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Research article

Production possibility frontiers and socioecological tradeoffs for restoration of fire adapted forests

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ABSTRACT

We used spatial optimization to analyze alternative restoration scenarios and quantify tradeoffs for a large, multifaceted restoration program to restore resiliency to forest landscapes in the western US. We specifically examined tradeoffs between provisional ecosystem services, fire protection, and the amelioration of key ecological stressors. The results revealed that attainment of multiple restoration objectives was constrained due to the joint spatial patterns of ecological conditions and socioeconomic values. We also found that current restoration projects are substantially suboptimal, perhaps the result of compromises in the collaborative planning process used by federal planners, or operational constraints on forest management activities. The juxtaposition of ecological settings with human values generated sharp tradeoffs, especially with respect to community wildfire protection versus generating revenue to support restoration and fire protection activities. The analysis and methods can be leveraged by ongoing restoration programs in many ways including: 1) integrated prioritization of restoration activities at multiple scales on public and adjoining private lands, 2) identification and mapping of conflicts between ecological restoration and socioeconomic objectives, 3) measuring the efficiency of ongoing restoration projects compared to the optimal production possibility frontier, 4) consideration of fire transmission among public and private land parcels as a prioritization metric, and 5) finding socially optimal regions along the production frontier as part of collaborative restoration planning.

1. Introduction

Restoration programs in many socioecological systems face substantial challenges prioritizing activities and balancing competing objectives (Maron and Cockfield, 2008; Bullock et al., 2011; Allan et al., 2013). These challenges have inspired researchers to develop a wide range of decision support frameworks and tools to help disentangle the spatial and temporal dimensions of restoration goals, and prioritize landscapes for restoration projects (Moilanen et al., 2009; Noss et al., 2009; Watts et al., 2009). Analysis frameworks include the use of production possibility frontiers (PPF) to understand and communicate decision tradeoffs in the production of ecosystem services generated from restoration programs (Maron and Cockfield, 2008; Cavender-Bares et al., 2015a). Tradeoff analyses reveal how the joint spatial organization of ecosystem stressors and services create conflicts and opportunities for restoration programs (Bennett et al., 2009; Allan et al., 2013; Schroter et al., 2014). For instance, spatially correlated restoration opportunities, i.e. co-located stressors and ecosystems services, create opportunities to achieve multiple restoration goals and sustain the production of various ecosystem services (Bennett et al., 2009). The use of PPFs and tradeoff analyses have been discussed as a useful framework for collaborative planning as a means to quantify decision tradeoffs to stakeholders and find socially acceptable and ecologically optimal outcomes (Schroter et al., 2014; Cavender-Bares et al., 2015b; King et al., 2015).

A potential application of PPFs and tradeoff analyses concerns the restoration of fire adapted forests in western North America. A century of selective logging, grazing, and fire suppression has led to widespread densification of forests and a reduction in fire resilient tree species (Noss et al., 2006; USDA Forest Service, 2012), most notably ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson). The result has been a substantial increase in forests that are now prone

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to high intensity wildfires and bark beetle epidemics. Large scale restoration programs initiated on the US national forests have been addressing the problem using a number of management techniques including: 1) selective thinning to reduce stand density, reduce surface and ladder fuels, and remove fire and drought intolerant species; and 2) mechanical treatments and prescribed fire to reduce surface and activity fuels generated from thinning operations (Brown et al., 2004; Agee and Skinner, 2005) (Fig. 1). Forest restoration programs have been widely discussed in the literature including ecological aspects (Moore et al., 1999; Brown et al., 2004; Noss et al., 2006), planning frameworks (Franklin and Johnson, 2012), implementation plans (Rieman et al., 2010), scientific guidelines (Franklin and Johnson, 2012), social constraints (Franklin et al., 2014) and conflicts with biological conservation efforts (Myers, 1995; Prather et al., 2008).

Despite the scrutiny of the program, the issue of prioritizing restoration investments across vast tracts of federal forests in the western US and quantifying associated tradeoffs among expected ecosystem services has received little attention. Restoration planning is inherently complex owing to the broad mix of underlying socioecological goals (USDA Forest Service, 2006, 2013). For instance, restoring historical fire adapted structure in dry fire-prone forests (Noss et al., 2006) while meeting economic outputs expected from restoration programs (Rasmussen et al., 2012) may not result in acceptable levels of wildfire risk reduction for communities on adjacent private lands (Ager et al., 2015), and may adversely impact habitat conservation reserves (Gaines et al., 2010). Prioritization on US national forests in particular is further complicated by collaborative planning processes enacted in US federal statutes (Schultz et al., 2012; Butler et al., 2015) where diverse stakeholder groups actively participate in the planning process. Tradeoff analysis tools and frameworks (e.g., King et al., 2015) to support restoration planning, either in a collaborative venue or otherwise, do not exist at either policy or implementation scales, despite their potential to improve the chance of long-term success (Rappaport et al., 2015).

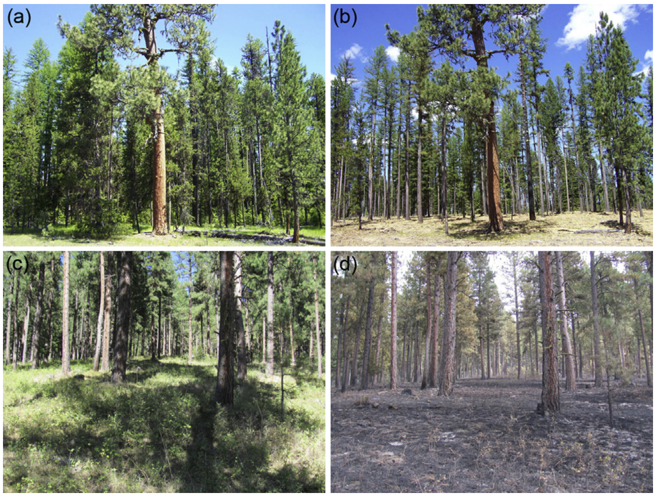

Fig. 1. Example restoration treatments within the Blue Mountains National Forests in eastern Oregon, USA. (a) Pre-treatment stand of ponderosa pine and western larch with advanced regeneration and densification from fire exclusion; (b) same stand as in (a) after receiving thinning treatment to reduce stocking density and select fire resilient species; (c) stand that has received mechanical thinning treatments five years prior is targeted for a maintenance underburning treatment to reduce surface fuels, mimicking natural fire; (d) same stand as in (c) after underburning treatment. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In this paper we describe the application of new analytical methods to analyze restoration tradeoffs on 3 million ha of fire-prone forests in the interior Pacific Northwest, USA. The study area was identified as a national priority to restore ecological resiliency to the diverse forest ecosystems, protect communities from wildfire, and provide economic opportunity to local wood processing mills (Rasmussen et al., 2012). However, the compatibility of these various socioecological objectives under alternative prioritization schemes, has yet to be examined. We asked three primary questions: 1) are there significant tradeoffs among socioecological restoration outcomes expected from the program; 2) are there benefits to a prioritization framework, i.e. can restoration goals be achieved more rapidly by focusing restoration investments on key areas, or are restoration targets evenly distributed; and 3) how efficient are current restoration activities relative to optimal as defined by production possibility frontiers? The study provides both new methods and concepts for forest restoration planning and an example of socioecological tradeoff analysis using spatial optimization.

2. Methods

2.1. Study area

The four national forests (Malheur, Ochoco, Umatilla and Wallowa-Whitman) in the Blue Mountain ecoregion of eastern Oregon and southeastern Washington cover 2.5 million ha (Fig. 2). The area contains numerous small mountain ranges with steep canyons and large areas of plateau, and is dissected by several rivers as part of the Columbia River basin. Elevations are mainly between 900 and 1500 m, although the highest peaks reach close to 3000 m. Dry forests of largely ponderosa pine dominate the lower elevations, with dry mixed conifer (grand fir (*Abies grandis* (Douglas ex D. Don) Lindl.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and moist conifer forests at the higher elevations. Cold dry forested areas are dominated by pure lodgepole pine (*Pinus contorta* Douglas ex Loudon) stands found throughout the area at mid to high elevations. The forests are a mosaic of stand age, density, and species composition as a result of harvest and natural disturbance. Wildfires and insect outbreaks in particular have impacted stand structure and composition over wide areas. About 22,000 ha (0.9%) are consumed annually by wildfires (1992–2013) (Short, 2015), most of which are lightning caused. Major forest insect epidemics are a regular occurrence (Ager et al., 2004) with current outbreaks observed for mountain pine beetle (*Dendroctonus ponderosae* Hopkins) and western pine beetle (*D. brevicomis* LaConte). A number of studies in and around the Blue Mountains have documented departure in stand structure and species composition from historical conditions due to fire exclusion. Most recently Hagmann et al. (2013) reported that stand densities have more than tripled over the past 90 years (68 ± 28 trees ha^{-1} to 234 ± 122 trees ha^{-1}) while mean basal area increased by less than 20%. Most importantly, basal area of larger, fire resilient trees (>53 cm dbh) declined by >50%, and the abundance of large trees as a proportion of the total number of trees per hectare decreased by more than a factor of five.

The US Forest Service (USFS) plans forest restoration treatments on about 20,000 ha annually or about 1.3% of the total managed area (excluding wilderness and roadless areas). It is estimated that 34% (506,696 ha) of managed forests are in need of active restoration (USDA Forest Service, 2013). Restoration objectives include protecting and retaining ecosystem services including clean air, clean water, biodiversity, recreational opportunities, and other services that are threatened by large scale disturbance. Specific treatments mirror management activities on other national forests