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Changes in Gambel Oak Densities in Southwestern Ponderosa Pine Forests Since Euro-American Settlement

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Abstract—Densities of small-diameter ponderosa pine (*Pinus ponderosa*) trees have increased in southwestern ponderosa pine forests during a period of fire exclusion since Euro-American settlement in the late 1800s. However, less well known are potential changes in Gambel oak (*Quercus gambelii*) densities during this period in these forests. We reviewed published literature to summarize changes in oak density in ponderosa pine forests over the past 140 years and evaluated the possibility that large-diameter oaks have decreased in density. All nine studies examining oak density changes found that densities of small-diameter oaks have escalated. Increases ranged from 4- to more than 63-fold. These increases are comparable on many sites to those of ponderosa pine. Studies in northern Arizona, which analyzed cut stumps and past and present diameter distributions, did not find strong evidence that large-diameter oaks on average have declined in density. However, since oak cutting varied across the landscape, this important question needs additional study. Actively or passively managing Gambel oak requires decisions about desired future conditions and how to attain them. A possible contention for passive management—that the overall abundance of oak has decreased—is not supported by research published to date.

Introduction

It is well documented that small-diameter ponderosa pine (*Pinus ponderosa*) trees have increased in density in southwestern forests since the late 1800s. It may be less well known, however, that dramatic changes in Gambel oak (*Quercus gambelii*) densities have also occurred during this period in these forests. Gambel oak is one of only a few deciduous trees in ponderosa pine forests and has numerous ecological and human values (Reynolds and others 1970). This understory or mid-story tree provides mast, forage, and habitat for wildlife and is prized by humans for fuelwood and aesthetics (Harper and others 1985). However, Gambel oak is often passively managed in ponderosa pine forests. This may partly result from poorly known treatment effects on Gambel oak or a perception that oak abundance has decreased.

In this note, we review published literature to ascertain: (1) changes in Gambel oak densities in ponderosa pine forests since Euro-American settlement in the late 1800s, (2) the timing and possible mechanisms responsible for these changes, and (3) whether data exist to substantiate a hypothesis that densities of large-diameter oaks have decreased. We begin by briefly reviewing the basic characteristics of Gambel oak's biology, specifically for the frequent-fire pine-oak forests (such as in Arizona and New Mexico) that are the focus of this synthesis.

Biological Characteristics

In ponderosa pine forests, Gambel oak stems can exceed 36 inches (91 cm) in diameter at breast height and 400 years in age (Reynolds and others 1970; Swetnam and Brown 1992). This clonal oak recruits new stems by vigorous sprouting, particularly after existing stems are top killed (Brown 1958; Harper and others 1985). Regeneration by seedlings to produce new genets, however, does occur. Neilson and Wullstein (1986) found that seedling densities ranged from 49 to 534/acre (120 to 1320/ha) on 15 plots in Arizona and New Mexico pine-oak forests. Fire can kill more than 50 percent of small stems less than 2 inches (5 cm) in diameter (Harrington 1985), but mortality probably decreases with increasing diameter (Fulé and others 2005). This observation concurs with Gambel oak's persistence in pine-oak forests that often burned at least once every 10 years before Euro-American settlement (Fulé and others 1997; Madany and West 1983).

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Density Changes

Our literature review uncovered nine studies reconstructing Gambel oak densities in the late 1800s in southwestern pine-oak forests. We were able to obtain numerical data from eight of the nine studies (table 1). The other study (Ruess 1995) provided graphical data with results consistent with those of the other studies. All studies reported increases in Gambel oak densities since settlement. Magnitudes of the increases ranged from 16 to 450 trees/acre (40 to 1112 trees/ha). These increases were often comparable to irruptions in ponderosa pine densities (table 1). While these studies were performed in northern Arizona, except for one in southern Utah, these increases are probably representative of upsurges in other pine-oak forests due to the nearly ubiquitous exclusion of historically frequent surface fires (Grissino-Mayer and others 2004). These fires probably partly kept woody regeneration in check (Fulé and others 1997).

Timing and Mechanisms for Increased Densities

Data from Fulé and others (1997) provide insight into the timing and probable mechanisms for the oak density increases. At Camp Navajo in northern Arizona, Fulé and others (1997) found that 40 percent of the 32 oaks/acre (80/ha) at the site in 1883 were less than 2 inches (5 cm) in diameter in 1883. Prior to 1883, frequencies of surface fires averaged 4 years, but 1883 represented the start of fire exclusion associated with settlement. The authors hypothesized that many of the small oaks present in 1883 would have been killed had frequent fires continued. This hypothesis concurs with prescribed burning experiments in southwestern Colorado (Harrington 1985) and northern Arizona (Abella and Fulé 2008) that documented fire-induced mortality of small stems less than 4 inches (10 cm) in diameter. Further augmenting oak densities in the study by Fulé and others (1997), a pulse of new stems also established from about 1885 to 1914 shortly after fire exclusion began. Several factors could have contributed to recruitment of these new stems. Pine logging and livestock grazing may have reduced tree and herbaceous competition with the oaks. Cutting of large oaks possibly stimulated dense sprouting. Finally, fire exclusion likely facilitated survival of the fire-susceptible small stems. In summary, the elevated oak densities of 191/acre (417/ha) at the site in 1994 probably arose due to survival of small-diameter oaks on-site in 1883, followed by the establishment of new stems during a period of fire exclusion.

Waltz and others (2003) reported a similar sequence of events in pine-oak forests in Grand Canyon-Parashant National Monument in northern Arizona. Their study documented a large irruption in oak density around 1870 coinciding with the cessation of frequent fires. Additional oaks recruited after that time. In southern Utah, Madany and West (1983) hypothesized that livestock grazing made grassy interspaces between oak clumps more susceptible to invasion by oak stems whose survival was facilitated by fire exclusion. Historical photos also suggest that any early post-settlement increases were further augmented by later stem recruitment during the 1900s (fig. 1). Stem maps shown in Ruess (1995) suggest that oak increases may have resulted from both vegetative expansion of existing clones and increased seedling establishment.

Table 1—Summary of studies measuring changes in oak and pine densities in southwestern ponderosa pine-Gambel oak forests.

	Gambel oak		Ponderosa pine			
Location	Pre[a]	Post[a]	Pre	Post	Pre year[b]	Reference
	- - - - - - - - - - - - - - - - Trees/acre- - - - - - - - - - - - - - - -					
Beaver Creek Watershed, N. AZ	1	63	17	769	1867	Covington and Moore 1994
Walnut Canyon, N. AZ	6	44	22	102	1876	Menzel and Covington 1997
Camp Navajo, N. AZ	34	191	26	291	1883	Fulé and others 1997
Kaibab National Forest, N. AZ	6 to 28[c]	64 to 177	18 to 43	167 to 1,353	1887	Fulé and others 2002a
Grand Canyon National Park, N. AZ	1 to 29	32 to 264	26 to 63	78 to 261	1879,1887	Fulé and others 2002b
Zion National Park, UT-pine/oak	0	2 to 104	1 to 23	16 to 102	1883	Madany and West 1983
Zion National Park, UT-oak woodland	31 to 115	459 to 565	0 to 1	0 to 48	1883	Madany and West 1983
Mt. Trumbull, N. AZ	17 to 30	75 to 127	13 to 17	173 to 276	1870	Roccaforte 2005
Mt. Trumbull, N. AZ	1 to 35	17 to 244	6 to 26	110 to 684	1870	Waltz and others 2003

[a]Pre = presettlement; post = postsettlement.
[b]Year for which presettlement densities were reconstructed, normally the last year in which surface fire occurred. Postsettlment measurements were made a few years before a study's publication date.

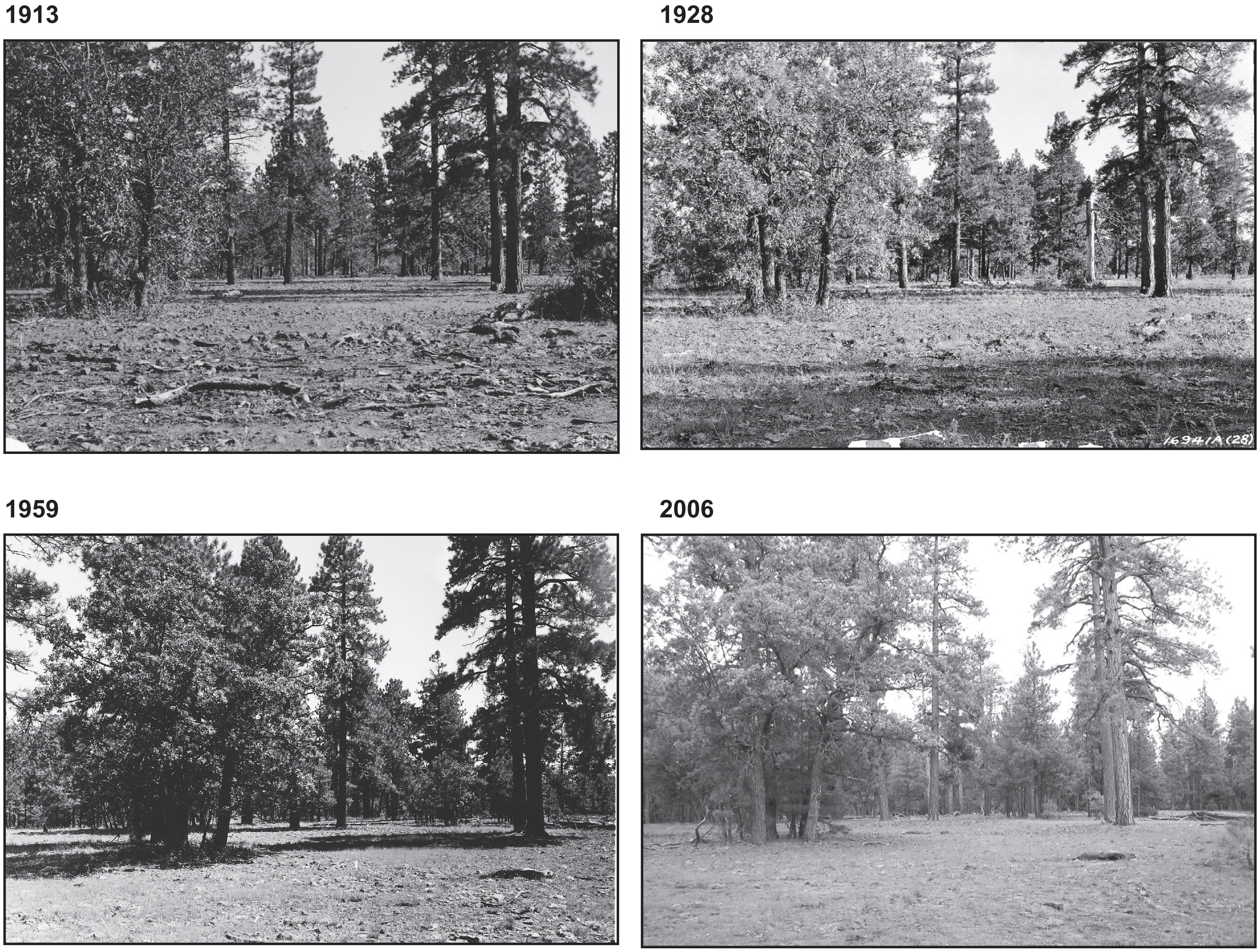

Figure 1—Ninety-three year photo series of a Gambel oak clump (left center) that increased in density by approximately 75 percent from 1913 to 2006. The photos were taken near Coulter Cabin in the Coconino National Forest, 12 miles (19 km) south of Flagstaff, Arizona. The 1913 photo was taken following a group selection harvest of ponderosa pine. The 1913 and 1928 photos were taken by Hermann Krauch (U.S. Forest Service photo 16491A), the 1959 photo was taken by M.M. Larson (U.S. Forest Service photo LA-86), and the 2006 photo was taken by A.J. Sánchez Meador. Photos provided by A.J. Sánchez Meador (U.S. Forest Service).

Large-Diameter Oaks

Research published to date suggests that densities of small-diameter oaks have sharply increased in the past 140 years in ponderosa pine-Gambel oak forests. Less clear, however, is whether large-diameter oaks have dwindled because of fuelwood harvest or other factors (Mast 2003). Diameter distributions at Camp Navajo, Arizona, in 1883 and in 1994/1995, suggest that densities of oaks greater than 10 inches (25 cm) in diameter have actually increased slightly since 1883 (fig. 2). Brischler (2002) analyzed densities of oak cut stumps in seven stands on the Coconino National Forest in northern Arizona and found that stump densities averaged 13/acre (33/ha). More than 70 percent of stumps, however, were less than 8 inches (20 cm) in diameter (inside bark at stump height), consistent with the high proportion of live stems and snags in these size classes (fig. 3). Brischler (2002) hypothesized that harvesting was greater for small- to medium-diameter (4 to 8 inch diameter) oaks than for large oaks because smaller oaks were more available, easier to cut and remove, less likely to be hollow, or less likely to be noticed as missing (in the case of illegal cutting). On the Kaibab National Forest near the South Rim of the Grand Canyon, Fulé and others (2002b) found that oak stumps less than 16 inches (40 cm) in diameter averaged 6/acre (15/ha) compared to 0.7/acre (1.7/ha) for stumps greater than 16 inches in diameter.

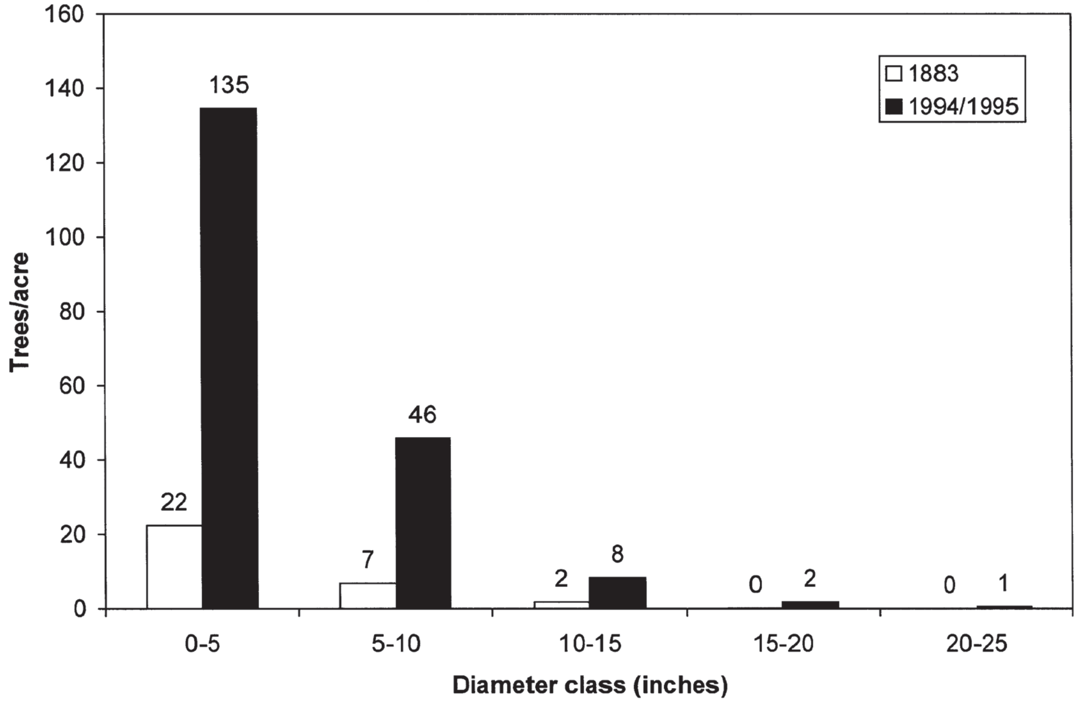

Figure 2—Gambel oak diameter distributions in 1883 and in 1994/1995 at Camp Navajo, northern Arizona. Data from Fulé and others (1997) and P.Z. Fulé (*unpublished data*).

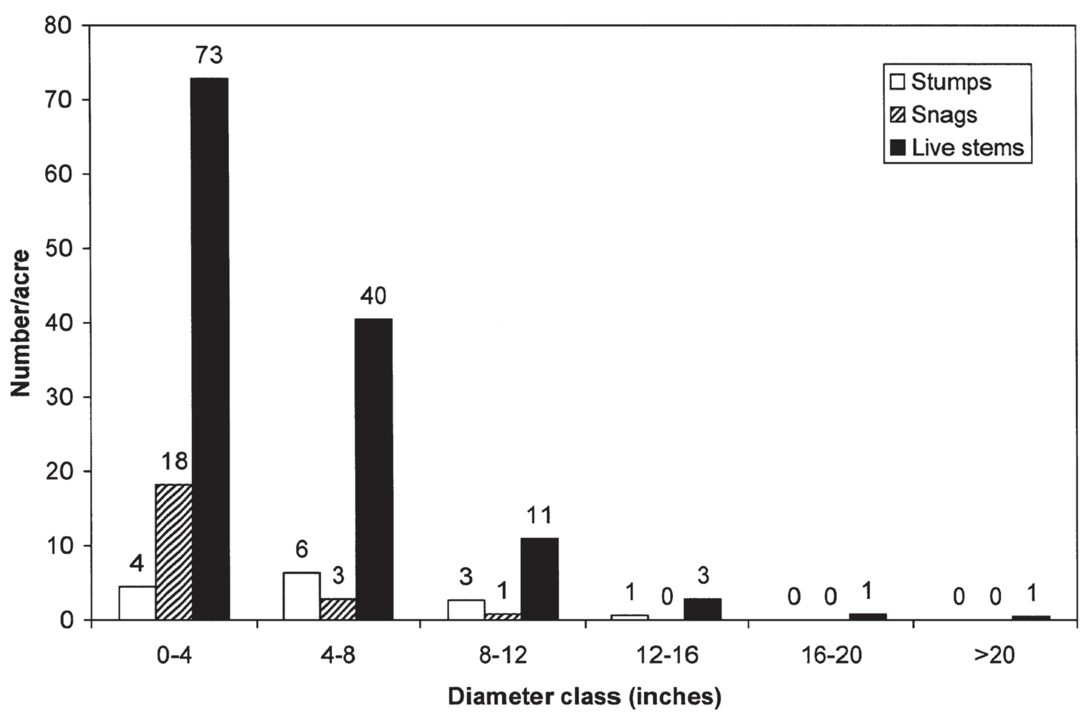

Figure 3—Diameter distributions of standing Gambel oak stems and cut stumps measured in 2000 and averaged for seven pine-oak stands, Coconino National Forest, Arizona. Data from Brischler (2002).

In forest reconstruction studies, it is possible that stumps from long-ago oak harvesting (for example, at the time of settlement) have decomposed and are missing from tree density estimates (Brischler 2002, Fulé and others 1997). However, Fulé and others (1997) noted that old oak stumps could be identified on their plots. Their observation is corroborated by Long's (1941) study of different-aged fences composed of oak posts in Arizona and New Mexico. He found that while 90 percent of the fence posts were from oaks less than 7 inches (18 cm) in diameter, posts persisted for more than 60 years (the oldest fences examined). A study on ponderosa pine by Moore and others (2004) provides additional support for the accuracy of forest reconstruction methods. By comparing reconstructed tree densities with quantitative forest inventory reports from the early 1900s, these authors found that reconstruction methods were accurate to within 10 percent for ponderosa pine tree density.

Past oak cutting varied across the landscape, making generalizations difficult about the possible losses of large oaks due to cutting from place to place (Brischler 2002). However, evidence has not been published to date indicating that densities of large oaks on average have diminished, certainly not to the extent that densities of large ponderosa pine have diminished due to harvesting (Covington and Moore 1994; Mast 2003). Nevertheless, additional research is needed to enrich our understanding of the demographics of large oaks in the past and the present. Furthermore, consideration should be given to conserving existing large oaks because of their ecological value for plant and animal habitat (Harper and others 1985, Reynolds and others 1970).

Management Implications

On many sites in the past 140 years, small-diameter stems of Gambel oak have increased in density as dramatically as those of ponderosa pine. Although additional research is needed to better understand the long-term dynamics of oak density and sprouting under different fire frequencies, there is evidence that the exclusion of fire since settlement has allowed many of these small oak stems to become established. Establishment of these stems probably would have been limited had a frequent-fire regime continued. Prescribed fire or mechanical thinning of small oak stems can temporarily reduce oak density while stimulating sprouting to provide a variety of shrubby and tree forms of oak. However, any type of disturbance that stimulates sprouting, but is followed by a disturbance-free period, is likely to further increase the density of small stems.

Although published evidence is limited for decreases in large Gambel oak since settlement, maintaining existing large oaks could be a priority because of their high ecological value. Tactics to protect large oaks during prescribed fire might include avoiding lighting near the bases of large oaks and keeping fuels (for example, pine slash) away from oaks (Abella and Fulé 2008). To further maintain health and crown vigor of large oaks, thinning competing trees (such as ponderosa pine) appears effective (Fulé and others 2005). Due to oak's clonal habit, it is unclear if the small stems that have proliferated since settlement compete for resources with large, old oak stems. This is an important research need. Managing Gambel oak, including the option of passive management, requires decisions about desired future conditions and how to attain them. A possible reason for passive management, that overall oak abundance has decreased, is not supported by published research.

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