Forest Ecology and Management 394 (2017) 73–85

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Post-1935 changes in Pinyon-Juniper persistent woodland on the South Rim of Grand Canyon National Park, Arizona, USA

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ARTICLE INFO

Article history:
Received 24 September 2016
Received in revised form 14 March 2017
Accepted 15 March 2017
Available online 8 April 2017

Keywords:
Pinyon-juniper woodland
Southwest
Grand Canyon National Park
Permanent plots
Vegetation change

ABSTRACT

Pinyon-juniper (*Pinus-Juniperus*) persistent woodland (PJPW) is widespread in western North America. This study examined changes in PJPW on the South Rim of Grand Canyon National Park (GCNP), Arizona, USA based on resampling study plots established in 1935 that are the earliest-known, landscape-level, quantitative documentation of PJPW. Resampling provided data essential to understanding post-1935 dynamics and current conditions, as well as developing ecologically based management practices.

Plots were divided into Core PJPW, Transition PJPW-Ponderosa Pine Forest (PJPW-PPF), and Seral PJPW. These differed greatly in their post-1935 vegetation dynamics. Core PJPW experienced high mortality of mid-diameter *Juniperus osteosperma* (JUOS) and *Pinus edulis* (PIED), large losses of total basal area, and increases of small-diameter JUOS. In context of other research, these changes indicate drought during 1953–1956, 1959–1964, and 2002–2011 led to increased mortality of JUOS and PIED and that Core PJPW is a dynamic system with phases of tree recruitment and mortality related to climate. In contrast, Transition PJPW-PPF was generally stable, likely as a result of less drought stress at the relatively high elevation where PJPW intergrades with PPF. Seral PJPW plots were early successional in 1935 and provided a uniquely long, quantitative documentation of succession. They changed most among the PJPW subtypes with large increases in total tree density and basal area as plots transitioned into tree-dominated successional stages.

Current conditions of Core PJPW in GCNP provide a model for restoration of PJPW in areas of similar environment. Elsewhere, managers should consider using contemporary data from the area's least-disturbed PJ vegetation. In general, the ultimate goal should be to restore to the least-altered present, not attempt to re-establish the past.

Likewise, findings suggest ongoing management of PJPW in protected areas should not focus on restoration of historical stand structure and composition, as done in PPF. Instead, management should emphasize leaving naturally occurring processes unimpaired. These include disturbances such as stand-replacing fire and native insect outbreaks that historically led to varied spatial and temporal stand composition and structure. However, active management may be needed when modern anthropogenic factors have potential to substantially alter key processes, e.g., if increasing cover of invasive plants such as cheat grass (*Bromus tectorum*) is likely to change the historical fire regime. Also, management plans for adjacent vegetation types such as PPF, shrublands, and grasslands need to consider potential short- and long-term impacts on PJPW. Additional challenges to management of PJPW are likely to arise with further climate change.

1. Introduction

Few data are available on multi-decadal dynamics of Pinyon-Juniper (*Pinus-Juniperus*) vegetation (PJ), despite PJ being widespread in western North America and the subject of numerous studies. Knowledge of such long-term dynamics is essential to

Abbreviations: GCNP, Grand Canyon National Park; JUOS, *Juniperus osteosperma*; NPS, National Park Service; PIED, *Pinus edulis*; PIPO, *Pinus ponderosa*; PJ, pinyon-juniper; PJPW, pinyon-juniper persistent woodland; PPF, ponderosa pine forest; QUGA, *Quercus gambelii*.

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http://dx.doi.org/10.1016/j.foreco.2017.03.018
0378-1127/

understanding current conditions, predicting future changes, and developing ecologically based management practices.

Datasheets from vegetation study plots sampled in PJ in 1935 in Grand Canyon National Park (GCNP), Arizona are the oldest-known quantitative sample of PJ across a landscape. Resampling these plots provides unique possibilities for research on PJ dynamics, especially because of the early date, large number, broad distribution, and minimal post-1935 human disturbance of the plots. Previous resampling of forested plots from 1935 in GCNP provided unique insights into forest dynamics and management practices (Vankat, 2011a, 2011b), and the present study was undertaken to yield such information on PJ.

PJ is dominated by *Pinus* spp. and *Juniperus* spp., but has a wide range of stand structures. One commonly used classification divides PJ into three broad types based on differences in canopy structure, understory characteristics, and historical disturbance regimes: savanna, wooded shrubland, and pinyon-juniper persistent woodland (PJPW; Romme et al., 2008, 2009). PJPW is the most widespread of these types in the American Southwest and the subject of this study. PJPW is present where climate and soils are consistently favorable to pinyons and/or junipers (Romme et al., 2008, 2009). Canopy cover ranges from nearly closed to very open, and tree height is up to 10 m. PJPW typically occurs on uplands with shallow, poorly developed, rocky soils (Jacobs et al., 2008). The understory of shrubs, subshrubs, grasses, and forbs is often sparse. Ground cover is typically bare soil and rock, with litter below trees.

The disturbance regime of PJPW has been dominated by the interactions of fire, insects, and weather. The historical fire regime was characterized by stand-replacing fires with turnover times of at least 400–600 years, and low-severity surface fires were unlikely to have been important (Floyd et al., 2000, 2004, 2008; Shinneman and Baker, 2009). Limiting factors for stand-replacing fires appear related to weather, with fires generally following dry winters and/or dry springs (Floyd et al., 2004) and requiring strong winds to spread (Floyd et al., 2008). Major outbreaks of pinyon bark beetles (*Ips confusus*) and subsequent mortality of pinyon pines have occurred multiple times in the American Southwest, including in the 1950s, 1990s, and 2000s (Allen, 1989; Swetnam and Betancourt, 1998; Breshears et al., 2005; Floyd et al., 2015). Each outbreak occurred with regional drought during which water stress reduced the ability of pinyon pines to resist bark beetles. Beetle outbreaks resulted in episodic tree mortality, which was followed by post-drought tree recruitment (Betancourt et al., 1993; Swetnam and Betancourt, 1998; Barger et al., 2009; Romme et al., 2009; Shinneman and Baker, 2009; Jacobs, 2011). Therefore, periodic drought increases the probability of both fire and insect outbreaks, but alternates with wet periods associated with pulses of tree regeneration and establishment (Swetnam et al., 1999; Romme et al., 2009; Shinneman and Baker, 2009).

Despite numerous studies, little is known about historical conditions and changes in PJ. Descriptions and photographs of PJ from the 19th century are too widely dispersed and PJ vegetation too varied for generalizations (Vankat, 2013b). Relict sites, mostly on mesa tops, have been sampled (e.g., Jameson et al., 1962; Rowlands and Brian, 2001 in GCNP), but such sites are not broadly representative. Stand reconstructions of 19th-century historical tree composition and structure through analysis of rings of living trees and estimation of ages of snags and downed logs have been attempted (Landis and Bailey, 2005; Huffman et al., 2008b); however, their accuracy is open to question (Vankat, 2013b). Resampling historical study plots, as done in this study, is another approach for insight into changes, but has been uncommon and previously limited to a span of a few decades.

The overall objective of this study is to use repeat sampling to determine and interpret changes in PJPW since 1935 on the South Rim of GCNP. Specific objectives are:

(a) Compare the vegetation of the different subtypes of PJPW.
(b) Compare the 1935–2011 vegetation dynamics of the subtypes in relation to climate.
(c) Compare the 1935–2011 vegetation dynamics of the subtypes in relation to fire and succession.
(d) Determine implications for restoration and ongoing management of PJPW.

2. Methods

2.1. Study area

GCNP is located on the Colorado Plateau in northern Arizona and includes nearly 5000 km^2 of highly diverse topography. This study is based on resampling the 1935 plots in PJPW on the South Rim of GCNP. PJPW is much more extensive and more continuous in distribution on the South Rim than on GCNP's North Rim, which has few 1935 plots in PJPW. Also, the 1935 plots in PJPW are more evenly distributed on the South Rim than in the Park's Inner Canyon, where they are clustered in a few areas.

PJPW is the most common vegetation type on the South Rim of GCNP, where it is dominated by PIED and *Juniperus osteosperma* (JUOS; see Table 1 for full scientific names of tree species sampled). At the upper portion of its elevational range on the South Rim, stands of PJPW may form a mosaic with stands of ponderosa pine forest (PPF), but with intergradation of PIED, JUOS, and other species. At low elevations, PJPW intergrades with sagebrush (*Artemisia tridentata*) shrubland. Small stands of grassland are sometimes present within PJPW. Most PJPW stands on the South Rim are on flat terrain or gentle slopes, at 1800–2300 m elevation, and on limestone parent material. The regional climate is characterized by a bimodal precipitation regime, with mostly snow in winter and monsoonal rainfall from mid-summer to early fall. The "Grand Canyon N P 2" weather station, located on the South Rim near an ecotone between PJPW and PPF, received an average annual precipitation of 40.8 cm, including 115.3 cm of snowfall, during 1976–2012 (Western Regional Climate Center, 2017).

The history of the landscape of PJPW on the South Rim includes millennia of use by Native Americans (Anderson, 1998) for hunting game, collecting pinyon nuts, raising agricultural crops, and sourcing wood for construction and fuel. Vegetation cover apparently was affected on a localized basis, possibly primarily through burning to create agricultural fields as has been described for other locations (cf. Kohler and Matthews, 1988; Kohler, 1992; Sullivan et al., 2015). The only common, widespread land use by early Euramericans in PJPW on the South Rim was livestock grazing, which began in the 1860s (Hughes, 1978; Anderson, 1998, Michael F. Anderson, personal communication). Following the creation of GCNP in 1919, the National Park Service (NPS) attempted to exclude livestock grazing, first by reducing grazing permits and shortening the grazing season and in the 1930s by building a fence along the southern boundary of the South Rim region of the Park (Hughes, 1978). Fire suppression, which began around 1905 in the GCNP area (see summary in Vankat, 2011a), is unlikely to have

Table 1
Tree species sampled. Nomenclature follows Integrated Taxonomic Information System (2017). Acronyms: first two letters of the genus and species.

Scientific name	Common name	Acronym
Juniperus osteosperma (Torr.) Little	Utah juniper	JUOS
Pinus edulis Engelm.	Colorado pinyon	PIED
Pinus ponderosa Douglas ex P. Lawson & C. Lawson	Ponderosa pine	PIPO
Quercus gambelii Nutt.	Gambel oak	QUGA