An Effects Assessment Framework for Dry Forest Conservation

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On the Ground

- Large patches of dry conifer forests have burned as high intensity crown fire, threatening life, property, and natural resources.
- Conservation practices such as mechanical thinning can reduce crown fire potential while promoting other benefits such as restoring forest heterogeneity, reducing post-fire erosion risk, and improving wildlife habitat.
- We report on a pilot study to apply landscape-scale effects modeling in the Colorado Front Range as a potential framework for forestlands CEAP.
- Spatially explicit estimates of conservation benefits to multiple resources provide a quantitative means to evaluate competing projects and to prioritize conservation outreach.

Keywords: Conservation Effects Assessment Project (CEAP), landscape-scale modeling, forest conservation, fire hazard, erosion risk, forest heterogeneity.

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Background

A host of pressures including grazing, logging, and a century of fire suppression have altered dry conifer forests of the western United States and created an urgent need for landscape-scale forest restoration.[1] Several national initiatives seek to increase the pace and scale of fire mitigation efforts on federal, state, and private forestlands.[2,3] The Conservation Effects Assessment Project (CEAP) was established in 2003 by the Natural Resources Conservation Service (NRCS) and the Agricultural Research Service with a goal of improving scientific understanding of the ecological effects of conservation practices supported by the U.S. Department of Agriculture (USDA) on private lands. CEAP provides a set of tools to address the USDA's strategic goal for enhancing conservation planning, assessment, and reporting outcome-oriented results.[4] CEAP frameworks for wildlife, wetlands, croplands, and grazing lands have been completed or are under development (see this issue); however, no formal assessment methods exist for forestlands. Because rangelands and dry forests in the western United States are often adjacent to one another and their uses overlap, we initiated an effort to develop a framework for landscape-scale assessment of conservation practices in forests jointly with the CEAP grazing lands effort. We report here on a pilot study to extend and apply landscape-scale effects modeling as a potential framework for forestlands CEAP. We focus initial efforts in the Upper South Platte Watershed in Colorado (Fig. 1), as the region has seen substantial financial investment in restoration efforts on public and private lands.[5]

Like many dry forests in the western United States, montane forests on the Colorado Front Range have departed considerably from pre-European settlement conditions. Tree density has increased by a factor of four in the lower montane zone and more than doubled in the upper montane zone[6] (Fig. 2). High continuity of forest fuels has contributed to uncharacteristic fire behavior and effects. Large patches of forest have burned as high intensity crown fire in several recent Front Range wildfires—such fires threaten life and property and exceed the limits of safe and effective wildfire suppression. Wildfire impacts include loss, of life; damage to property; degraded water quality[7]; erosion and sediment impacts to water supplies[8]; and large patches of tree mortality that alter wildlife habitat and slow forest recovery.[9] A warming climate threatens to exacerbate these negative impacts.[10]

In response to undesirable wildfire effects, diverse stakeholders are engaged in the management of dry forests to restore natural ecosystem structure and function and increase forest resilience to future disturbances. Common conservation practices for hazardous fuel reduction include mechanical thinning and/or prescribed fire with the goal of decreasing tree density and disrupting continuity of fuels.[11] More recent conservation efforts also focus on achieving a broad suite of ecological objectives, including: restoring variability in forest structure; increasing understory productivity and diversity; conserving old and large trees; and reinstating natural and prescribed fire regimes.[1] The focus on understory and habitat characteristics is in contrast to

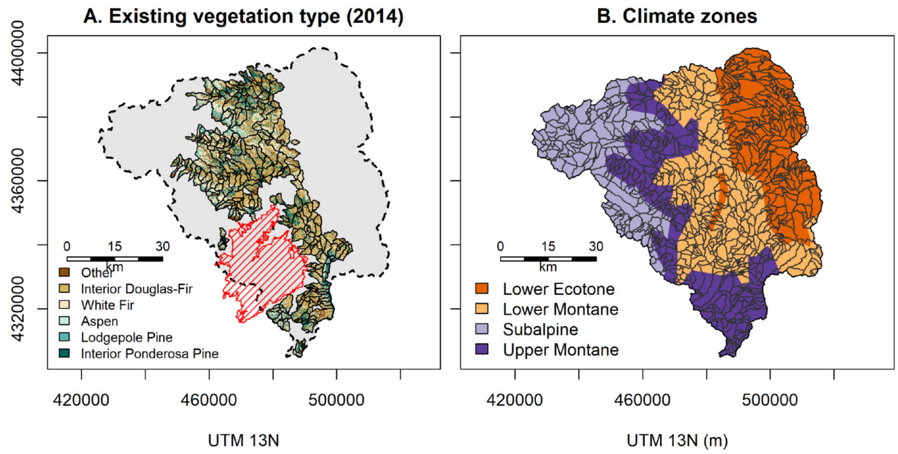

Figure 1. A, Dominant cover in forested catchments of the Upper South Platte watershed intersecting the upper and lower montane zones. Vegetation data summarized from LANDFIRE.[21] Outline of the 2005 Hayman fire is shown in red hatching. **B**, Map of climate regimes including lower ecotone, lower montane, upper montane, and subalpine zones.

traditional forestry practices, which remove the largest and most valuable trees and promote uniformly sized and spaced trees to maximize wood production. Historically, dry conifer forests of the Front Range were characterized by frequent openings and lower stand densities.[6,12] Thus, restoration efforts emphasize increasing landscape-scale variability in forest structure, which is expected to increase forest resilience to disturbances and improve wildlife habitat.[13]

Briske and others[14] evaluated CEAP's ability to quantify rangeland conservation effects and concluded that evaluations should: 1) consider a broad suite of natural resources and ecological processes, and 2) consider the effects of spatial scale and landscape context.[15] Many dry forest conservation objectives, such as increasing structural heterogeneity and reducing wildfire risk to homes and water supplies, are boundary-crossing and scale-spanning issues that can benefit from landscape-scale planning.[5,16] Investing in conservation actions on private land can yield more significant reduction in wildfire risks than similar actions on remote areas of public lands with few values at risk.[17] Landscape-scale assessment and prioritization of forest restoration can borrow from advances in wildfire risk and forest restoration benefits assessments, which show that treatment placement can greatly impact ecological benefits.[5,16,18,19] Landscape-scale assessment can also reveal tradeoffs in ecological outcomes between different conservation approaches. Large-scale fuel reduction treatments, for example, may reduce fire hazard but decrease wildlife diversity,[20] and placement of treatments to reduce soil erosion and impacts to water supplies may differ depending on considerations of scale.[5]

Here we present an assessment framework to quantify forest conservation effects and inform landscape-scale conservation strategies, including components to assess changes in forest structure, wildfire hazard, and erosion risk. Individual modeling components in this general framework can be amended and expanded for multiple geographies and additional ecological values.

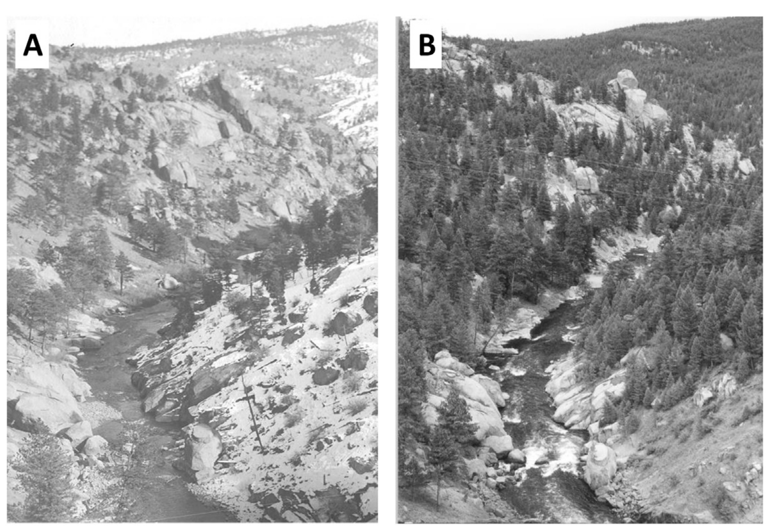

Figure 2. Paired photographs illustrating dramatic change in forest density and spatial patterns along the South Platte River in the Pike National Forest, Colorado in 1903 (photo courtesy of Denver Water Department archives) and 1999 (photo courtesy of Laurie S. Huckaby, USDA Forest Service).

Framework for Modeling Landscape-Scale Benefits of Dry Conifer Forest Restoration

Framework Overview

Stevens and others[20] demonstrated an approach for comparing tradeoffs between landscape-scale forest management strategies by combining models of fire behavior, smoke emissions, and bird abundance in the Lake Tahoe Basin. We extend and operationalize this general framework to assess the ecological effects of common dry forest conservation practices. Using spatial data on existing forest and fuel structure, simulations of a range of conservation practices can be used to represent expected changes in forest and fuel structure. This framework can be used to compare conservation practices such as 1) fuel hazard reduction (spatially homogeneous restoration treatments), and 2) ecological restoration (using an algorithm that produces spatially heterogeneous forest structure based on historical reference conditions) (Fig. 3A). Conservation practice simulations can be used as inputs to ecological models to assess change for multiple desired outcomes of forest restoration such as 1) forest heterogeneity, 2) potential fire behavior, and 3) post-wildfire soil erosion (Figs. 3B–C). This framework supports analysis of tradeoffs between conservation practice type and location, and the resulting outcomes for multiple resources. We describe individual model components (conservation practice simulations and ecological models) that are currently under development to address resource concerns in a pilot study in the Colorado Front Range, but we emphasize that this framework can be extended with additional model components to quantify relevant metrics for other resource concerns.

Conservation Practice Simulations

Data on current forest structure and fuel conditions are available from the LANDFIRE program, which provides nationally consistent spatial data (30 m resolution) on forest and fuel structure, including canopy cover, canopy bulk density, canopy base height, canopy height, and fire behavior fuel models.[21] Conservation practice impacts on forest and fuel structure can be simulated by adjusting these data according to typical effect sizes.[22] This approach is commonly used to explore landscape-scale impacts of management practices on fire behavior and risk.[5,20,23]

In addition to reducing forest density and hazardous fuels, restoration guidelines for the Front Range call for forests with greater abundance of large openings in drier, less productive sites; and they emphasize higher tree density and larger tree groups in more productive locations.[13] To simulate these practices, we developed a restoration algorithm that simulates landscape-scale reductions in forest canopy cover while maintaining historical levels of spatial variability across climatic and topographic gradients (Fig. 4). Climatic zones developed for this study are informed by annual variability in temperature and moisture regimes (PRISM Climate Group 2004) and are congruent with elevation-based ecological zones.[24] Topographic position (wetter or drier slopes) is captured using a topographic moisture index as a proxy for fine-scale topographic driven moisture gradients.[25] We classified each National Hydrologic Dataset Plus (NHD Plus) catchment[26] in the Upper South Platte watershed by climatic zone (subalpine, upper montane, lower montane, and lower ecotone; Fig. 1B). We divided each catchment into wetter and drier regions based on topographic moisture index

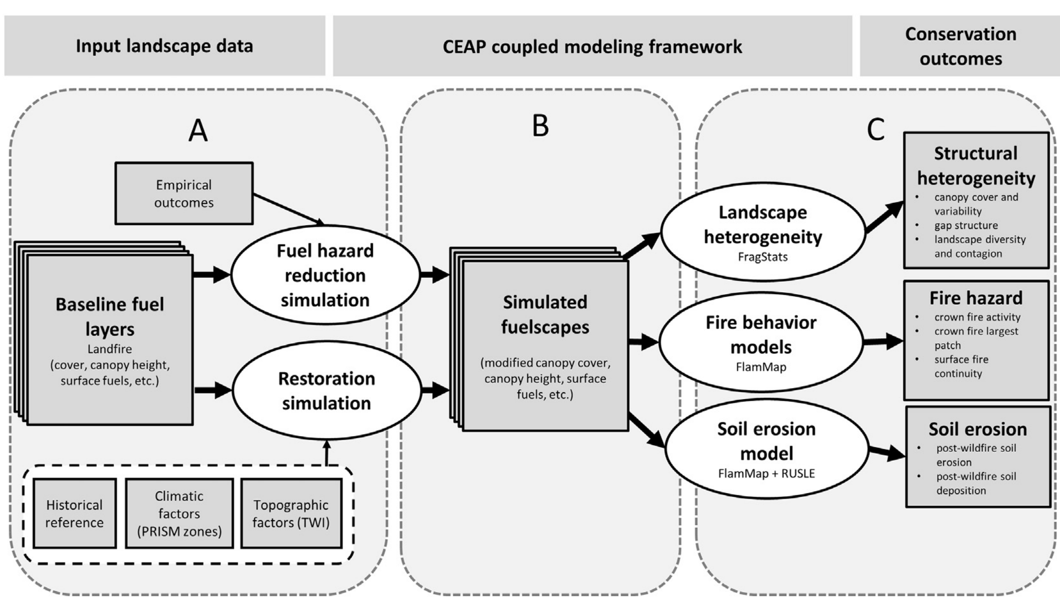

Figure 3. Diagram demonstrating a framework for comparing conservation outcomes of various restoration approaches. Landscape scale data on forest fuel structure LANDFIRE,[21] are input into models to simulate restoration treatments (**A**) by altering relevant fuel traits informed by empirical outcomes or historical reference data. Resulting simulated fuelscapes (**B**) are then used as inputs to ecological models. In the Upper South Platte pilot study, we emphasize model components (**C**) to estimate conservation practice impacts on spatial heterogeneity,[29] wildfire behavior,[33] and soil erosion.[36] Model components can be amended or expanded for other geographies and resource concerns. Data layers and inputs are shown as grey rectangles and modeling software and algorithms are shown as white circles.

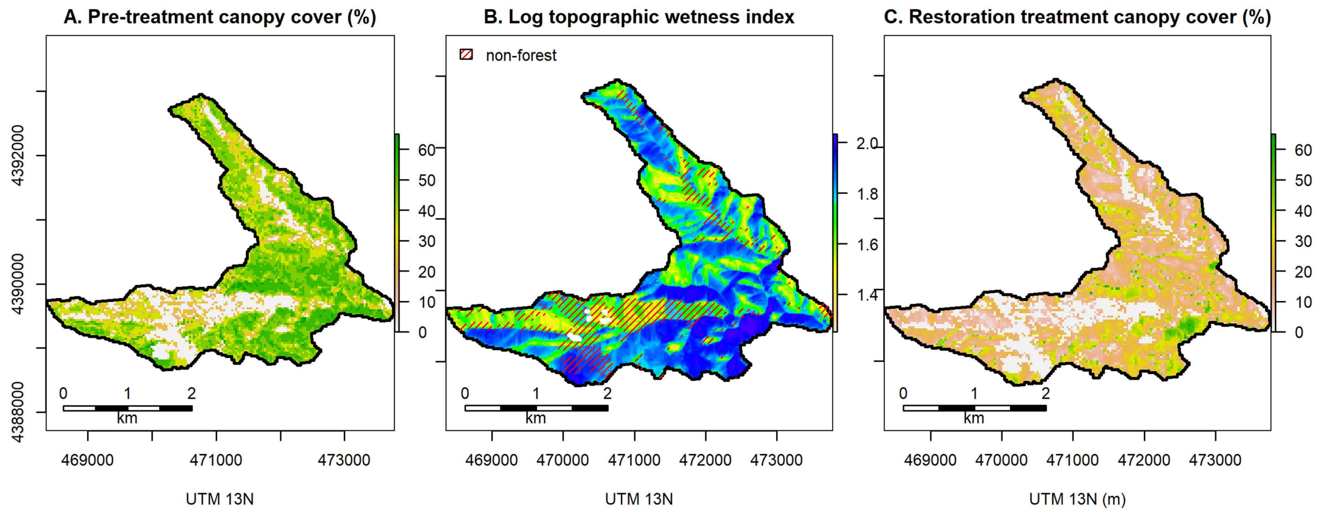

Figure 4. Example baseline data and restoration simulation outputs from a catchment in the Upper South Platte watershed illustrating (**A**) existing canopy cover data from LANDFIRE,[21] (**B**) topographic wetness index identifying moisture gradients across the catchment (note natural log scale), and (**C**) simulated restoration treatment to restore historic levels of mean and variability of canopy cover across wet and dry slopes.

(Fig. 4B). For both wet and dry regions of each catchment, the restoration simulation assigns target canopy cover distributions to match the historical distribution for the corresponding climate regime and moisture class—providing target canopy cover for the catchment with similar mean and variability to historical canopy cover in similar settings (Fig. 4C). This method simulates restoration treatments that vary in intensity across the landscape based on climatic and topographic gradients. More generally, this approach can be used to explore the effects of other conservation practices by exploring scenarios that vary in type, extent, or intensity. Post-treatment conditions from conservation practice simulations (Fig. 3B) can then be used as inputs to a number of different components to quantify potential ecological effects (Fig. 3C). In the section below, we describe model components to address resource concerns in the Front Range including models of spatial heterogeneity, fire behavior, and post-fire erosion.

Framework Components

Forest Spatial Heterogeneity

Treeless openings, or gaps, are important for understory plant diversity and wildlife habitat, and tree encroachment has reduced their frequency and size.[27] Thus, gap creation and enhancement are common restoration goals in the region.[28] To assess conservation practice effects on forest spatial structure, canopy cover and variability in canopy cover can be quantified at multiple scales. Metrics such as landscape diversity and relative contagion can inform how conservation practices influence large-scale spatial heterogeneity; and quantification of gap density, size, shape, core area, and nearest neighbor distances can inform the extent to which gap structure relates to desired conditions.[29,30] Spatial forest structure metrics can be used as proxies for wildlife or understory plant habitat quality, or as inputs to quantitative models; for example, forest structure and heterogeneity metrics can be used to predict avian diversity.[20]

Fire Behavior

High severity wildfire is a threat to many forest resources, especially in dry forests that are poorly adapted to large patches of tree mortality. In addition, restoration goals commonly emphasize forest conditions that facilitate prescribed fire. Historically, the Colorado Front Range experienced relatively frequent low- to mixed-severity fire including some component of high severity fire.[31,32] However, dry conifer forests are not resilient to large continuous patches of high severity fire,[9] and area of stand-replacing fire is trending upwards in recent decades.[10] FlamMap fire behavior modeling software[33] can be used predict fire type as a proxy for fire severity to assess how conservation practices change potential for large, high severity patches and potential for prescribed fire use under a range of conditions (e.g., severe fire weather or prescribed burning conditions). Patch metrics of modeled active crown fire can be used to estimate conservation practice effectiveness at reducing large, continuous patches of crown fire under severe weather. Similarly, the continuity of areas expected to burn as surface fire under moderate weather can be used to assess the degree to which conservation practices can promote the use of prescribed fire.

Post-Wildfire Soil Erosion

Forest restoration and fuels reduction can mitigate wildfire risk to water supplies by reducing wildfire severity and post-fire erosion. The effectiveness of conservation practices at mitigating this risk depends both on the ability of fuel reduction treatments to change fire behavior and severity, and landscape characteristics that determine erosion potential including soils, topography, and climate.[5,16,34] To estimate the impact of conservation practice, post-treatment fuel conditions can be used as inputs to FlamMap to model crown fire activity as a proxy for burn severity.[35] Post-fire erosion can be estimated with the Revised Universal Soil Loss Equation (RUSLE)[36] calibrated with field-measured effects on cover and soil erodibility by burn severity.[37] Empirical estimates of hillslope sediment delivery ratio can then be used to predict sediment delivery to streams.[38] This method has been shown to make reasonable post-fire erosion predictions for the range of slopes (≤ 40%) that are feasible for forestry operations and can be coupled with sediment transport models to scale gross erosion predictions to watershed-scale sediment yields.[16] These benefits, which are conditional on fire occurrence, can be converted to expected benefits using spatially explicit estimates of wildfire likelihood from local or national-level assessments.[39] We focus on risk of post-fire erosion and sedimentation, which is of particular concern in the Colorado Front Range, but this risk assessment framework can be expanded to include other human assets and natural resources, such as wildlife habitat, recreation areas, and homes.[40]

Application of Model and Future Work

CEAP seeks to develop frameworks to estimate conservation practice benefits on broad suites of resources at multiple scales.[14,15] Forestlands CEAP will advance this goal by developing and applying tools to assess the effects of common forest restoration practices on forest spatial heterogeneity, fire behavior, and post-fire erosion. Spatially explicit estimates of conservation practice benefits can be used to evaluate proposed projects and to prioritize agency investments across large landscapes. Baseline assessments provide information necessary to guide strategic conservation investment at local and large landscape scales. Simulating conservation effects on forest structure and fuels provides a flexible platform for assessing a range of ecological effects because of the wealth of ecological models that can be related to these variables. Spatially explicit estimates of conservation benefits can be used to target investments to meet specific resource goals, or to identify regions where broad ecological objectives can be achieved across multiple resources. These analyses also provide information on the off-site effects of conservation practices on locally relevant wildfire and watershed issues. Forestlands CEAP will develop and expand NRCS assessment tools used to prioritize and incentivize voluntary conservation on non-industrial private forests.

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