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Human influences on fire regimes and forest structure in the Chihuahuan Desert Borderlands

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ABSTRACT

Recent research in isolated sites in southwestern North America suggests that spatial variation in land use history can result in differences in the dates of fire exclusion onset and the extent to which forests have changed in response to fire cessation. We investigated the relationships among fire, land use, and forest structure in three mountain ranges that straddle the Texas–Mexico border including The Davis Mountains Preserve of The Nature Conservancy and Big Bend National Park in west Texas, and The Maderas del Carmen Protected Area in northern Coahuila, Mexico. We quantified fire regime characteristics (frequency, size, severity, and seasonality) and forest stand structure using dendroecology. Frequent low severity fire was a dominant force shaping forest structure and species composition historically. Mean fire return intervals prior to fire exclusion (1700–1900) ranged from 1 to 29 years for fires scarring >25% of the fire-scar samples. The per-sample fire return intervals ranged from 15 to 25 years signifying historically frequent fires at any one location on the landscape. The contemporary period was characterized by a doubling of fire return intervals across all three sites, probably as a result of fire exclusion through livestock (sheep) grazing. The presence of older trees in the tree age data suggested that fires were predominantly low in severity and that tree regeneration occurred during fire free intervals. Our results show that the disruption of frequent, low severity fire regimes in our sites resulted in widespread tree regeneration. This study documents the importance of sheep grazing as a causal factor of fire exclusion in west Texas and northern Mexico, which occurred in the early to mid-1900s, well after the 1880s cattle boom.

1. Introduction

Fire is a key disturbance process influencing tree survival and regeneration (Agee, 1993; Whelan, 1995; DeBano et al., 1998). Frequent, low intensity fires maintained forest structure and dynamics for millennia in western North America prior to Euro-American settlement (Swetnam and Baisan, 1993; Rodríguez-Trejo and Fulé, 2003). Grazing, logging, and direct fire suppression since the late 1800s have stimulated a shift from historically open and park-like forests with little understory fuels to dense forests with high live and dead fuel loads through much of the American Southwest (Cooper, 1960; Moore et al., 2004; Heinlein et al., 2005) and parts of Mexico (Fulé and Covington, 1996; Yocom et al., 2010).

Recent research in isolated sites in southwestern North America suggests that spatial variation in land use history can result in differences in the dates of fire exclusion onset and the extent to which forests have changed in response to fire cessation (Fulé and Covington, 1996; Heyerdahl and Alvarado, 2003; Stephens et al., 2003; Fulé et al., 2005; Sakulich and Taylor, 2007). While most of the western United States experienced widespread fire exclusion beginning in the late 19th and early 20th centuries, fires continued later into the 20th century in several sites that experienced a lag in the onset of livestock grazing due to their inaccessibility (Sakulich and Taylor, 2007; Grissino-Mayer and Swetnam, 1997). While climatic variation may have also been a factor influencing tree regeneration in the early 1900s (Savage and Swetnam, 1990), fire exclusion at many sites in Mexico did not occur until the 1950s when much of northern Mexico was exposed to livestock grazing for the first time through the redistribution of lands to community land holders called ejidos (Heyerdahl and Alvarado, 2003; Fulé et al., 2005; Yocom et al., 2010).

Fire regulated landscapes in southwestern North America display considerable spatiotemporal variation in fire regime characteristics. Geographically isolated sites with rugged terrain

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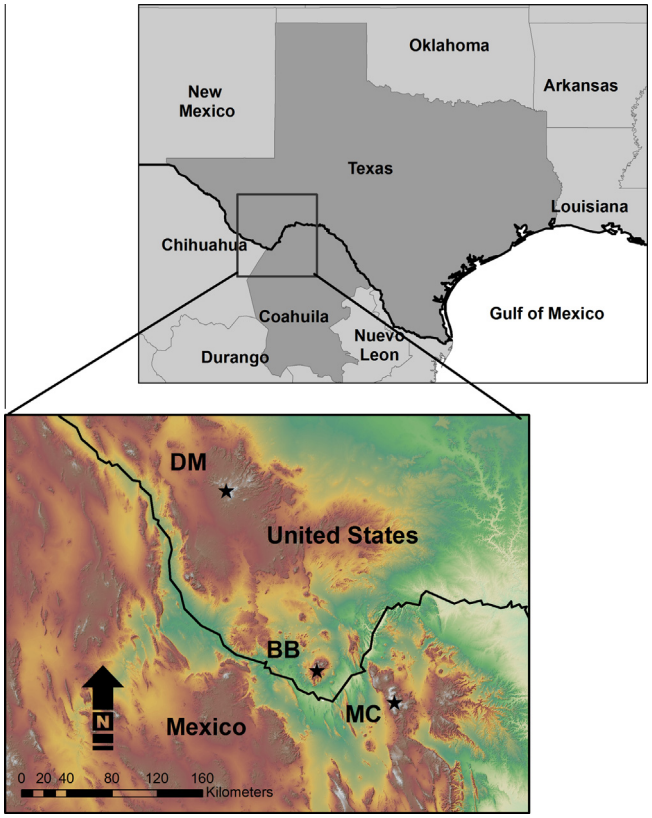

Fig. 1. Location of the three study sites in the Chihuahuan Desert Borderlands. DM = The Davis Mountains Preserve of The Nature Conservancy, BB = Big Bend National Park, and MC = Maderas del Carmen Protected Area.

and scarce water supplies may have experienced different land use histories than other more readily accessible parts of the Southwest. Moreover, regions that transverse international boundaries like the US–Mexico border offer a unique opportunity to explore how divergent sociopolitical histories have influenced historical fire regimes and forest stand structure.

The Chihuahuan Desert Borderlands (CDBs) region (Fig. 1) encompasses the states of Texas and New Mexico in the United States, and Chihuahua, Coahuila, and Nuevo Leon in Mexico. The rugged mountains in this area host remote and highly fragmented forests of fire adapted pine, oak and mixed conifer as part of the northern extension of the Sierra Madre Oriental (Warshall, 1995). They are globally significant centers of biodiversity and endemism (Ferrusquía-Villafranca et al., 2005; CONABIO, 2006; Poulos and Camp, 2010). However, we know little about the drivers of historical CDB fire variability and their influence on forest dynamics.

We investigated the effects of fire, grazing, logging, and direct fire suppression on the forest structure of three "Sky Island" forests (DeBano et al., 1998) of the CDB that straddle the US–Mexico border. We were specifically interested in understanding: (1) how fire regimes have varied over space and time; (2) the extent to which divergent land use histories across the Texas-Mexico border affected fire regime characteristics; and (3) how historical fires influenced contemporary forest stand structure.

2. Methods

2.1. Study area

The Sky Island forests of the arid American Southwest and northern Mexico are distributed across high elevations of the Sonoran and Chihuahuan deserts of the Sierra Madre Oriental and Sierra Madre Occidental (Warshall, 1994). Current Sky Island forests are post-Pleistocene relicts, and their contemporary distributions are considered the result of species migrations from lowlands to uplands during early Holocene warming (Lanner and VanDevender, 1981; VanDevender and Spaulding, 1979). Forests are bound at lower elevations by deserts dominated by shrub and succulent desert flora, where tree establishment and growth is limited by high temperature and moisture limitation.

The three protected areas straddle the US–Mexico border (Fig. 1). They include the Davis Mountains Preserve of The Nature Conservancy (DM) and Big Bend National Park (BB) in west Texas, and the Maderas del Carmen Protected Area (MC) in northern Coahuila, Mexico. These are located in the northern edge of the Sierra Madre Oriental, which begins as a mountain archipelago in New Mexico in the United States, and continues southward 1350 km to the states of Puebla and Querétaro in Mexico (Warshall, 1994; Ferrusquía-Villafranca et al., 2005) (Fig. 1). The mountains formthe southeastern edge of the Basin and Range Geographic Province, and they are considered an ecological transition zone, sharing biological affinities with flora of the Rocky Mountains and the Sierra Madre Ranges (Muldavin, 2002).

The mountains are volcanic, and consist mainly of extrusive igneous rock. They originated 35–39 million years ago in the same Oligocene orogeny that formed most of the Front Range of the Rocky Mountains. The development of the Sierra Madre Oriental during the Oligocene epoch of the Cenozoic made it the first cordillera to develop in northern Mexico, and provided generalized geographic diversity, which in turn led to habitat diversity (Ferrusquía-Villafranca et al., 2005). The terrain is rugged and extremely complex, consisting of rocky uplands separated by steep walled canyons. Soils of the three study areas are a mixture of mollisols and entisols. They are composed of moderately deep gravelly loam, which is well drained and non-calcareous (USDA Soil conservation Service, 1977). Runoff is medium to rapid and soil water capacity is low.

High elevation forests (above 1500 m elevation) in this region are composed of piñon-juniper, oak, pine-oak, and mixed conifer woodlands (Poulos and Camp, 2010). Piñon-juniper woodland is the main low to mid-elevation forest type in all three study areas. This vegetation type is dominated by Mexican piñon pine (*Pinus cembroides* Zucc.), alligator juniper (*Juniperus deppeana* E. Von Steudal), gray oak (*Quercus grisea* Liebmann), Emory oak (*Quercus emoryi* Leib.), and weeping juniper (*Juniperus flaccida* Schltdl.) Pine-oak forests dominate middle to high elevations of the three sites. These forests are widespread across the larger MC range, but they are restricted to valley bottoms in the other two smaller, lower-elevation sites. Pine-oak forests are primarily composed of ponderosa pine (*P. ponderosa* D. Douglas ex P. Lawson var. *arizonica* (Engelmann) Lawson) and oak associates. In MC, southwestern white pine (*P. strobiformis* Engelmann) is also a major component of this forest type. Oak woodlands exist in BB and MC over a range of elevations and their species composition varies both by elevation and local site conditions. Mixed conifer forests cover middle and high elevations in MC, and they are dominated by Coahuila fir (*Abies durangensis* Martínez var. *coahuilensis* (I.M. Johnson) Martínez), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and Arizona cypress (*Cupressus arizonica* Greene). Douglas-fir and Arizona cypress also have limited populations in Boot Canyon in BB, but they are absent from DM. Taxonomy follows Nixon (2002) for the Mexican oaks, CONABIO (2009) for the Mexican pines, and Powell (1998) for all other species.

The modern climate is arid, characterized by cool winters and warm summers. Precipitation is distributed bimodally in late summer and winter with the majority of precipitation falling during summer storms as part of the North American Monsoon System.