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Rangeland Ecology & Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: http://www.elsevier.com/locate/rama

Assessing the Potential for Transitions from Tallgrass Prairie to Woodlands: Are We Operating Beyond Critical Fire Thresholds?

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ARTICLE INFO

Article history:
Received 15 June 2015
Received in revised form 21 March 2016
Accepted 22 March 2016
Available online xxxx

Key Words:
catastrophic shifts
forecasting
mesic grasslands
regime shifts
resilience
tipping points

ABSTRACT

A growing body of evidence suggests humans are pushing ecosystems near or beyond key ecological thresholds, resulting in transitions to new, sometimes undesirable phases or states that are costly to reverse. We used remotely sensed fire data to assess if the Flint Hills—a landscape of tallgrass prairie in the Central Great Plains, United States—is operating beyond fire frequency thresholds. Long-term fire experiments and observational evidence suggests that applying prescribed fire at return intervals > 3 yr can lead to transitions from grassland to shrubland. Fire return intervals > 10 yr and complete fire suppression, in particular, can result in transitions to woodlands over 30 − 50 yr. Once shrublands and woodlands are established, restoration back to grassland is difficult with prescribed fires. We applied these fire frequency cutoffs to remotely sensed fire data from 2000 to 2010 in the Flint Hills, identifying the extent of tallgrass prairie susceptible to shrub and tree expansion. We found that 56% (15 620 km^2) of grasslands in this region are burned less than every 3 yr and are therefore susceptible to conversion to shrub or tree dominance. The potential effects of this large-scale shift are greater risk for evergreen *(Juniperus virginiana)* woodland fires, reduced grazing potential, and increased abundance of woodland adapted species at the expense of the native grassland biota. Of the 12 127-km^2 area likely to remain grassland, 43% is burned approximately annually, contributing to vegetative homogenization and potential air-quality issues. While this synthesis forecasts a precarious future for tallgrass prairie conservation and their ecosystem services, increases in shrub or tree dominances are usually reversible until fire frequency has been reduced for more than 20 yr. This delay leaves a small window of opportunity to return fire to the landscape and avoid large-scale transformation of tallgrass prairie.

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Introduction

A major challenge in rangeland stewardship is managing in the face of uncertainty and multiple trade-offs (Westoby et al., 1989; Chapin et al., 2011; Collins et al., 2011). Two core challenges are avoiding ecological thresholds or "tipping points" (Walker and Salt 2006; Briske et al., 2008; Rockström et al., 2009, Barnosky et al., 2012) and maintaining the social and ecological diversity that confers adaptive potential to unknown challenges in the future (Chapin et al., 2011; Carpenter et al., 2012). In this synthesis, we focus on fire management in tallgrass prairie, which, along with grazing, is one of the most widely manipulated ecological processes in grasslands, savannas, and related rangelands (Bowman et al., 2009; Archibald et al., 2012; Ellis et al., 2013).

The tallgrass prairie grasslands of the Central Great Plains play an important societal role in this region. The geology over much of the Flint Hills landscape—our study region—precluded conversion to tillage agriculture but was conducive to cattle ranching (Smith and Owensby 1978), which remains a prominent source of agricultural livelihoods throughout much of the landscape (Middendorf et al., 2009). Intact tallgrass prairie provides a suite of other ecosystem services, such as freshwater, resistance to soil erosion, wildlife habitat, and mitigation of nutrient deposition (Kaufman et al., 1990; Fuhlendorf et al., 2009; McLauchlan et al., 2014; Matlack et al., 2008). Tallgrass prairie also has an important conservation role. In North America, tallgrass prairie has been reduced to ~4% of its historical extent (Sampson and Knopf, 1994), making it one of the most altered ecosystems in North America

Z.R. was supported by a Dept of Education "Graduates Addressing Areas of National Need" fellowship awarded to Kansas State University (KSU) Biology and NSF postdoctoral fellowship (DBI 1402033). This work was partially made possible by multiple Long-Term Ecological Research grants from National Science Foundation (current DEB 1440484), Division of Biology and the Agricultural Experimental Station at KSU.

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http://dx.doi.org/10.1016/j.rama.2016.03.004
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Please cite this article as: Ratajczak, Z., et al., Assessing the Potential for Transitions from Tallgrass Prairie to Woodlands: Are We Operating Beyond Critical Fire Thresholds?, Rangeland Ecology & Management (2016), http://dx.doi.org/10.1016/j.rama.2016.03.004

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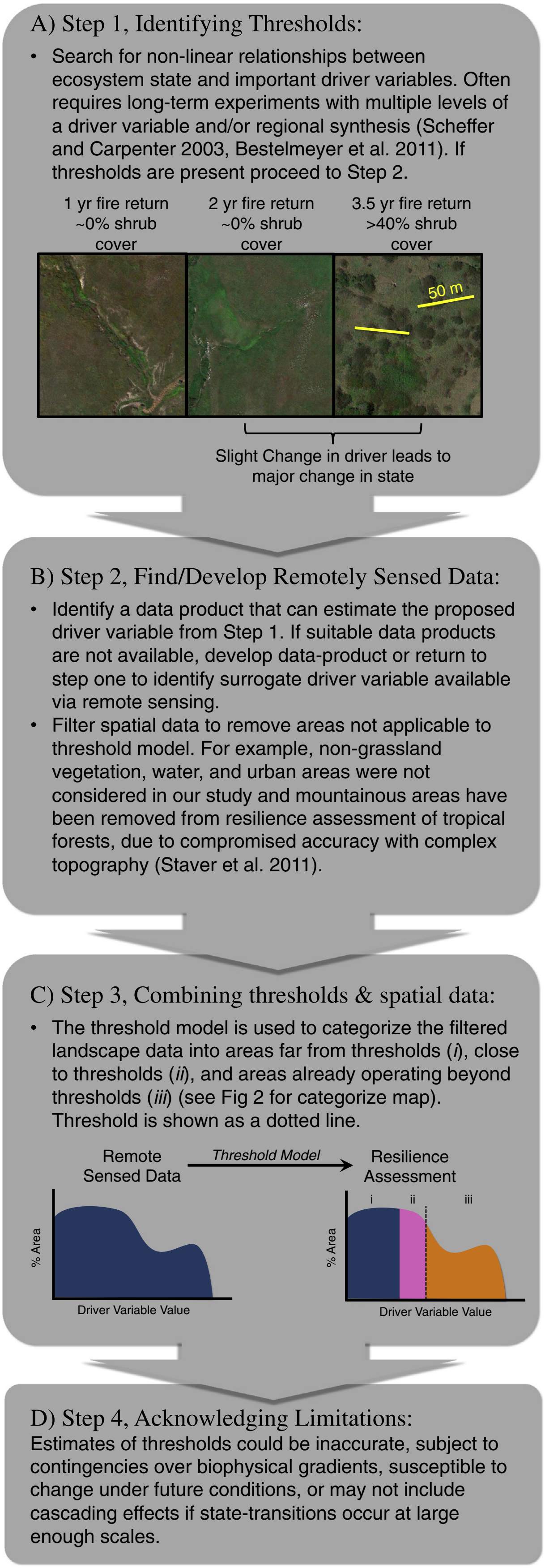

Fig. 1. A schematic of the process used in this study to combine an ecological threshold framework with remotely sensed data. Satellite images in "Step 1" are from Google Earth imagery in the year 2012 in lowlands of watersheds 1D, 2A, and 4B at Konza Prairie Biological Station and LTER (located in Riley County, KS). Note that the darker green vegetation in the 3.5-yr fire return interval are large shrub species capable of overtopping and excluding grasses (primarily Roughleaf Dogwood, *Cornus drummondii*). No shrubs are present in the aerial photographs shown for 1- and 2-yr fire return intervals.

(Hoekstra et al., 2005). Loss of this landscape contributes to the decline of grassland bird populations, one of the fastest diminishing avifauna in North America (Sauer and Link 2011). The Flint Hills landscape is the largest remaining tract of intact tallgrass prairie landscape (Samson and Knopf 1994). For this reason, loss of grasslands within this region has a major impact on tallgrass prairie conservation.

Many challenges exist to maintain economic productivity and biodiversity in tallgrass prairies, including the Flint Hills. One is the transition of tallgrass prairie to shrublands and woodlands, often referred to as "woody encroachment" (Briggs et al., 2005; Fig. 1). Woody encroachment alters ecosystem structure and function of temperate grasslands, resulting in a loss of biodiversity and grazing productivity (Coppedge et al., 2001; Engle et al., 2008; Fuhlendorf et al., 2008; Eldridge et al., 2011; Ratajczak et al., 2012; Anadon et al., 2014). Transitions to woodlands near urban and suburban areas may also pose a danger to humans, as woodlands can sustain large crown fires with flames up to 15 m in height, with the potential to cast embers into settled areas (Twidwell et al., 2013a, 2013b).

Transitions to shrubland and woodland in temperate climates are largely attributed to changes in fire management (Briggs et al., 2005; Peterson et al., 2007, Bond 2008; see discussion for other factors). In the Flint Hills, humans are a major determinant of where and when fires occur (Stambaugh et al., 2013; Twidwell et al., 2013b). In tallgrass prairie, reoccurring fire intervals of > 3 yr between fires can potentially result in transitions to shrublands or woodlands (Ratajczak et al., 2014a and see methods). While 1- to 2-yr fire intervals are common in some portions of tallgrass prairie, the geographic extent of tallgrass prairie burned infrequently enough to foster transitions from grassland to shrubland and woodland is still debated (Engle et al., 2008; Twidwell et al., 2013a, b), but empirical assessments are lacking. Current and projected increases in grazing pressure (Fuhlendorf et al., 2008), winter precipitation (Nippert et al., 2013), and atmospheric CO_2 (Bond and Midgley 2012) should further increase the probability of transitions to shrubland/woodland.

Woody encroachment is not the only fire-related management concern in the Central Great Plains. Many cattle ranching operations employ frequent spring burns to remove dead litter and enhance palatability, leading to greater and more consistent weight gain in cattle (Smith and Owensby 1978; Vermeire and Bidwell 1998). While annual spring burning is beneficial in curtailing woody encroachment, it also can homogenize plant and avian communities (Kaufman et al., 1990; Collins et al., 1998; Reinking 2005; Matlack et al., 2008; Fuhlendorf et al., 2009; Collins and Calabrese 2012; McNew et al., 2015). More recently, smoke from prescribed burns has been implicated in urban air-quality problems, stimulating the discussion and adoption of various smoke management options (see http://www.ksfire.org/ for more details).

The transformative and often intransigent nature of ecosystem transitions to shrubland and woodland (Briggs et al., 2005; Twidwell et al., 2013a) make it critical to forecast the potential for shrub and tree expansion. Similarly, relying primarily on annual burning at a large scale could reduce the adaptive potential to unforeseen challenges (Carpenter et al., 2012), in addition to its noted potential impacts on air quality. Combining satellite estimates of fire frequency (Mohler and Goodin, 2011) with the recently developed fire threshold framework for the Central Great Plains (Ratajczak et al., 2014a), we assess the susceptibility of the Flint Hills to shrubland and woodland transitions. This study area is a landscape of tallgrass prairie and multiple human uses and settlement types, with ~28,000 km^2 of grassland (Fig. 2). For

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