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Effects of projected climate change on vegetation in the Blue Mountains ecoregion, USA

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ABSTRACT

We used autecological, paleoecological, and modeling information to explore the potential effects of climate change on vegetation in the Blue Mountains ecoregion, Oregon (USA). Although uncertainty exists about the exact nature of future vegetation change, we infer that the following are likely to occur by the end of the century: (1) dominance of ponderosa pine and sagebrush will increase in many locations, (2) the forest-steppe ecotone will move upward in latitude and elevation, (3) ponderosa pine will be distributed at higher elevations, (4) subalpine and alpine systems will be replaced by grass species, pine, and Douglas-fir, (5) moist forest types may increase under wetter scenarios, (6) the distribution and abundance of juniper woodlands may decrease if the frequency and extent of wildfire increase, and (7) grasslands and shrublands will increase at lower elevations. Tree growth in energy-limited landscapes (high elevations, north aspects) will increase as the climate warms and snowpack decreases, whereas tree growth in water-limited landscapes (low elevations, south aspects) will decrease. Ecological disturbances, including wildfire, insect outbreaks, and non-native species, which are expected to increase in a warmer climate, will affect species distribution, tree age, and vegetation structure, facilitating transitions to new combinations of species and vegetation patterns. In dry forests where fire has not occurred for several decades, crown fires may result in high tree mortality, and the interaction of multiple disturbances and stressors will probably exacerbate stress complexes. Increased disturbance will favor species with physiological and phenological traits that allow them to tolerate frequent disturbance.

Practical Implications

The paleoecological literature tells us that the distribution and abundance of plant species in the Blue Mountains has responded to climatic variation in the past. Altered productivity and functionality of new combinations of species in the future may or may not be a concern, depending on local management objectives and the influence of vegetation on other resources (water, animal species, etc.). Extirpation is rarely without impacts, but ''saving'' some species will be difficult in a rapidly changing climate, making it more realistic to focus on maintaining functionality regardless of species changes.

Increased disturbances are expected to have greater effects on vegetation than gradual effects of higher temperature. Current vegetation management in the Blue Mountains focuses on ecological restoration, including forest density management and hazardous fuel reduction, especially in dry forests that have not experienced fire for several decades. These restoration activities are generally effective, at least at smaller spatial scales (hundreds to a few thousand hectares), reducing the intensity of wildfires and enhancing protection of structures.

Climate-smart management will mostly fine-tune existing practices and help prioritize restoration treatments, rather than cause a major change in management. For example, it would be appropriate to focus treatments at the upper ecotone of where certain species might be expected to move in the future, rather than at the lower ecotone where it would be difficult to maintain those species.

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Desirable stand densities may be lower in the future, in order to maintain tree vigor and make forests "firesafe." Topographic features that affect local climate will merit greater emphasis in how they affect habitats and management prescriptions.

Climate change will affect species and ecosystems in the Blue Mountains ecoregion and we anticipate that altered distribution and abundance of existing vegetation will occur by the end of the 21st century. Direct effects of temperature and indirect effects of disturbance can be incorporated in existing monitoring programs to detect significant changes and develop appropriate management responses. Including climate change as a component of risk assessment will ensure that resource planning will be robust at broad spatial and temporal scales.

1. Introduction

Future climate change is expected to alter vegetation structure and composition, terrestrial ecosystem processes, and the delivery of important ecosystem services over the next century. Climate influences the spatial distribution of major vegetation biomes, the abundance of species and communities within biomes, biotic interactions, and the geographic ranges of individual species. Climate also strongly influences disturbance processes that shape vegetation structure and composition. Land managers are increasingly challenged with developing science-based adaptation strategies to reduce the potential adverse effects of climate change on vegetation and associated ecosystem resources. Here we assess potential effects of climate change on upland vegetation in the Blue Mountains ecoregion using long-term paleoecological records, evidence from experimental and observational studies, and simulation model projections. The assessment includes direct effects of physical factors (e.g., temperature) and indirect effects of disturbance (e.g., wildfire) and other stressors.

The Blue Mountains ecoregion extends from the Ochoco Mountains in central Oregon (USA) to Hells Canyon of the Snake River in northeastern Oregon and adjacent Idaho, and then north to the canyons and basalt rimrock of southeastern Washington (see Halofsky et al., in press). Consisting of mountain ranges in a southwest to northeast orientation, the ecoregion functions ecologically and floristically as a transverse bridge between the Cascade Mountains province to the west, and the middle Rocky Mountains province to the east. The ecoregion is a collection of small mountain ranges and lower elevation valleys and exhibits substantial geographic variability (Wyatt, 2017). Elevation in the region ranges from 267 to 3000 m with high points throughout the Wallowa-Whitman (Sacajawea Peak, 3001 m), Malheur (Strawberry Mountain, 2756 m), and Umatilla (Vinegar Hill Northeast, 2147 m) National Forests. Climatic differences, created in part by complex topography, further contribute variability across the ecoregion. The southern portion is in the rain shadow of the Cascade Range and is associated with warmer and drier Great Basin climatic patterns. While the northern part of the ecoregion is technically east of the Cascade Range, maritime airflow is funneled through the Columbia River Gorge, resulting in higher precipitation (40–200 cm annually) and less seasonally varied temperatures (Heyerdahl et al., 2001).

Vegetation in the Blue Mountain ecoregion reflects the complex elevational, climatic, and disturbance gradients found throughout the area (Wyatt, 2017). Six vegetation zones (Powell, 2012) and numerous plant associations (e.g., Johnson and Clausnitzer, 1995) (Figs. 1–3) have been defined. The lowest elevation plains zone contains grasslands and shrublands. The foothills zone is usually dominated by western juniper (*Juniperus occidentalis*), often with curl-leaf mountain-mahogany (*Cercocarpus ledifolius*) and antelope bitterbrush (*Purshia tridentata*) shrublands. In the northern Blue Mountains, the foothills zone generally supports tall shrublands, often with western serviceberry [*Amelanchier alnifolia*], black hawthorn [*Crataegus douglasii*], and western chokecherry [*Prunus virginiana*]. Located above the western juniper woodlands is the lower montane zone, containing dry conifer forests with ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and grand fir (*Abies grandis*). Warm, dry forests at low-mid elevations are common, with a long history of human use and historical fire exclusion that have altered species composition, forest structure, and stand density. Upper montane forests include Douglas-fir, grand fir, and subalpine fir (*Abies lasiocarpa*). At high elevation, dominant species are Engelmann spruce (*Picea engelmannii*), subalpine fir, and whitebark pine (*Pinus albicaulis*). An alpine zone is often present at high elevation where trees are absent.

2. Assessment context

We use (1) paleoecological records, (2) evidence from experimental and observational studies, and (3) model projections to assess potential climate change effects on future vegetation composition and structure. When different lines of evidence are in conflict, we often rely on autecological and local knowledge and derived logical inferences to weigh different lines of evidence.

In a study at Mud Lake (one of the Anthony Lakes near the crest of the Blue Mountains, 2100 m), pollen profiles indicated more ponderosa pine in approximately the warm mid-Holocene period (~9000–6000 BP before present herinafter BP) as compared the current composition of lodgepole pine (*Pinus contorta* var. *latifolia*), subalpine fir, and Engelmann spruce (Hansen, 1943). The Holocene Epoch began 12,000–11,500 years ago at the close of the Paleolithic Ice Age as the Earth entered a warming trend and the glaciers of the late Paleolithic retreated. A study at Lost Lake (Umatilla National Forest on the edge of the Vinegar Hill-Indian Rock Scenic, 870 m), where grand fir, Douglas-fir, western larch (*Larix occidentalis*), and lodgepole pine have been dominant for the past 7600 years, documented a transition from open woodland to closed canopy forest near the end of mid-Holocene warming and the start of cooler, wetter conditions (4000 BP) (Mehringer, 1997). A study in the eastern Cascade Range (700 m) indicated the development of a pine-oak woodland at 9000 BP at a site currently dominated by ponderosa pine (Whitlock and Bartlein, 1997). Finally, grassland and shrubland dominated the earliest part of the record (20,000 BP), transitioning to ponderosa pine (high elevation) and shrub-steppe (low elevation) in the early Holocene, and mixed conifer forest at higher elevations in the mid-Holocene in the Blue Mountains (Blinnikov et al., 2002).

Climate-informed models that simulate the effects of climate change on vegetation include species distribution models (SDM), process-based models, and landscape models. SDMs correlate current climate and species distributions, then project future suitable habitat (Kerns et al., 2009). Process models are species specific or simulate groups of species with similar functional types. Although the latter do not explicitly include species, they project regionally specific information by incorporating biological processes (e.g. competition) (Bachelet et al., 2001). Landscape models simulate landscape change and processes (e.g., succession, wildfire), and can be spatial or distributional, including nonspatial state-and-transition models (Kerns et al., 2012).

2.1. Modeling approaches and broad-scale projections

Several types of vegetation models were used to project conditions to the end of the 21st century for the Blue Mountain