Temporal Changes in Forest Cover at the National Bison Range

BIOS 35503-01: Practicum of Environmental Field Biology

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Abstract

Treelines in high elevation forests are temperature limited such that increasing temperatures linked to global climate change are causing upslope shifts of treelines worldwide. While such shifts in range are predicted based on shifting isotherms, response at the regional level is often more complex, with local environmental conditions playing an important modifying role. In the present study, aerial photographs were used to investigate changes in forest cover and treeline shifts in the National Bison Range (NBR). A downslope migration of treelines was identified with limited upslope migration. The changes in treeline position identified also led to increases in forest area. The downslope migration of trees is likely caused by fire suppression in the NBR.

Introduction

Global climate is warming at an alarming rate with extensive impacts on ecological communities of the world. The mean global temperature has risen by *c.* 0.6^{o}C in the 20th century (Easterling *et al.* 2000) and the rate of warming for the period 1979-2012 was $0.25\,^{o}$C per decade (Collins *et al*. 2013). The dramatic climate change witnessed in past decades is primarily attributed to anthropogenic emissions of greenhouse gases (GHG), and warming is likely to continue at the same or an accelerated rate for the foreseeable future (Hansen *et al.* 2005; Meehl *et al.* 2005), with global temperatures predicted to rise by another $1.4\text{-}5.8^{o}$C by the year 2100 (Wigley, 2005).

Climate is an important factor that influences species' ranges; it determines distribution of organisms through species-specific physiological thresholds of temperature and water availability (Woodward, 1987). Climate-linked range shifts have already been reported in various plant and animal taxa (Walther *et al.* 2002; Parmesan &

Yohe, 2003); changes in the distribution of birds, butterflies, vertebrate and invertebrate species, and plants have been observed (Walther *et al.* 2002). Mountain plants are especially vulnerable to changes in climate (Pauli *et al.* 1996) because they are highly sensitive to warming temperatures and have limited habitat for migration (Pauli *et al.* 2003).

Rising temperatures associated with anthropogenic GHG emissions are predicted to lead to species migration poleward and upward in elevation (Penuelas & Boada, 2003; Krajick 2004). However, range-shift is not a universal response; many treelines show no change in position despite warming temperature (Hättenschwiler & Körner, 1995; Harsch *et al.* 2009). This difference in response may be a result of the complex ways in which factors affecting species distribution interact. Thus, simple correlation with rising temperatures is not always observed. Likewise, although an upward altitudinal range shift is widely reported for forests in response to warming climate, environmental variability among sites leads to differences in response. For instance, some forests may be unable to shift in range due to steep slopes or lack of sites with adequate geomorphic characteristics (Macias-Fauria & Johnson, 2013). Moreover, there could be a time lag between warming temperatures and forest response, which can be caused by a range of processes that make conditions for seedling recruitment unsuitable (Greenwood *et al.* 2014).

Understanding the processes that drive treeline advance is important to predict future changes in forest distribution. The shift of treeline to higher elevations can have negative impacts on mountaintop communities given their isolation (Greenwood *et al.* 2014); this could lead to reduction and fragmentation of available habitat and eventually species loss (Halloy & Mark, 2003). Furthermore, treeline advance could have

implications on regional carbon budget; an increase in forest area could mean more carbon stored in tree biomass but enhanced soil organic matter decomposition due to priming effects from trees could lead to a decreased amount of carbon stored in the soil (Hartley *et al.* 2012).

The present study examines spatial and temporal changes in forest treeline at the National Bison Range (NBR). The area includes montane forests and grasslands that has been conserved since 1908 for the recovery of bison population. Montane environments are ideal for detecting forest range shifts because of the steep climatic gradient across elevation (Kupfer & Cairns, 1996). Moreover, the area's ecotone between forest and grassland is easily discernable from aerial photographs. The goal was to determine how realized shifts in treeline correspond to those predicted from warming regional temperatures. Aerial photography data were used to assess changes in treeline position, forest elevation and forest density.

Methods

Study Area

The National Bison Range (NBR) lies in the Flathead River Valley in western Montana (47^o19'N, 114^o12'W; Fig. 1). It is a National Wildlife Refuge consisting of small, low-rolling mountains, and it is connected to the Mission Mountain Range by a gradually descending spur. Range elevation varies from 788 meters to 1489 meters at High Point on Red Sleep Mountain. The 7504-ha range is a diverse ecosystem of grasslands, forests, riparian areas and ponds (USFWS, 2013). The grassland is dominated by Palouse Prairie vegetation, with blue-bunch wheat grass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), and rough fescue (*Festuca scabrella*) as the principal

species. At high elevation, Douglas-fir (*Pseudotsuga menziesii*) stands dominate north aspects and ponderosa pine (*Pinus ponderosa*) stands dominate south aspects (Unsworth *et al.* 1990).

Between 1909 and 2013, average annual rainfall at the NBR was 34.57 cm, and the mean annual temperature was 7.4^{o}C. Precipitation values for the years 1948 and 1949 were not included in these averages, as these data were unavailable. Temperature at the NBR has increased over the last decade; the mean temperature for the period 2003-2013 has increased by 0.34^{o}C compared with 1909-1955 mean value. Moreover, average precipitation has decreased by 6 cm in the same period.

Aerial images

Three sets of georeferenced aerial photographs were used to examine temporal changes in treeline position and forest cover. The images date to 1955, 1990, and 2013 and were provided by the United States Geological Survey (USGS), Montana State Library, and the Montana Department of Natural Resources and Conservation (DNRC). The 1955 images were 4-meter resolution images, and the 1990 and 2013 images were 1-meter resolution. A digital elevation model (resolution of 10-meter) was also used and all analyses were conducted using ArcMap 10 (ESRI, 2011, Redlands, CA, USA). Due to limited data availability, only two forest patches within the NBR were examined in this study. Hereafter, the patches will be referred to as bird-patch and high-point patch (Fig. 2).

Changes in forest cover and relative-age classification

Polygons were manually created to delineate the forest patches, and these were converted to raster format for analyses. The forest layer was multiplied by a 10-meter

resolution Digital Elevation Model (DEM) to obtain an elevation value for each pixel of forest cover for each year. This was then used to examine changes in maximum, minimum and mean elevation of forest among years.

Diameter-at-breast height (DBH) was measured at 20 random points within a forest patch and at 10 points along the edges of a patch. Five trees were sampled per point, and the average DBH value (in inches) was multiplied by a growth factor of five to get relative-age of the trees. This was then used to interpolate the age of trees within the whole forest patch and create a map of the forest based on relative-age.

Results

Shift in forest distribution and extent

Raster classification and DEM analysis of forest cover show that minimum and mean elevation of forest decreased for both patches (Table 1). For the bird patch, there was no change in the maximum elevation of forest cover among the years, but the minimum elevation decreased by 31.8 meters between 1955 and 2013. As a result, there was an increase in forest area (by 16.9 ha). The high-point patch showed an increase in maximum elevation of forest cover by 25.6 meters between 1955 and 1990, but then decreased by 8 meters in the period 1990-2013. Its minimum elevation decreased by 10.1 meters between 1955 and 2013. Overall, the mean elevation of forest cover decreased by 17.8 meters and the patch-area increased by 20.8 ha.

Relative-age classification

The classification of the forest patches based on relative-age confirms that young trees are appearing near the edges of the forest patches (Fig. 3).

Discussion

Repeat aerial photography demonstrated that the bird-patch and high-point patch in the NBR have shifted downwards in elevation over recent decades, despite warming temperatures and decreased precipitation at the local level. Thus, the realized shifts did not correspond with the predicted shifts from upward isotherm movement due to regional warming. One reason that could explain the woody encroachment that has occurred is fire suppression. Periodic fire is considered essential for the maintenance and function of grassland ecosystems (Axelrod 1985), as it impacts the surrounding plant community and alters resource availability of the post-fire environment (Heisler *et al.* 2003). With a decrease in fire frequency, grass productivity declines and woody species increase in both density and cover (Knight *et al.* 1994). To prevent wildfires, the U.S. Fish and Wildlife Service (USFWS), which manages the NBR, removes second-growth Douglas-fir by hand-clearing, piling slash and burning piles after the danger of fire has past (USFWS, 1992). However, the shortage of personnel and other resources limits the forest management work FWS can do (Personal Communication). Thus, in this regard, the downward altitudinal shift of the forest may not be surprising.

Treeline advances reported in the literature are highly variable; while some treelines are highly responsive (Devi *et al.* 2008), others show a lag behind isotherm movement (Szeicz & Macdonald, 1995). These disparities between isotherm movement and treeline response highlight the complex interaction of ecological and physical factors that determine treeline shifts. One of these factors that may explain the limited upward shift observed in this study is lack of habitat availability. Particularly for the bird-patch, limited habitat availability could have prevented an upward migration, as the forest patch is mainly situated on top of a hill. Another element that could have hindered the

migration of trees to higher elevation is ungulate browsing. The NBR is home to white-tailed deer, mule deer, and elk, and browsing by these animals could be preventing saplings from growing to adults, thus, limiting tree migration.

The progressive woody encroachment and increase in forest area revealed in this study could have further implications for the surrounding environment. As trees encroach into grassland areas, grass biomass, density and cover decline (Auken, 2009). On the long run, this change in biomass from herbaceous to woody species can affect species composition by shifting the animal population from grazers to browsers. With woody plant encroachment, there is also a shift in the location of plant biomass, carbon and nitrogen pools from belowground in grasslands to aboveground in woodlands (McKinley *et al.* 2008).

The forest change described here show that for two of the forest patches of the NBR, treeline has mainly shifted downwards in elevation, with only one patch showing an upward migration. The marked downward shifts may be a result of fire-suppression. More effort needs to be made in the management of the forests to prevent expansion of the forest and subsequent loss of the grassland ecosystem. With additional data, other forest patches within the NBR could be studied in future researches. Moreover, temporal changes in forest density could be investigated.

Acknowledgments

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Figure 1 National Bison Range
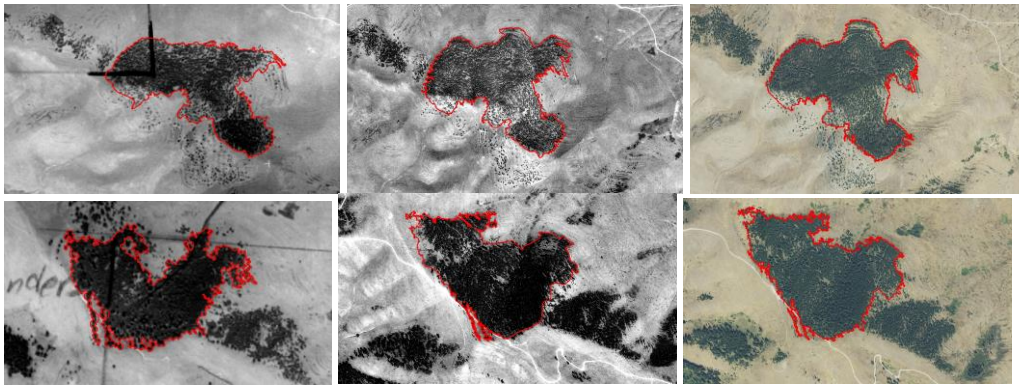
Figure 2 Forest extent of the bird-patch (top) and high-point patch (bottom). Images from left to right are from 1955, 1990, and 2013.

Table 1 Temporal changes in forest elevation in the National Bison Range, calculated based on manual forest classification of aerial photographs and subsequent raster multiplication with a 10-meter resolution DEM

Forest	Year	Highest elevation of tree cover (meters)	Mean forest elevation (meters)	Lowest Point of tree cover (meters)	Area (ha)
Bird Patch	1955	1188.3	1071.2	953.0	59.4
	1990	1188.3	1062.7	929.8	68.4
	2013	1188.3	1056.4	921.2	76.3
High-Point Patch	1955	1451.1	1300.0	1119.8	31.6
	1990	1476.7	1289.4	1122.1	49.9
	2013	1468.7	1282.2	1109.7	52.4
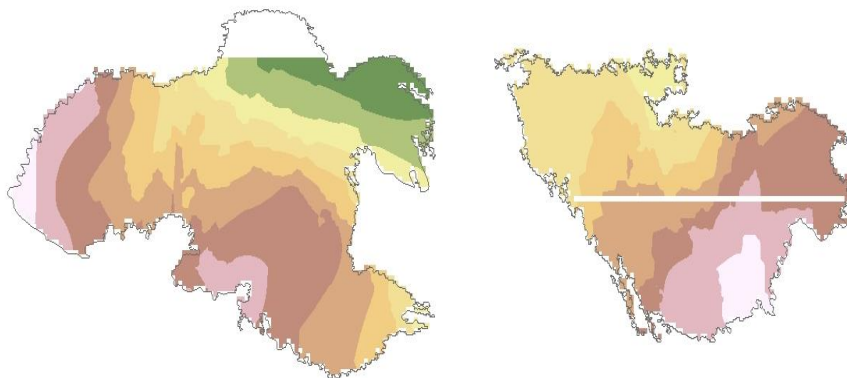
Figure 3 Classification of trees in bird-patch (left) and high-point patch (right) based on relative-age.