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An object-oriented approach to assessing changes in tree cover in the Colorado Front Range 1938–1999

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ABSTRACT

In the wake of numerous catastrophic wildfires, forest management policies have been implemented in recent years in the United States with the goals of reducing fire risk, including the National Fire Plan and the Healthy Forest Restoration Act. A key premise underlying these policies is that fire suppression has resulted in denser forests than were present historically that now have higher fire risk. To evaluate this premise for the northern Front Range, Colorado, we used object-oriented image analysis to compare change in tree cover delineated from historical and modern imagery. Historical photographs from 1938 and 1940 were scanned, orthorectified, and overlaid on Digital Orthoimagry Quarter Quadrangles (DOQQs) from 1999. Using an object-oriented image analysis technique, the photos were then finely segmented and classified into two classes: tree and non-tree. Trees are heterogeneous in appearance in black and white aerial photography, so we employed separate membership functions to identify four visually distinct types: ‘interior forest’, ‘isolated trees’, ‘dark forest’, and ‘edge forest’. Our classification strategy employed spatial relationships between objects in addition to spectral information, so that our classification is fairly robust to variations in illumination. Based on the classification of fine objects, we then calculated the percent tree cover within a larger set of objects for the two time periods. We estimate that average tree density across the study area increased minimally (4%) during the 60-year period, with considerable spatial variation across the landscape. The results of the analysis illustrate that, consistent with independent tree-ring evidence, the highest increase in tree density is in areas characterized by low initial density, south-facing slopes, low elevations, and ponderosa pine dominance. In contrast, the highest elevation areas dominated by mixed conifer and lodgepole pine forests revealed no significant change in tree cover. Furthermore, there is no significant difference between objects dominated by low, medium, and high departure from historical conditions, as classified in the Landfire Fire Regime Condition Class (FRCC) data product. The results of the study can help managers prioritize forest treatments aimed at restoring pre-suppression forest structure.

1. Introduction

Wildfires have imposed increasing economic and environmental costs in recent years. Annual appropriations to federal agencies to prepare and respond to wildland fires approached $3 billion during the years 2001–2005 (US GAO, 2007). A small but increasing fraction of federal money goes toward forest treatments that aim to reduce the intensity and spread of wildfires. In 2007, the final year of the Healthy Forests Restoration Act, 13 million dollars were spent on such treatments (DOI and USDA, 2007).

A key premise of fuel-reduction treatments – such as mechanical thinning and controlled burns – is that forest fuels have increased as a result of fire suppression activities as well as drought, insect infestations, and disease. Illustrating this is the rationale for the Healthy Forests Initiative, which aims to reduce wildfire risk: ‘‘America’s public lands have undergone radical changes during the last century due to the suppression of fires and a lack of active forest and rangeland management. Our forests and rangelands have become unnaturally dense, and these unhealthy forests are vulnerable to unnaturally severe wildfires.’’ (White House, 2003).

But to what degree have canopy fuel loads – and in particular tree cover – increased and where have such increases occurred since the advent of fire suppression? Such information is valuable in prioritizing forest management at local scales aimed at restoring pre-suppression forest structure and fuels. Numerous studies in

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the ponderosa pine forests of the southwestern United States indicate that fire suppression has indeed resulted in fuel accumulation and uncharacteristic susceptibility to crown fires (Covington and Moore, 1994; Fule et al., 1997). However, it is unclear how these results apply to other ponderosa pine-dominated forests outside the region. For example, in the Colorado Front Range tree-ring reconstruction of historic forest structures and fire history records indicates that ponderosa pine ecosystems were spatially heterogeneous, containing patches of dense stands even before fire suppression (Kaufmann et al., 2000; Ehle and Baker, 2003; Sherriff and Veblen, 2008). Unfortunately, tree-ring reconstructions of past forest structure are extremely labor-intensive and not typically spatially contiguous. The main alternative to tree-ring reconstructions for evaluating departure from historic conditions is the continent-wide Fire Regime Condition Class (FRCC) data layer of the Landfire project. However, the FRCC layer is based on simulated reference conditions (Hann et al., 2004) and is usually not validated locally.

To complement existing research, we compared orthorectified historic aerial photography (from 1938 and 1940) to modern digital orthoimagery quarter quadrangles (DOQQs) from 1999 in the northern Front Range of Colorado. The northern Front Range is dominated by ponderosa pine, but also includes mixed conifer and lodgepole pine forests at higher elevations. Our research questions are: (1) To what degree has tree cover increased from 1938 to 1999 and (2) How has tree cover changed with respect to elevation, aspect, slope, dominant vegetation type, historic tree cover, and fire regime condition class?

To make these comparisons, we applied an object-oriented technique that segmented the images into homogeneous objects and then quantified the percent cover of trees within those objects. Object-oriented image analysis holds two primary advantages over traditional pixel-based methods. First, while pixels are classified solely on spectral and sometimes textural information, objects can also be classified on size, shape, pattern and spatial relationships. This is especially important in this case, as black and white aerial photographs have limited spectral data on which to base a classification. Secondly, while pixels are fixed in size and shape, objects are able to represent ecologically meaningful areas at multiple scales (e.g. groups of trees, or landscape patches) (Laliberte et al., 2004).

In a variety of recent studies, object-oriented analyses have yielded higher classification accuracies compared to pixel-based methods. For example, the integration of image segmentation, expert knowledge, and nearest neighbor classifier led to substantially improved land use classifications along an urban-to-agricultural gradient in Pennsylvania (Platt and Rapoza, 2008). In California, an object-oriented approach was better able to delineate the wildland-urban interface because it is able to more accurately classify built area in a highly vegetated landscape (Cleve et al., 2008). Object-oriented strategies that use object-correlation images were also found to be better than pixel-based strategies for change detection in Las Vegas (Im et al., 2007).

Object-oriented image analyses have been successfully applied to myriad studies on vegetation and fuels. For example, object-oriented approaches have been used to classify fuel types in Spain, as proper fuel classification requires the consideration of spatial context (Arroyo et al., 2006). Other studies applied object-oriented methods to mapping shrub encroachment in the Southwest US (Laliberte et al., 2004), extracting forest inventory parameters (Chobey et al., 2006), measuring woodland expansion (Pillai et al., 2005), documenting change in fractional forest cover in Switzerland (Waser et al., 2008), and estimating tree size diversity (Ozdemir et al., 2008) and stem volume (Ozdemir, 2008) in Mediterranean forests, and delineating forest vegetation using classification trees (Mallinis et al., 2008). While a few studies employ panchromatic aerial photos (e.g. Laliberte et al., 2004; Pillai et al., 2005; Browning et al., 2009), most studies use various high resolution multi-spectral imagery in their object-oriented image analysis.

2. Methods

2.1. Study area and data

Our study area is the montane zone of the northern Front Range of Colorado, which contains parts of Gilpin, Jefferson, Boulder, and Larimer Counties (Fig. 1). The montane zone is located approximately between 1830 and 2740 m. At the lowest elevations, the montane zone is dominated by a mixture of ponderosa pine (*Pinus ponderosa)*, Douglas-fir (*Pseudotsuga menziesii*), and grasses. Prior to fire suppression, these areas were characterized by frequent fires at an interval of 10–40 years (Veblen et al., 2000; Sherriff and Veblen, 2007). At the higher elevations ponderosa pine and Douglas-fir still dominate on south-facing slopes, but other species such as lodgepole pine (*Pinus contorta)* and aspen (*Populus tremuloides)* can also be important on north-facing slopes. Historic fire intervals at the higher elevations were 30–100 years prior to fire suppression and included high severity crown fires (Veblen and Lorenz, 1986; Sherriff and Veblen, 2008). We expected increased tree density at the lowest elevations of the montane zone since these areas were historically kept open by frequent fires, but less of an increase in tree density at the highest elevations where fires were less frequent and of mixed-severity and as a consequence stands were often historically dense.

We started with 52 historic aerial photographs (approximate scale 1:20,000) commissioned by the USDA Soil Conservation Service and the USDA Forest Service and scanned at 600 ppi with 24-bit color (~1m pixels). We orthorectified each 1938/1940

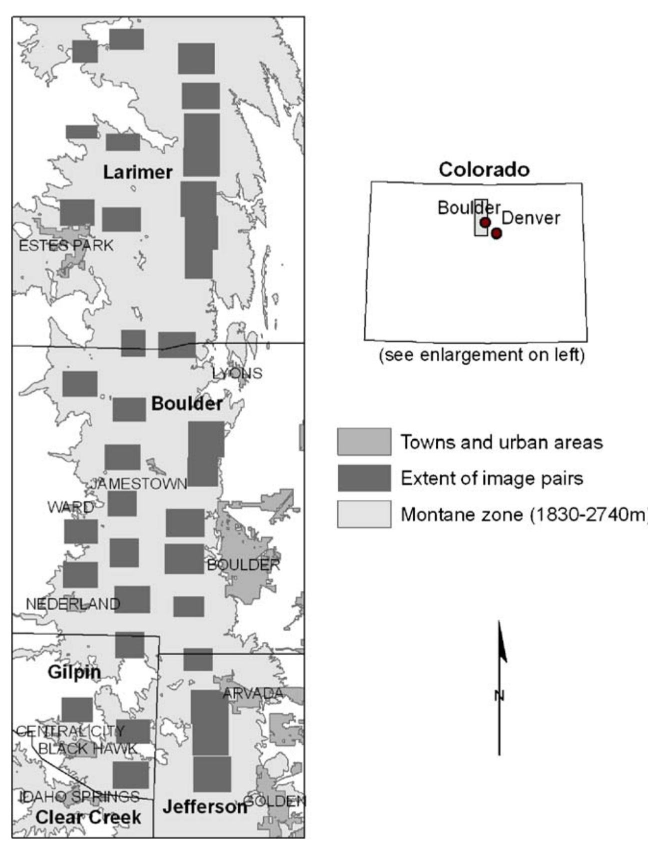

Fig. 1. Study area in the northern Colorado Front Range.