determine if the actions of humans in prehistory could continue to impact the distribution of woody plants on the modern day landscape.

2. Materials and methods

2.1. Study site

The AFNM was established in 2000 and lies ~102 km north of Phoenix, Arizona. This 29,000 ha desert grassland and riparian ecosystem is managed and operated by the Bureau of Land Management (BLM). Elevation in the AFNM ranges from 655 m in the riparian zone along the perennial Agua Fria River to 1400 m in the northern hills. Precipitation averages 39.1 cm, with most rain falling during late summer monsoons, after a normally dry May and June. Monthly mean temperatures range from a low of 7.4 °C in January to a high of 26.7 °C in July, with a mean annual temperature of 16.2 °C.

Semi-desert grassland covers most of the region and generally occurs on basalt and granite-derived soils. Major species of these grasslands include tobosa grass (*Pleuraphis mutica* Buckley [syn. Hilaria mutica (Buckley) Benth.]), grama species (*Bouteloua* Lag. spp.), threeawn (*Aristida* L. spp.), New Mexico needlegrass (*Achnatherum perplexum* Hoge and Barkworth [syn. *Stipa perplexa* (Hoge and Barkworth) Wipff and S.D.Jones]), curly mesquite (*Hilaria belangeri* (Steud.) Nash), western wheatgrass (*Pascopyrum smithii* (Rydb.) Barkworth and Dewey [syn. *Agropyron smithii* Rydb.]), squirreltail (*Elymus elymoides* Swezey [syn. *Sitanion elymoides* Raf.]), and vine mesquite (*Panicum obtusum* H.B. and K.).

At this latitude (34 °N) in Arizona the gradient in elevation includes the southern and lower edge of the range for juniper (*Juniperus monosperma* [syn. *Juniperus occidentalis* var. *monosperma* Engelm.]) in the north and the northern and upper edge of the range for mesquite (*Prosopus velutina* Wooton) in the south. This provides an ideal opportunity to study range expansion in both of these woody species that are known to be expanding throughout the western United States (Bock and Bock, 1993).

Our research area lies within the Perry Mesa Archaeological District (National Register of Historic Places) in which over 300 archaeological sites, including many large masonry pueblos with 30 to over 100 rooms, numerous dispersed 1–10 room hamlets, and petroglyph concentrations are documented. This desert grassland and riparian ecosystem experienced a sizeable agricultural occupation from the late A.D. 1200s to the early 1400s, and livestock grazing since the mid-1800s (Briggs et al., 2006). The AFNM was viewed as a good area for livestock by early ranchers since its large flat surface was covered with grasses and permanent water was accessible in the canyons below. Cattle grazing was introduced into the area around the mid-1870s after the US Army had resettled local Yavapai and Apache tribes to reservations and provided their lands to ranchers. Cattle have grazed the entire area since that time. Basque immigrants introduced sheep ranching to the area in the 1930s and continue to drive sheep onto the area through the present. Today, the BLM administers the lands of AFNM and continues to regulate cattle and sheep grazing within the monument.

We focused on a subset of the AFNM based upon availability of existing geographical information system (GIS) database coverage for archaeology, soils and digital elevation models (DEMs; 10 m resolution), accessibility to field sites and previous work at those sites (Fig. 1; Briggs et al., 2006). We obtained eight aerial photo image files of the study area taken in 1940, from National Air Survey Center Corporation (Bladensburg, MD). These images provide contiguous coverage from near the southern, and lower end of the monument through the northern, and higher elevations of AFNM. The images were

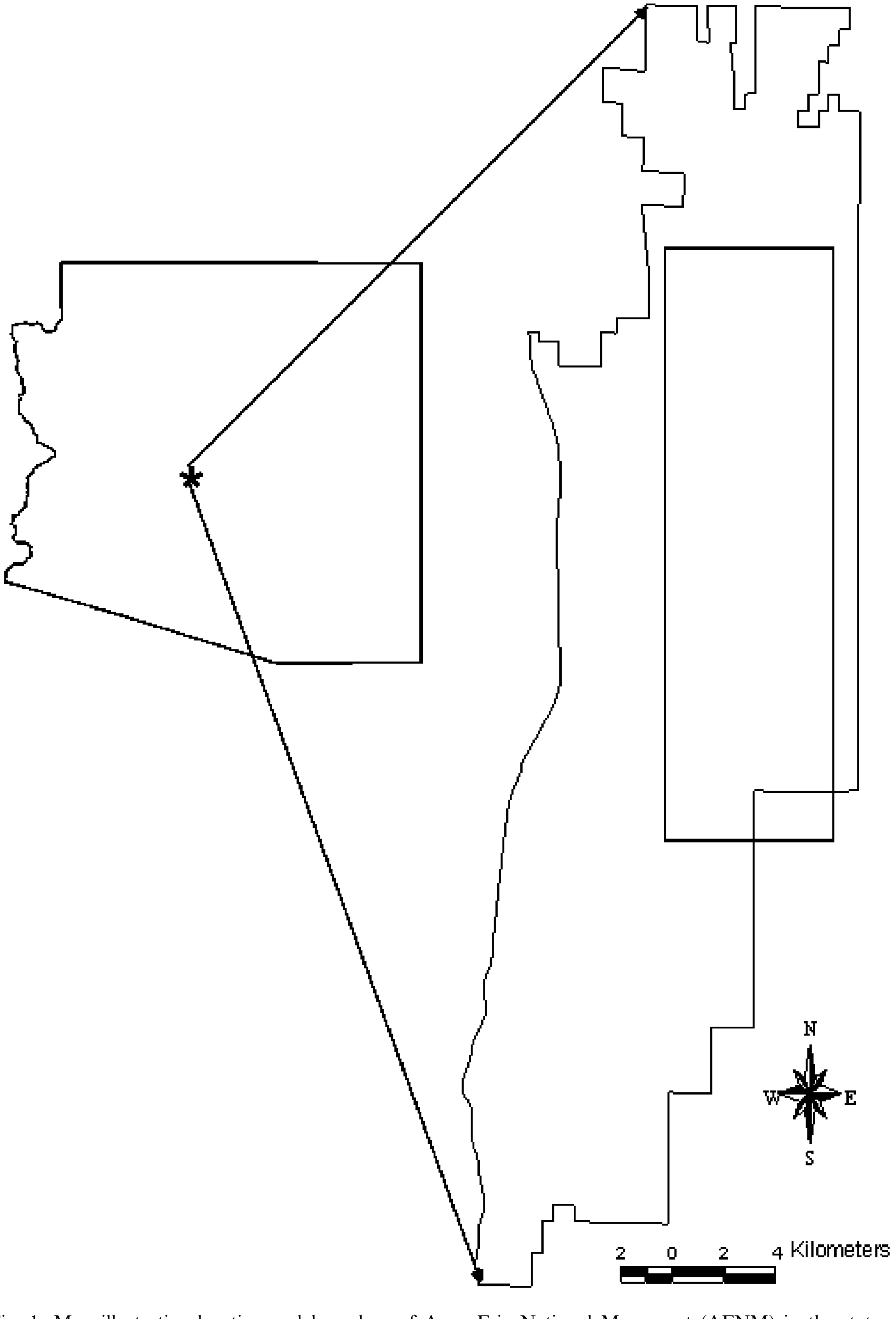

Fig. 1. Map illustrating location and boundary of Agua Fria National Monument (AFNM) in the state of Arizona. Inner box represent study site showing the boundaries of the aerial photographs from 1940 to 2001 and the extent of the geographical information system database that was developed for this study.

digitally scanned at ~1-m resolution. For the 2001 images, we obtained Digital Orthophoto Quarter Quad photographs with a resolution of 1 m, georeferenced to UTM zone 12. Using 45 ground control points that were identifiable as existing on both the 2001 photos and the 1940 photos, the 1940 photographs were geo-referenced to the 2001 images. A first-order polynomial was applied for georeference and registration, and the maximum root mean square error allowed was one pixel (1 m^2).

The resulting 1940 image files were overlaid using the Mosaic procedure with the Image Matching option in ERDAS IMAGINE, thus creating a contiguous image of the study area. Areas that were shaded (e.g. steep canyons and areas with a very high density of trees) and in which it was impossible to distinguish between vegetation, rock outcrops and shadows were masked in both years and not used in the estimation of the woody plant cover. These areas totalled less than 4% of our study area.

We took training samples from the 2001 images using 123 ground-truthed points that we field verified to be covered by woody vegetation. Areas determined to be covered by woody vegetation were at least 1 m^2 (e.g. the canopies of the woody vegetation were at least 1 m^2). Using these training samples, we then ran a supervised classification on the 1940 and 2001 images using a maximum likelihood classification. The resulting images represented the estimated woody vegetation coverage for 1940 and 2001 within the study area. Detailed ground-truthing revealed a high agreement of our estimates of woody cover. Although we cannot directly verify the woody vegetation cover in either time period using standard error assessment (as we do not have ground-truthing data from 1940 or 2001), we are assuming our estimates are reliable for both time periods. Similar analyses and photo interpretations have been done in previous studies from other areas (Knight et al., 1994). All analysis of the aerial photographs was done using ERDAS IMAGINE image processing software.

For additional comparison of the woody vegetation distribution, we developed a GIS database for our study site. This database included location of six pueblos with more than 40 rooms, soils, elevations, slopes and aspects. For elevations, aspects and slopes, a DEM with 10 m resolution of the study area was obtained (http://ned.usgs.gov/). Nine categories for slopes (0°–6°, 6°–11°, 11°–17°, 17°–22°, 22°–27°, 27°–33°, 33°–38°, 38°–44° and >44°) and nine aspects (N, NW, NE, E, W, S, SE, SW, and flat) were determined from the DEM, extracted and the coverage of woody vegetation for each categories from both time periods were determined. In addition, nine elevation categories (975–1016, 1017–1058, 1058–1099, 1100–1142, 1143–1183, 1184–1225, 1226–1267, 1268–1308 and >1308 m) were calculated from the DEM and again the coverage of woody vegetation for each category from both time periods were obtained for each value.

We obtained soils data for our GIS database from the soil survey geographic database (SSURGO) (http://www.az.nrcs.usda.gov/technical/soils/index.html). We then calculated the % of woody vegetation from the nine major soil types (major was defined to be >5% in total area) on our study site. All analyses were conducted in ARC/GIS. To determine if the % of woody vegetation present at each of the elevation, slope, aspect values and soil types differed from what was expected from a normal distribution based upon the amount of area that each value occupied in the landscape, a goodness of fit test was conducted using the *G*-statistic (Sokal and Rohlf, 1995). In addition, we constructed a GIS model to determine which combination of our 35 parameters (nine elevation values, nine slope values, nine aspect values and eight soil types) would explain the largest degree of change in the amount of woody vegetation over the 41-year time period.

Centered on each of the six pueblos, we created multiple concentric circles of 100 m increments out to 2 km. We concentrated on these larger pueblos (>40 rooms), as Kruse (in press) report that these larger sites have more of an impact on the surrounding landscape than sites with fewer rooms. We then determined the woody covers within each of the increments surrounding the pueblos. We created similar concentric circles surrounding six points randomly chosen within areas of similar physiographic composition to the pueblo locations. These served as comparative controls and we determined the woody covers within each of the increments around the control points. The results were compared to determine if the locations of woody plants within 2 km of the pueblos were significantly different from locations of woody plants within 2 km of random points in the landscape. Since the areas of the differed increments were not uniform in area and the distribution of landscape attributes, we used the GIS to determine the % of woody cover within each increment adjusted by area. A goodness of fit test was conducted against the observed % distribution of woody plants within each increment from the pueblo against the observed % distribution of woody plants within each increment from the random points using the *G*-statistic (Sokal and Rohlf, 1995). To determine if the distribution changed as a function of distance, we also plotted the difference from the observed % distribution of woody plants within each increment from the pueblo against the observed % distribution of woody plants within each increment from the random points by distance from the points (pueblo or random point). If the slope of the line was determined not to be significantly different from zero, then the presence of the pueblo would not have any impact on the distribution of woody plants. We also conducted a goodness of fit test to determine if the impact of the individual pueblos were similar across the study area.

3. Results

From 1940 to 2001, we estimated that the amount of woody vegetation at our study site increased from 559.7 ha (6.1% of the area) to 1326.6 ha (14.4%); an increase of 766.9 ha (Fig. 2). This represents an average increase of approximately 18.7 ha per year. However, this increase was not uniform across the landscape. Based upon our analysis from the DEM, the largest increase on the landscape occurred on slopes less than 6° and in the elevation range from 1142 to 1183 m (Fig. 3). As expected, the amount of woody vegetation was greater on the north facing aspects during both sampling periods (Fig. 4; top panel). Soil types were also very important in the expansion of woody vegetation across the area (Fig. 4; bottom panel). The greatest increase in woody vegetation occurred on the Ro soil types (Rock Land (fine montmorillonitic, thermic typic chromusterts)); we estimated that on this soil type woody vegetation increased by 254 ha (33% of the total increase in woody vegetation over the 41-year-time period). However, this increase only represents ~25% of this soil type, suggesting that no soil types are limiting the expansion of woody vegetation at this site (Fig. 4; bottom panel). Thus, it appears that there is no correlation between landscape composition and the expansion of woody vegetation at our site (Figs. 3 and 4).

Results from the goodness of fit tests showed that in both time periods, the distribution of woody vegetation for the different slope values was significantly different from what one would expect from a normal distribution (1940; $G = 65.92$; $p < 0.001$; 2001; $G = 49.36$; $p = 0.001$). However, this was not the case for aspect during both sampling periods (1940;

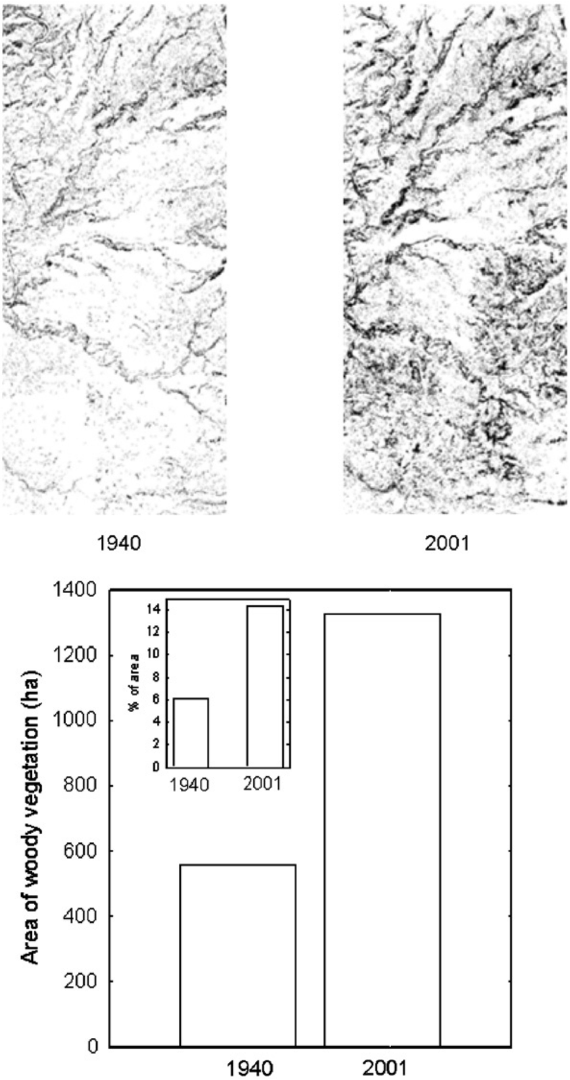

Fig. 2. Top panel: Locations of woody plants as determined from aerial photographs in 1940 (left) and 2001 (right) at the AFNM study site. Bottom panel: Overall area of woody vegetation as determined from aerial photographs in 1940 and 2001 at the AFNM study site. Insert: Percentage of the study site that was estimated to be covered by woody vegetation in 1940 and 2001.

$G = 12.87$; $p = 0.12$; 2001; $G = 11.74$; $p = 0.16$). Analysis of the distribution of woody vegetation with respect to elevation showed a shift during the focal time period, as in 1940 the distribution of woody vegetation on the different elevation values was significantly different from what one would expect from a normal distribution ($G = 17.36$; $p = 0.03$) while in 2001 no significant difference was found ($G = 4.22$; $p = 0.84$).

Based upon our analysis, a model that included the soil types Rock Land and Springerville with elevations from 1142 to 1183 m and slopes from 0° to 6° could account

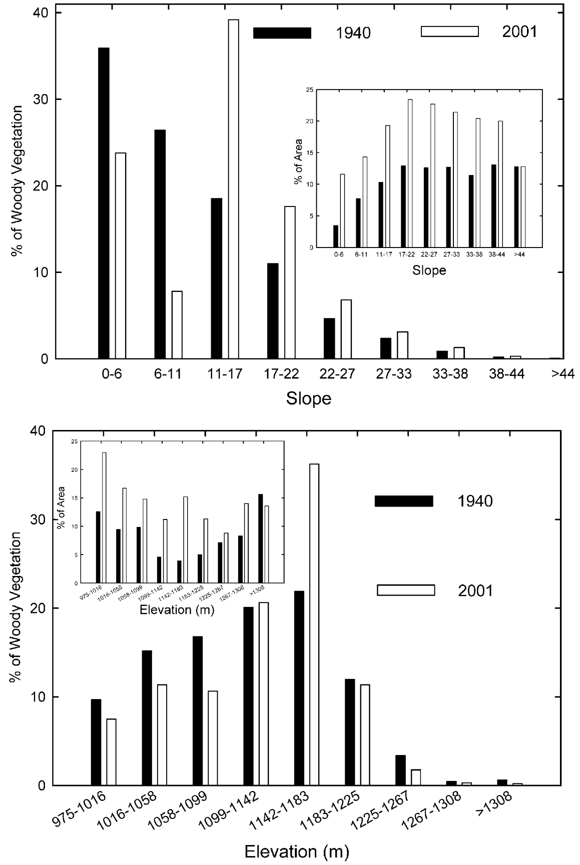

Fig. 3. Top panel: The change in woody vegetation cover from 1940 to 2001 on each of the slope values calculated from the DEM of the AFNM study site. The largest increase from 1940 to 2001 occurred on slopes from 0° to 6°. Insert. The amount of woody vegetation on each of the slope values presented as a % of the area within each slope range. Bottom panel: The change in woody vegetation cover from 1940 and 2001 on each of the elevation ranges calculated from the DEM of the study site at the AFNM study site. Over 90% of the woody vegetation was found on elevations <1225 m; the greatest change in woody vegetation was found between 1142 and 1183 m. Insert. The amount of woody vegetation on each of the elevation values presented as a % of the area within each of the values.

for 30.3% (234 ha) of the increase in woody vegetation at our study site between 1940 and 2001 (Fig. 5). No other combinations of variables accounted for more than 9% of the total increase in woody vegetation.

No significant difference between the observed % distribution of woody plants within each 100 m increment away from the pueblo against the observed % distribution of woody plants within each 100 m increment from the control points were found in 1940 or in 2001 (1940, $G = 0.03$, $p > 0.88$; 2001 $G = 1.37$, $p > 0.76$). In 1940, however, the difference between the % of woody plant cover from the pueblo areas against the % of woody plant cover from the random areas plotted against distance found a significant non-linear relationship (best-fit model is: $y = a + b\ln(x)$; $r^2 = 0.43$, $p = 0.002$; Fig. 6, top panel) while

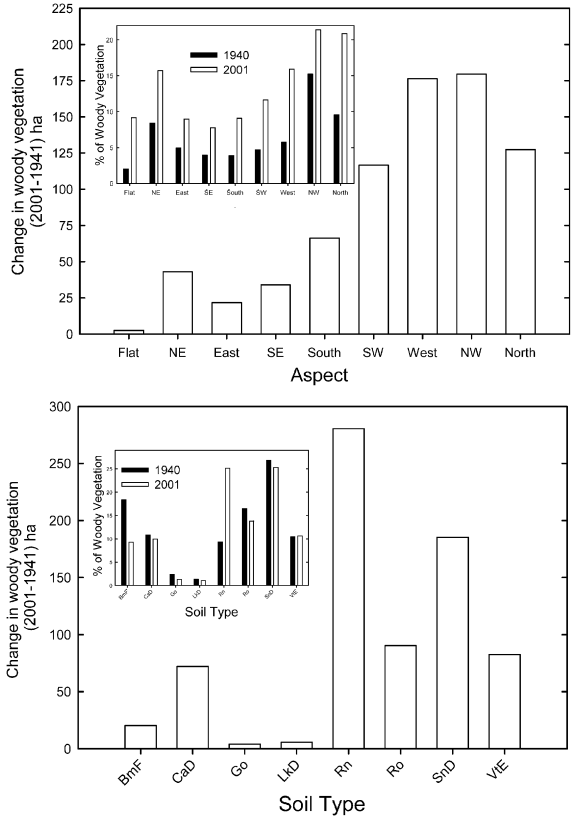

Fig. 4. The change in woody vegetation cover from 1940 to 2001 on each of the aspect values calculated from the DEM of the study site at the AFNM study site. Insert: The amount of woody vegetation on each of the aspect values presented as a % of the area within each of the aspects. Bottom panel: The change in woody vegetation cover from 1940 to 2001 on each of the soil types (that was >5% of the area) of the study site at the AFNM study site. The greatest increase was found on Ro. Insert: The amount of woody vegetation on each of the soil values presented as a % of the area within each of the soil type. (BmF = Barkerville cobbly sandy loam (sandy-skeletal, mixed, mesic typic ustorthents); CaD = Cabezon–Springerville complex (clayey, montmorillontic, mesic lithic argiustolls); Go = Gila (coarse-loamy, mixed (calcareous), thermic Typic torrifluvents); LkD = Lonti gravelly sandy loam; (fine, mixed, mesic ustollic haplargids) Rk = rim rock cobbly clay (fine montmorillonitic, thermic typic chromusterts); Ro = rock land (fine montmorillonitic, thermic typic chromusterts); SnD = Springerville–Cabexon complex (fine monotmorillonitic, mesic aridic-argiustolls); VtE = Venezia–Thunderbird complex (loamy, mixed, mesic lithic haplustolls)).

in 2001, no relationship was found (Fig. 6, bottom panel). When the analysis was restricted to the first 700 m surrounding each pueblo or point, however, a significant linear relationship was found from both time periods (1940, $r^2 = 0.67$, $p = 0.02$; 2001, $r^2 = 0.97$, $p = 0.002$; Fig. 6, top and bottom inserts). Although the amount of woody vegetation was different around each of the pueblos, the goodness of fit test in 1941 and 2001, revealed no significant differences between the pueblos (1940, $G = 1.72$, $p = 0.89$; 2001, $G = 3.69$, $p = 0.60$). This suggests that the impacts of the pueblos are uniform across the study site.

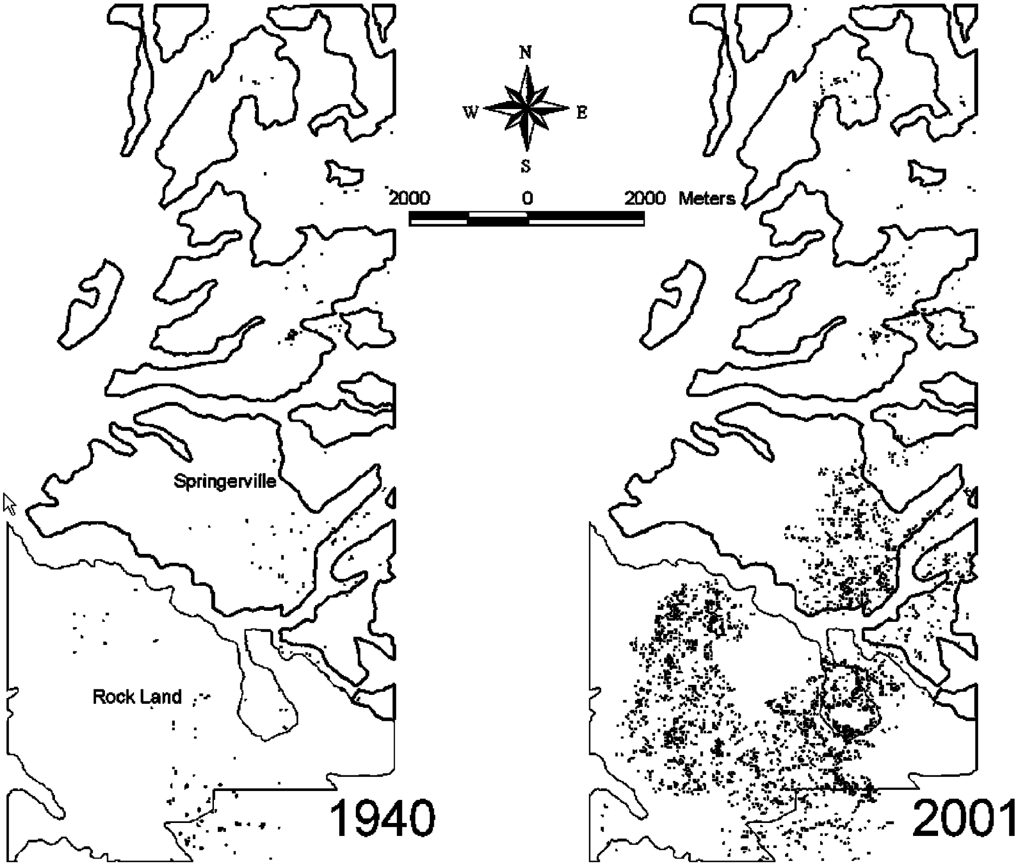

Fig. 5. Results from the GIS model that was developed to examine where the largest increase in woody expansion had occurred on our study site within the AFNM. This model found that the greatest increase of woody vegetation occurred on two soil types (Rock land and Springerville) and on slopes less than 6 and from 1142 to 1183 m. Over 30% of the increase in woody vegetation occurred using these variables and no other combinations of variables accounted for more than 9% of the total increase in woody vegetation. This increase in woody vegetation as observed using the aerial photographs can be best attributed to increases in mesquite (*Prosopus velutina*).

4. Discussion and conclusions

As in many places across the southwest, woody vegetation has increased at the AFNM over the time period analyzed in this study. Based upon our measurements of woody cover, we estimate that at the AFNM, the extent of woody cover within our study area increased from 559.7 ha (6.1%) in 1940 to over 1326.6 ha (14%) in 2001. This represents an average increase of over 18 ha per year during this time period. This study was not designed to examine the mechanism behind this increase but as in most areas in the southwest, we are assuming that it is due to overgrazing by cattle or sheep and reduced fire frequency (Van Auken, 2000). Indeed, grazing by cattle and sheep is ongoing and there are many anecdotal accounts of the vast number of animals that have grazed this area during the past decades

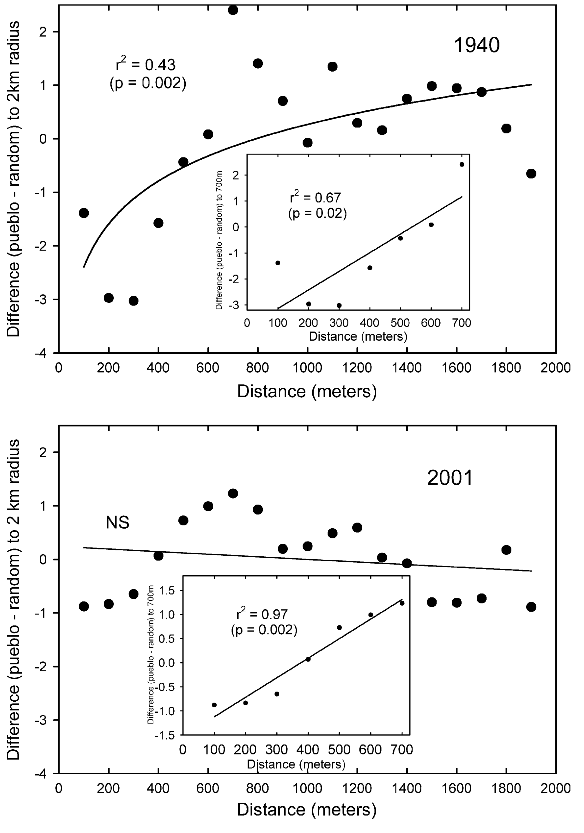

Fig. 6. The difference between the distribution of woody plants within 2 km of the six pueblos and the distribution of woody plants within 2 km of six random points within the study sites plotted out to 1900 m in 1940 (top panel) and in 2001 (bottom panel). The non-linear relationship to the points in 1940 suggest that locations closer to the pueblos are more impacted than those farther away. In 2001 no relationship was found. Both inserts: The difference between the distribution of woody plants from the six pueblo that were within 2 km of the study site and the distribution of woody plants from 6 random points within the study site plotted out to 700 m. Briggs et al. (2006) reported that pueblos impacted the number of woody plants out to 600 m. The significant relationship in both years (1940 $r^2 = 0.26$; 2001, $r^2 = 0.97$) suggest that the presence of pueblos on the AFNM landscape is still impacting the distribution of woody plants ~750 year after their construction.

In the 1850s, there were virtually no cattle recorded in Arizona, by the 1880s there were roughly 136,000 cattle and by 1890 a total of 927,880 cattle were recoded in Arizona. This rapid increase in large grazing animals and continued pressure soon degraded much of the grasslands. Due to drought and over use of the land the number of cattle also dropped, but only to around 800,000 until the 1920s when the Arizona cattle population climbed to an all time high of over 1,000,000 (Mayro and McGibbon, 2004). During this same time period there has been an increase in the woody species across the west (Bahre, 1991; Bahre and Shelton, 1993; Curtin, 2002; Fleischner, 1994; Glendening, 1952; Gori and Enquist, 2003). These species include mesquite and a variety of cactus in many southern areas of the west and juniper in more northerly latitudes and higher altitudes (Bahre and Shelton, 1993; Humphrey and Mehrhoff, 1958). Ranchers and range managers were already aware of diminishing grasses and increasing shrub cover by 1898, less than 30 years after the introduction of grazing to southeastern Arizona (Bentley, 1898; Smith, 1899).

In addition to grazing and fire, periodic droughts have also been implicated in the increase in woody vegetation on grasslands. We obtained Palmer Drought Severity Index (PDSI) (known operationally as the Palmer Drought Index (PDI) from http://www.ncdc.noaa.gov/oa/climate/onlineprod/drought/ftppage.html), in order to measure the duration and intensity of any long-term drought during our study period. Long-term drought is cumulative, so the intensity of drought during the current month is dependent on the current weather patterns plus the cumulative patterns of previous months. These data came from analysis of tree-rings from about 50 km from our study area, and were used in an attempt to determine if any long-term weather patterns might explain the change in woody vegetation cover at our site. During the 61-year period covered by our study, there was a major drought in the region during the 1950s but with only two data points (1940 and 2001), no quantitative assessment of the importance of drought can be conducted. It is, however, possible that during the extensive drought of the 1950s, grasses were stressed, providing trees (especially mesquite) a competitive advantage (Schlesinger et al., 1990).

Our analysis does not allow us to determine which woody species increased over time, but mesquite (*Prosopus velutina*) is the most plausible species to have increased its cover over the duration of our study. Juniper (*J. monosperma*), the other co-dominant woody plant in our system is more restricted to the northern and higher elevations of the AFNM, and since most of the increase in woody vegetation occurred between the lower elevations of 1142 and 1183 m, the most likely woody plant to have increased its cover is mesquite (*Prosopus velutina*). Cat claw acacia (*Acacia greggii* A.Gray [syn. *Senegalia greggii* (A. Gray) Britton and Rose]) is also common at the site, but is not an aggressive invader of desert grasslands. The other possible plant that could be responsible for the increase is prickly-pear *Opuntia* Mill sp. This species is also increasing in many locations across the southwest (Bock and Bock, 1993; Huebner et al., 1999). More extensive ground-truthing of our coverages is needed before we can be certain which species are responsible for the increase in woody plant coverage recorded in this study.

The increase in woody plants did not occur uniformly across the landscape. As mentioned above, the largest increase on the landscape occurred on slopes less than 6° and in the elevation range from 1142 to 1183 m (Fig. 3). In addition, soil types were influential in that the largest increase in woody vegetation occurred on the soil types Rock Land and Springerville. In summary, a simple model which included the soil types Rock Land and Springerville with the elevation from 1142 to 1183 m and slopes from 0° to 6° could account for 30.3% (234 ha) of the increase in woody vegetation at our study site from 1940 to 2001 (Fig. 5).

The results presented in this paper support Fredrickson et al. (2006) who recently proposed the idea that mesquite expansion may have ultimately occurred in the absence of widespread livestock grazing during the last 130 years because of removal of barriers created by indigenous peoples. In this study, we present data that shows that abandoned pueblos have an impact on the current spread and distribution of woody vegetation across this landscape (Fig. 6). Briggs et al. (2006) reported that the area up to 600 m surrounding one pueblo has significantly less rock cover than areas further away, and that woody plant density also decreased with proximity to the pueblo. They postulated that the most plausible explanation for the relationship between rocks and woody vegetation is that the rock cover provides "safe sites" for the woody vegetation. Through their activities in the past (moving rocks to build the pueblo and/or to clear fields) humans altered the landscape in a way that continues to affect the current distribution of plants, ~600 years after the pueblo was abandoned (Briggs et al., 2006). This study supports their findings as across a larger landscape which encompasses six different pueblos, we see an impact of the abandoned pueblos on the distribution pattern of woody plants. All of these pueblos are located on either the Rock Land or Springerville soil type and are in the elevation range that had the largest increase in woody vegetation. Like Briggs et al. (2006), we do not think the impact of the pueblos on woody vegetation is direct and are not certain of the direct mechanism, but demonstrate that the presence of the pueblos is having an impact on the distribution of the modern day woody plant cover. Thus, as Peters and Havstad (2006) report, historic legacy is a key element that contributes to the spatial and temporal heterogeneity seen in arid landscapes. This impact is not limited to the arid southwest. Some of the most dramatic effects of prehistoric human activities on ecosystems have recently emerged from studies in the tropics. For example, in the "pristine" rainforests of New Georgia, recent archaeological studies have reported that the rainforests have regenerated in less than 150 years (Bayliss-Smith et al., 2003). Similar studies have been reported in central African rainforests (van Gemerden et al., 2003) and from a dense rainforest in the upper Xingu region of Brazil (Heckenberger et al., 2003). Many other examples including those from Europe, Asia and Australia are discussed by Gilson and Willis (2004). It is critical that more research into the impact that prehistoric human activities have on the modern day landscape be conducted.

Acknowledgements

We would like to thank the Arizona State University (ASU) Office of the Vice President for Research, the Bureau of Land Management (JSA041006), and the National Park Service (CESU Cooperative Agreement grant; CA-H1200-04-0002) for their monetary support. Partial funding was also provided by the IGERT in Urban Ecology and the CAP-LTER programs at ASU. While writing this manuscript, J.M. Briggs was supported by a Charles Bullard Fellowship from the Harvard Forest, Harvard University and from NSF DEB-0614349. We would also like to thank the many students (both undergraduate and graduate) and fellow faculty members at ASU who help us collect some of the data presented in this paper as part of the multi-disciplinary course (Archaeology and Ecology: Legacies on the Landscape) organized by Kate A. Spielmann.

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