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Mapping Tree Canopy Cover in Support of Proactive Prairie Grouse Conservation in Western North America☆

Michael J. Falkowski [a,*], Jeffrey S. Evans [b,c], David E. Naugle [d], Christian A. Hagen [e], Scott A. Carleton [f], Jeremy D. Maestas [g], Azad Henareh Khalyani [h], Aaron J. Poznanovic [i], Andrew J. Lawrence [j]

[a] Department of Ecosystem Science and Sustainability, Colorado State University, Fort Collins, CO 80523, USA
[b] The Nature Conservancy, Fort Collins, CO 80524, USA
[c] Department of Zoology and Physiology, University of Wyoming, Laramie, WY 82071, USA
[d] Wildlife Biology Program, University of Montana, Missoula, MT 59812, USA
[e] Department of Fisheries and Wildlife, Oregon State University, Bend, OR 97702, USA
[f] US Geological Survey, New Mexico Cooperative Fish and Wildlife Research Unit, Las Cruces, NM 88003, USA
[g] US Department of Agriculture, Natural Resources Conservation Service, Redmond, OR 97756, USA
[h] Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523, USA
[i] Department of Forest Resources, University of Minnesota, St. Paul, MN 55108, USA
[j] New Mexico State University, Department of Biology, Las Cruces, NM 88003, USA

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ABSTRACT

Invasive woody plant expansion is a primary threat driving fragmentation and loss of sagebrush (*Artemisia* spp.) and prairie habitats across the central and western United States. Expansion of native woody plants, including conifer (primarily *Juniperus* spp.) and mesquite (*Prosopis* spp.), over the past century is primarily attributable to wildfire suppression, historic periods of intensive livestock grazing, and changes in climate. To guide successful conservation programs aimed at reducing top-down stressors, we mapped invasive woody plants at regional scales to evaluate landscape level impacts, target restoration actions, and monitor restoration outcomes. Our overarching goal was to produce seamless regional products across sociopolitical boundaries with resolution fine enough to depict the spatial extent and degree of woody plant invasion relevant to greater sage-grouse (*Centrocercus urophasianus*) and lesser prairie-chicken (*Tympanuchus pallidicinctus*) conservation efforts. We mapped tree canopy cover at 1-m spatial resolution across an 11-state region (508 265 km^2). Greater than 90% of occupied lesser prairie-chicken habitat was largely treeless for conifers (<1% canopy cover), whereas > 67% was treeless for mesquite. Conifers in the higher canopy cover classes (16 − 50% and >50% canopy cover) were scarce (<2% and 1% canopy cover), as was mesquite (<5% and 1% canopy cover). Occupied habitat by sage-grouse was more variable but also had a relatively large proportion of treeless areas ($\bar{x}$ = 71, SE = 5%). Low to moderate levels of conifer cover (1 − 20%) were fewer ($\bar{x}$ = 23, SE = 5%) as were areas in the highest cover class (>50%; $\bar{x}$ = 6, SE = 2%). Mapping indicated that a high proportion of invading woody plants are at a low to intermediate level. Canopy cover maps for conifer and mesquite resulting from this study provide the first and most geographically complete, high-resolution assessment of woody plant cover as a top-down threat to western sage-steppe and prairie ecosystems.

Introduction

In the western United States and southern Great Plains, the expansion of invasive woody plants into predominantly treeless landscapes has structurally altered these ecosystems and reduced habitat availability for many wildlife species (Brown and Archer, 1999; Engle et al., 2008; Miller et al., 2011). Expansion of native woody plants, including conifer (primarily *Juniperus* spp.) and mesquite (*Prosopis* spp.), over ca. 130 years is primarily attributable to wildfire suppression, historic periods of intensive livestock grazing, and changes in climate (Brown and Archer, 1989; Miller and Wigand, 1994; Miller and Rose, 1999;

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* Correspondence: Michael J. Falkowski, Dept of Ecosystem Science and Sustainability, Colorado State University, Fort Collins, CO, 80523, USA.
E-mail address: M.Falkowski@colostate.edu (M.J. Falkowski).

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Waichler et al., 2001; Miller et al., 2005; Van Auken, 2009). Woody encroachment increases surface water runoff and erosion by shading out the native abundance and diversity of herbaceous cover (Buckhouse and Gaither, 1982; Gaither and Buckhouse, 1983; Miller et al., 2011). With increased runoff and rainfall interception, encroachment can lower the water table, thus reducing water availability in the system, benefitting more deeply rooted species such as mesquite (Baker, 1984; Heitschmidt et al., 1988; Wilcox, 2002; Thorp et al., 2013; Ansley et al., 2014). Woody encroachment—related habitat changes in turn can have negative consequences on prairie grouse by altering food availability and predator dynamics, among others.

Indeed, impacts to wildlife populations from woody encroachment—related changes in ecosystem dynamics are well known. In the southern Great Plains the invasion of eastern redcedar *(Juniper virginiana)* and mesquite into prairie ecosystems has been linked to population declines in the lesser prairie-chicken (*Tympanuchus pallidicinctus,* hereafter prairie-chicken[s]) (Fuhlendorf et al., 2002; Hunt and Best, 2010) and other grassland nesting birds (Coppedge et al., 2001; Grant et al., 2004). Similarly, woody species encroachment has been demonstrated to impact site occupancy of greater prairie-chicken (*Tympanuchus cupido;* McNew et al., 2012). In a recent study, prairie-chicken space use was constrained by the distribution and density of invasive mesquite trees (Boggie et al., 2017-this issue) and redcedar (Lautenbach et al., 2017-this issue). In sage-steppe ecosystems of the Great Basin, numerous studies have documented impacts from conifer encroachment to greater sage-grouse (*Centrocercus urophasianus,* hereafter sage-grouse; Doherty et al., 2008; Atamian et al., 2010; Doherty et al., 2010; Casazza et al., 2011; Baruch-Mordo et al., 2013; Knick et al., 2013a, 2013b) and other sagebrush obligates (Noson et al., 2006; Larrucea and Brussard, 2008; Woods et al., 2013; Holmes et al., 2017-this issue).

Broad-scale mapping of invasive woody species is urgently needed to inform proactive management to restore habitats impacted by woody encroachment already under way through partnership efforts, such as the National Resource Conservation Service (NRCS)-led Sage-Grouse Initiative (SGI; NRCS, 2015a) and Lesser Prairie-chicken Initiative (LPCI; LPCI, 2015). To date, SGI has invested $760 million in sage-grouse conservation, including the mechanical removal of early successional conifer to restore 182 610 ha (451 239 ac) of sage-steppe habitats in and around sage-grouse population strongholds (NRCS, 2015a). Similarly, LPCI has invested $1.06 million in prairie-chicken habitat conservation and, with partners, has leveraged 67 723 ha (166 112 ac) of prairie restoration through redcedar and mesquite removal.

Regional mapping of woody invasion using remotely sensed data to inform species and ecosystem conservation has become increasingly feasible and desired, yet efficacy depends on the scale of the object of interest (e.g., individual or stand of wood plants), sensor-specific resolutions, and spatial extent of the mapping area of interest (Coops et al., 2007; Falkowski et al., 2009). Remote sensing systems that acquire images with large spatial extents will have a lower spatial resolution and will ultimately measure less spatial detail as compared with images acquired by higher spatial resolution sensors that provide detailed depictions of ecosystem characteristics across small spatial extents. The emergence of object-based image analysis (OBIA) techniques and very high spatial resolution (VHSR) data (spatial resolution < 2 m) has resulted in increased accuracy and precision of woody plant mapping. OBIA methods extract objects of interest from digital imagery by first grouping together neighboring pixels with similar spectral and spatial properties and then classifying these pixel groups into objects of interest (e.g., trees). When using VHSR data for mapping woody plants, OBIA outputs are typically polygons delineating specified objects of interest (e.g., woody plants or patches of woody plants; Poznanovic et al., 2014).

Among the various OBIA methods available, spatial wavelet analysis (SWA) is the most efficient method because it requires the least user input and the least amount of processing time to characterize tree and shrub cover, while preserving relatively high accuracies (Poznanovic et al., 2014). In SWA, individual trees are identified by both reflectance and shape, marked with spatial coordinates (x, y), assigned with an image-derived tree crown diameter value, and converted to points and circular buffers indicating tree location and crown area (Falkowski et al., 2006; Smith et al., 2008; Poznanovic et al., 2014). The detailed output provided by SWA can be used to calculate useful metrics including canopy cover, tree density, canopy configuration, and crown diameter distributions, many of which have been identified as important drivers of sage-grouse lek activity (Baruch-Mordo et al., 2013) and prairie-chicken space use (Lautenbach et al., *this issue*; Boggie et al., *this issue*).

In this paper we present the results of a project focused on mapping invasive woody plants at regional scales. These maps are ultimately used to evaluate the threat of invasive woody plants on prairie grouse, aid in spatial targeting of restorative actions, and support the quantification and tracking of restoration progress and outcomes. Our overarching goal is to produce seamless regional products across political and administrative boundaries with a resolution fine enough to allow a nuanced depiction of the spatial extent and degree of woody plant invasion. Toward this end, our mapping framework meets five criteria to ensure its utility:

1. Accurate mapping of woody plant abundance at low canopy values because both grouse species avoid otherwise suitable habitats at < 5% tree canopy cover (e.g., Fuhlendorf et al., 2002; Baruch-Mordo et al., 2013; Knick et al., 2013a, 2013b)
2. Adequate tree-level detail (e.g., tree location and crown diameter) to provide the most flexibility for estimating multiple woody plant metrics such as canopy cover, tree density, spatial canopy configuration, and crown size distributions that could be leveraged in proactive conservation (Baruch-Mordo et al., 2013)
3. High level of consistency in derived woody plant metrics through the leveraging of freely available VHSR data that are collected in a uniform manner
4. Automated processing techniques that directly derive encroachment information from the VHSR data, avoiding methods that require empirical data for parameterization or calibration (e.g., image classification or spectral mixture analysis)
5. High level of automation (through OBIA) given the vast size of the mapping extent, which is balanced and blended with manual image interpretation to maintain consistency and accuracy

Methods

Study Areas

Conifer and mesquite mapping were conducted across two different geographic areas, both corresponding to sage-grouse and prairie-chicken distributions. The sage-grouse mapping area (referred to as SGI mapping extent hereafter) included 414 803 km^2 of occupied habitat within the Western Association of Fish and Wildlife Agencies (WAFWA) Sage-Grouse Management Zones III—V and VII. Mapped areas include priority areas of conservation (PACs) and all surrounding occupied non-PAC habitats regardless of ownership. The prairie-chicken mapping area (referred to as LPCI mapping extent hereafter) included 107 242 km^2 of occupied habitat within four WAFWA ecoregions and included focal areas, connectivity zones (FACZs), and all surrounding modeled habitats (Van Pelt et al., 2013); (Figs. 1 and 2).

Remotely Sensed Data

Digital orthophotos from the National Agriculture Imagery Program (NAIP) were leveraged for mapping woody invasive plants across the SGI and LPCI mapping extents. The NAIP program consistently collects aerial imagery across the United States during the growing season on a 3-yr repeat cycle (USDA FSA, 2016). NAIP imagery data are typically four bands (red, green, blue, and near infrared) with a spatial resolution