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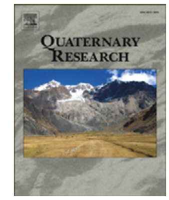

Using fire regimes to delineate zones in a high-resolution lake sediment record from the western United States

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ABSTRACT

Paleoenvironmental reconstructions are important for understanding the influence of long-term climate variability on ecosystems and landscape disturbance dynamics. In this paper we explore the linkages among past climate, vegetation, and fire regimes using a high-resolution pollen and charcoal reconstruction from Morris Pond located on the Markagunt Plateau in southwestern Utah, USA. A regime shift detection algorithm was applied to background charcoal accumulation to define where statistically significant shifts in fire regimes occurred. The early Holocene was characterized by greater amounts of summer precipitation and less winter precipitation than modern. Ample forest fuel and warm summer temperatures allowed for large fires to occur. The middle Holocene was a transitional period between vegetation conditions and fire disturbance. The late Holocene climate is characterized as cool and wet reflecting an increase in snow cover, which reduced opportunities for fire despite increased availability of fuels. Similarities between modern forest fuel availability and those of the early Holocene suggest that warmer summers projected for the 21st century may yield substantial increases in the recurrence and ecological impacts of fire when compared to the fire regime of the last millennium.

Introduction

Recent episodes of historically unprecedented tree mortality suggest that forest ecosystems in western North America (WNA) are undergoing substantial and rapid reorganization (Williams et al., 2010). Forest disturbance regimes are decoupling from historic norms due to warming temperatures, advancing spring snowmelt, and increasing aridity that are resulting in novel ecological outcomes and states (Scheffer et al., 2001; Westerling et al., 2006; Raffa et al., 2008). Long-term ecological records, such as those reconstructed from sediments archived in lakes, offer key insights into abrupt changes in climate and disturbance regimes. During the coming century, new ecological challenges will require a re-evaluation of land stewardship policies that will benefit greatly from consideration of longer term ecological records (Willis and Birks, 2006).

Because fire is a keystone ecological process across a diversity of landscapes, the fire-regime concept is often emphasized as a common and accessible construct for interdisciplinary discourse (Falk and Swetnam, 2003; Conedera et al., 2009; Whitlock et al., 2010). Fire regimes are timescale-dependent, and therefore may include numerous biotic and abiotic attributes to describe fire variability (Whitlock et al., 2010). Over longer temporal scales, fire regimes are responsive to insolation variability, climate dynamics, human pressures, and forest composition (Power et al., 2008, 2012). Here we define "fire regime" as the disturbance characteristics of fire frequency and severity over centennial to millennial timescales.

Recent advances in quantitative techniques used to reconstruct wildfire from lake sediments include quantitative biomass metrics (Marlon et al., 2006; Seppä et al., 2009); compilation of the Global Palaeofire Database (Power et al., 2010); statistical decomposition and peak detection schemes (Long et al., 1998; Higuera et al., 2010); paired proxy approaches using historical records, tree rings, and lake sediments (Higuera et al., 2011); charcoal dispersion models (Higuera et al., 2007); and circumspect laboratory, field, and site selection protocols (Whitlock and Millspaugh, 1996; Whitlock and Larsen, 2001; Ali et al., 2009).

Building on these advances, we apply a regime shift detection algorithm to determine where statistically significant shifts in charcoal accumulation occur (Rodionov, 2004). We characterize these shifts as a switch in fire regimes attributable to climate-mediated changes in vegetation structure and composition. We elected to examine the paleoecological reconstruction presented here through the lens of wildfire because of the ecologically isolated location of our study site. This condition allows us to discount the possibility of immigration of fire-prone or fire-adapted species, known in many regions to be an important catalyst

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for fire regime shifts (e.g., Lynch et al., 2004; Ohlson et al., 2011). In our analysis, we assume that climate-driven changes to forest structure, fuel moisture, and fire-season length are dominant controls on fire recurrence and magnitude.

In this lake-sediment reconstruction we use charcoal to delineate stratigraphic zones. Stratigraphic records are typically analyzed using clustering, binary, or optimal statistical approaches to identify periods of similar (or uniform) pollen composition (Grimm, 1987; Ritchie, 1995; Bennett, 1996). However, these approaches implicitly assume that plant diversity and/or changes in plant community composition are the primary objective(s) of the reconstruction. At most sites, the pollen assemblage provides a minimum estimate of the surrounding plant communities, under-representing species present by an order of magnitude (Ritchie, 1995). Furthermore, the reliability and representativeness of zones are often influenced by the temporal resolution of pollen samples, which may vary considerably within a single core and among sites (Bennett, 1996). On the other hand, stratigraphic charcoal records can be analyzed efficiently at every contiguous centimeter and are representative of climate effects on biomass and forest stand conditions. In ecologically isolated landforms, such as sky islands in southwestern USA, the immigration of novel species into upland forests is improbable due to vast expanses of *Artemisia* (sagebrush) steppe at lower elevations that has persisted across the southwest since at least the Pleistocene (Davis, 1990; Davis and Pitblado, 1995). Therefore, delineating biostratigraphic zones using a pollen assemblage may be less useful in these and similar ecosystems. In contrast to pollen records, charcoal records from these sky island ecosystems exhibit considerable variability and can be used to characterize time-transgressive reorganizations of vegetation and fuel structure (Morris, 2011).

This sedimentary charcoal reconstruction is the first high-resolution fire history for the Markagunt Plateau ("Markagunt," here after) (Fig. 1a). Information about the long-term role of fire on the Markagunt is of great interest because numerous private residences and commercial structures, including the Brian Head Ski Resort, exist within a matrix of federally managed wildland. In this paper we describe Holocene

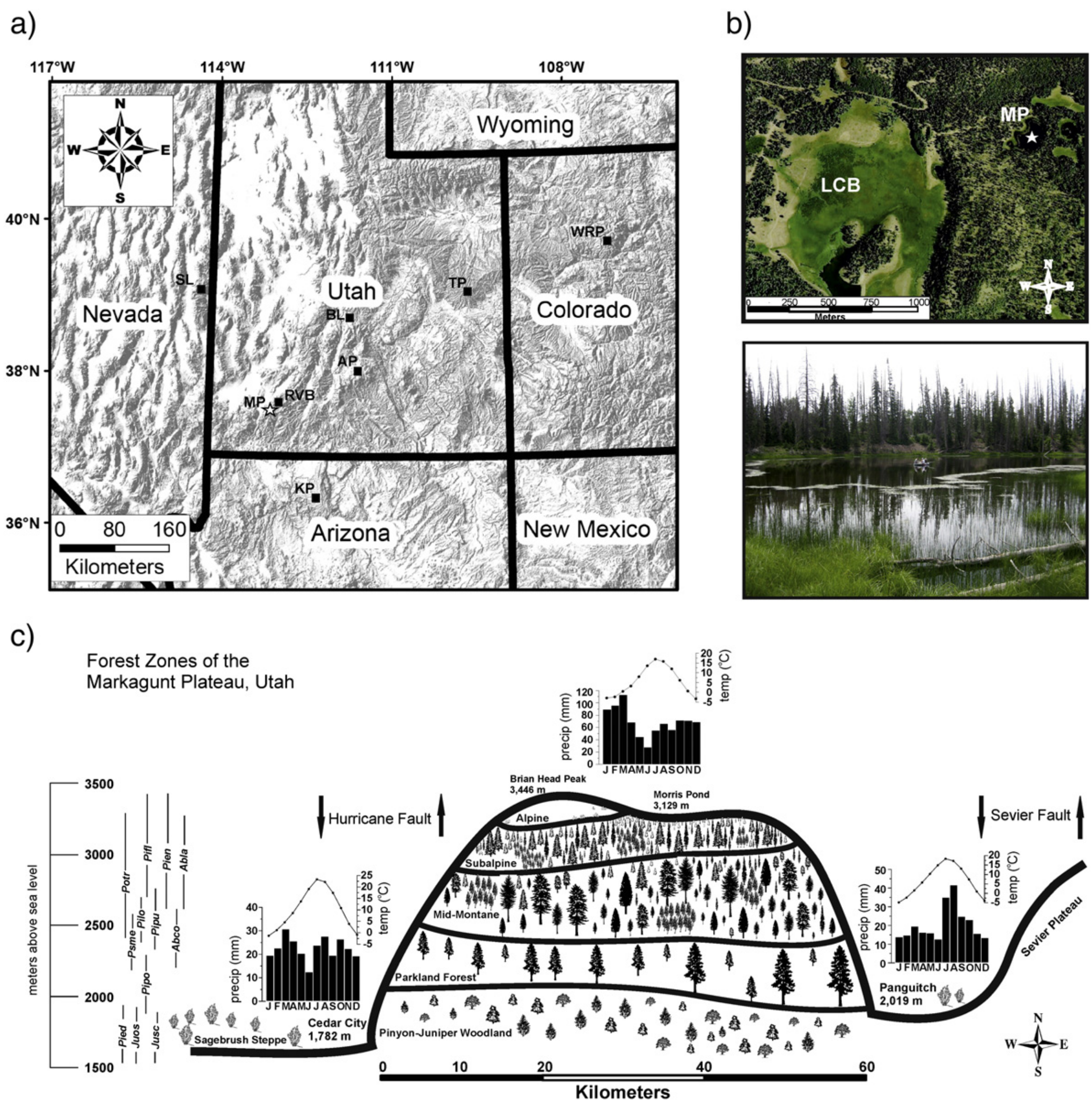

Figure 1. a) Map of the western United States depicting the location of the Markagunt Plateau (☆) and other sites discussed herein (■): BL = Blue Lake (Morris et al., 2010), KP = Kaibab Plateau (Weng and Jackson, 1999), AP = Aquarius Plateau (Morris and Brunelle, 2012), RVB = Red Valley Bog (Madsen et al., 2002), SL = Stella Lake (Reinemann et al., 2009), TP = Tavaputs Plateau (Knight et al., 2010), and WRP = White River Plateau,(Anderson, 2011, 2012). b) Images of Lowder Creek Bog (LCB) (Anderson et al., 1999) and Morris Pond (MP) (this study) sites; ☆ indicates approximate location where sediment cores were collected. c) Schematic representation of forest zones and climagraphs depicting relationships among key forest taxa, precipitation, and temperature versus elevation.