Fuel treatment effectiveness: Avoiding damages and losses, an annotated bibliography

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Background

The costs associated with fuel treatments are often justified because they can reduce potential damages and losses to valued resources in the event of a wildfire. When encountered by wildfire, fuel treatments often result in reduced fire intensity within the footprint of the fuel treatment, which can lead to ecosystem benefits while avoiding damages to critical watershed services, timber products, wildlife habitat, and other valued resources (Kalies and Yocom-Kent 2016). Fuel treatments can also provide opportunities for firefighters to safely and effectively conduct fire suppression and point protection operations during wildfires, thereby minimizing damages to human communities, infrastructure, and other values (Moghaddas and Craggs 2007; Syphard et al. 2011). Economic analyses can be used to determine return on investment for a given fuel treatment program or to determine the relative value of alternative fuel treatment strategies. Resource economists and scientists agree that such analyses should include market and non-market resources, consider the role of firefighters in conjunction with fuel treatments in protecting resources, and use a risk framework in which the probability of wildfire influencing valued resources is considered (Ager et al. 2010; ERI 2013; Scott et al. 2016; Spies et al. 2017). Existing analyses, however, often rely on simplified assumptions with regard to the effects of wildfire on market and non-market resources and too often do not consider the role of firefighter operations in conjunction with fuel treatments in protecting resources. To strengthen these analyses, improved understanding of the effects of wildfire, with and in the absence of fuel treatments and fire suppression operations, on fire-induced damages to market and non-market resources is needed (Thompson et al. 2015).

The following annotated bibliography summarizes existing studies that contribute to our knowledge on the effects of wildfire, with and in the absence of fuel treatments and fire suppression operations, on fire-induced damages to valued resources. Because much of the literature on fuel treatment effectiveness deals with ecological values and reviews on this topic have been published (e.g., Kalies Yocom-Kent 2016), this bibliography exclusively considers human values, such as human communities, infrastructure, cultural resources, watershed services, timber products, and firefighter safety. The bibliography includes empirical studies in which wildfires burn through areas previously subject to fuel treatments, and modeling studies in which return on investment of fuel treatments with regard to human values is estimated. The bibliography does not include studies that detail wildland fire risk methodologies and assessments, as many review papers have been published on the topic (e.g., Thompson et al. 2015). The bibliography also does not include studies that examine the relationships between fuel treatments and wildfire suppression costs, as such studies have also been subject to extensive review (e.g., Thompson and Anderson 2015).

Methods

The Google Scholar database was used to find relevant studies using the following search terms: fuel treatment, housing, infrastructure, recreation, watershed, and firefighter safety. Studies were included in the annotated bibliography if they examined the fate of valued resources (e.g., community and firefighter safety, housing, infrastructure, watershed services) subject to wildfire and the influence of fuel treatments and/or firefighting operations in determining that fate. Studies also were included if they calculated a return on investment for fuel treatments considering these valued resources. For each study included, the literature cited section and the

'cited by' feature in Google Scholar were used to find additional studies that may be included in the bibliography. Studies within the bibliography are grouped according to the general approach used to address the topic (i.e., case study, empirical modeling, return on investment, literature review). For each study, annotations include a short summary, values considered, and study location.

Conclusion

This exercise confirms that few studies have examined the effectiveness of fuel treatments and fire suppression actions with respect to avoiding loss of valued resources during wildfires. Most of the studies available on this topic are case studies, in which investigators rely on reconnaissance of specific wildfires and interviews with firefighters to determine the role of fuel treatments and firefighting in protecting critical resources (see *case studies* below). These case studies do suggest that when fuel treatments are designed appropriately (e.g., both canopy and surface fuels are treated), they reduce fire intensity and can thus be safely and effectively utilized by firefighters for fire suppression and point protection operations, thereby protecting human communities and improving firefighter safety and suppression efficiency.

Using data on a national level or from a number of high loss wildfire events (e.g., 2009 Australia wildfires and 2003 Cedar Fire), a number of investigators have recently developed empirical models to explain factors that contribute to structure loss (see *empirical modeling studies* below). Not all of these studies address fuel treatments specifically and none consider the role of firefighting operations. Most of these studies do suggest that there is a correlation between presence of fuel treatments and reduced housing loss and that this correlation is likely stronger the closer fuel treatments are to communities.

Other investigators have attempted to calculate a hypothetical return on investment for fuel treatments in specific areas by modeling potential fire behavior and post-fire erosion under different fuel treatment (and no treatment) scenarios (see *return on investment –modeling studies* below). They then determine the economic implications of potential fire behavior and post-fire erosion under different scenarios for a number of valued goods and services, such as structures, infrastructure, reservoir storage capacity, public health, fire suppression costs, and timber. Not all of these studies approach the analyses using a risk framework. All studies calculate a positive return on investment for fuel treatments at least under some circumstances. The investigators, however, make several simplified assumptions regarding relationships between wildfire and valued resources. Although these studies present innovative methodologies that may be adapted to other settings, future investigations would be strengthened by more robust information regarding these assumptions.

Finally, a number of literature reviews deal at least in part with the subject of fuel treatments and their interaction with loss of valued resources from wildfires (see *literature reviews* below). Most of these reviewers concluded that even though some evidence suggests fuel treatments can be effective in reducing damages to valued resources, the literature on this subject in general is limited.

Annotated bibliography

Case studies

Bostwick, P., J. Menakis, and T. Sexton. 2011. **How fuel treatments saved homes from the 2011 Wallow Fire**. Available at https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5318765.pdf (last accessed 5/2/2018)

Summary: Using photos, maps, and interviews with firefighters and area residents, the authors detail the progression of the 2011 Wallow Fire in Arizona, and how fuel treatments dating back to 2004 allowed firefighters to extinguish spot fires and conduct firing operations, ultimately saving much of the communities of Alpine and Greer. In addition, efforts on the part of residents to create defensible space allowed firefighters to protect individual structures threatened by the fire.

Values considered: structures, fire suppression efficiency
Study location: Arizona

Fites, J.A., M. Campbell, A. Reiner, and T. Decker. 2007. **Fire behavior and effects relating to suppression, fuel treatments and protected areas on the Antelope Complex Wheeler Fire**. Available at https://www.fs.fed.us/adaptivemanagement/reports/fbat/Antelope_FINAL3_12_04_07.pdf (last accessed 5/2/2018).

Summary: This report highlights an investigation of fuel treatments subject to wildfire during the 2007 Antelope Complex in the Plumas National Forest, California. Based on personal observations and interviews with firefighters, investigators concluded that areas treated mechanically and with prescribed fires allowed firefighters to conduct direct attack and burnout operations in several instances. A defensible fuel profile zone, similar to a large shaded fuel break, provided a safe escape route for firefighters when a column collapsed, cutting off two other escape routes. Fuel treatments also reduced the amount of effort needed to prepare for burnout operations.

Values considered: firefighter safety, fire suppression efficiency
Study location: Plumas National Forest, California

Graham, R.T., T.B. Jain, and M. Loseke. 2009. **Fuel treatments, fire suppression, and their interaction with wildfire and its impact: The Warm Lake experience during the Cascade Complex of wildfires in central Idaho, 2007**. Gen. Tech. Rep. RMRS-GTR-229. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 36 p.

Summary: This report represents an investigation into the 2007 Cascade Complex of wildfires in central Idaho, and details the influence of fuel treatments on fire behavior, suppression actions, and structure loss. The wildfires burned through several areas previously subject to fuel treatments designed to protect many residences around Warm Lake. A total of 9,095 acres were treated between 1996 and 2006 with mechanical treatments and prescribed fire. In almost every case, mechanical treatments were followed by prescribed fire to reduce surface fuels. The fuel treatments allowed fire crews to conduct safe burnout operations. The location of fuel treatments was used to determine placement of fire lines and the incident command post. The fuel treatments were effective in influencing fire behavior and allowing firefighters to protect the vast majority of structures in the area. Only two rustic structures burned in the fire.

Values considered: Fire suppression efficiency, structures, firefighter safety
Study location: Central Idaho

Graham. R., M. Finney, C. McHugh, J. Cohen, D. Calkin, R. Stratton, and N. Nikolov. 2012. **Fourmile Canyon Fire Findings**. Gen. Tech Rep. RMRS-GTR-289, Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 110p.

Summary: This report represents an investigation of the 2010 Fourmile Canyon Fire in Colorado, which burned 6,181 acres and 162 structures. The investigators assessed the effectiveness of fuel treatments and suppression actions during this fire by conducting interviews with federal, state, and local agency representatives and examining home loss in relation to burn severity and fuel treatments. Within the fire perimeter, 600 acres had previously been subject to fuel treatments, representing 9.7% of the burned area. These treatments were primarily near structures and designed to create defensible space. Treatments consisted of thinning in conjunction with piling, chipping or mastication of surface fuels. Treatments were not followed-up with prescription burning to reduce surface fuel loading. Likely because surface fuels were not reduced, there was no evidence that the fuel treatments modified fire behavior or provided protection to structures.

Values considered: structures
Study location: Colorado Front Range

Harbert, S., A. Hudak, L. Maer, T. Rich, and S. Robertson. 2007. **An assessment of fuel treatments on three large 2007 Pacific Northwest Fires**. Available at https://www.forestsandrangelands.gov/success/stories/2007/documents/pnw-fuel-treatment-effectiveness-assessment-2007.pdf (last accessed 5/2/2018).

Summary: This report summarizes an investigation of fuel treatment effectiveness for three wildfires that burned in Oregon in the summer of 2007, the Monument Fire, the GW Fire and the Egley Complex. Significant acreage within the fire perimeters had previously been subject to mechanical thinning and prescribed fire. Based on personal observation and interviews with firefighters and fuels managers, the investigation concludes that in many cases the fuel treatments provided opportunities for firefighters to utilize direct attack and conduct burnout operations, thereby increasing suppression efficiency and effectiveness.

Values considered: fire suppression efficiency
Study location: Oregon

Murphy, K. T. Rich, and T. Sexton. 2007. **An assessment of fuel treatment effects on fire behavior, suppression effectiveness, and structure ignition on the Angora Fire**. U.S. Department of Agriculture, Forest Service, Pacific Southwest Region, R5-TP0-25. Available at http://bofdata.fire.ca.gov/board_committees/monitoring_study_group/msg_archived_documents/msg_archived_documents_/murphy_usfs_2007_a.pdf (last accessed 5/2/2018).

Summary: This report details an investigation of the effectiveness of fuel treatments subject to the 2007 Angora Fire near Lake Tahoe, California in terms of reduced structure loss, fire suppression effectiveness, and public safety. Investigators based their findings on ground and aerial reconnaissance, interviews with homeowners, firefighters, scientists, and fire behavior experts, and review of available video and photos. They concluded that most fuel treatments burned with low intensity surface fire, thereby producing less smoke and fewer embers. This provided greater visibility and enhanced the ability to evacuate residents. Fuel treatments adjacent to subdivisions provided effective safety zones for fire fighters, which allowed them to safely extinguish spot fires near structures.

Values considered: structures, community safety, firefighter safety.
Study location: Lake Tahoe, California.

Moghaddas, J.J. and L. Craggs. 2007. **A fuel treatment reduces fire severity and increases suppression efficiency in a mixed conifer forest**. International Journal of Wildland Fire 16: 673-678.

Summary: This case study describes suppression actions on the 2005 Bell Fire, a 35-acre fire that ignited within a fuel treatment on the Plumas National Forest in California. Based on conversations with the Incident Commander and fire crews, the fuel treatment allowed fire crews to access the main fire and attack it directly. It also allowed the Incident Commander to maintain visual contact with the crews throughout the fire. Based on personal observation, fire retardant in untreated areas ended up mostly in the tree crowns and did not penetrate to the surface fuels. In the treated area, however, fire retardant was visible on the surface fuels, indicating that the openness created by the treatment allowed for greater penetration and coverage of retardant. All of this indicates that the fuel treatment increased fire suppression efficiency and firefighter safety. The Incident Commander and fire crews speculated that had the fire ignited in the untreated area, it likely would have been much larger and more difficult to suppress.

Values considered: firefighter safety, fire suppression efficiency
Study location: northern Sierra Nevada Mountains, California.

Rogers, G., W. Hann, C. Martin, T. Nicolet, and M. Pence. 2008. **Fuel treatment effects on fire behavior, suppression, and structure ignition: Grass Valley Fire, San Bernadino National Forest**. United States Department of Agriculture R5-TP-026a. 35p. Available at

https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev7_008376.pdf (last accessed 5/2/2018).

Summary: This report details an investigation of fuel treatment effectiveness during the 2007 Grass Valley Fire on the San Bernardino National Forest, which destroyed 199 structures. Roughly half of the 1,242 acre fire had previously been subject to fuel treatments. The investigators used ground and aerial reconnaissance, photos, videos, interviews, and review of documents to determine the effectiveness of these fuel treatments in terms of fire behavior, fire effects, structure ignition, fire suppression, public safety, and egress. The fuel treatments were effective in reducing fire intensity, which allowed firefighters to focus on structure protection and to attack the fire directly. The fuel treatments also increased visibility which likely enhanced firefighter safety. On private lands, several dead trees had previously been removed along roadsides. This likely facilitated evacuation of the affected communities as trees falling on roadways was minimal.

Values considered: structures, firefighter safety, fire suppression efficiency, and community safety
Study location: San Bernardino National Forest, California

Empirical modeling studies

Alexandre, P.M., S.I. Stewart, M.H. Mockrin, N.S. Keuler, A.D. Syphard, A. Bar-Massada, M.K. Clayton, and V.C. Radeloff. 2016a. **The relative importance of vegetation, topography and spatial arrangement on building loss to wildfires in case studies of California and Colorado.** Landscape Ecology 31: 415-430.

Summary: Using a database of structures exposed to the 2003 Cedar Fire (San Diego County, California) and the 2010 Fourmile Fire (Boulder County, Colorado), investigators developed a logistic regression model that predicts local and landscape factors that contribute to structure loss. Explanatory variables represented vegetation, topography, building and neighborhood configuration, and measures of landscape connectivity and contagion. The influence of fuel treatments was not considered and it is unclear if there were many fuel treatments in these landscapes prior to the wildfires. No single model explained building loss across all communities. Topography, spatial arrangement of buildings, and vegetation connectivity seemed to explain most of the variation in building loss. The study did not consider effects of fire behavior or fire suppression actions.

Values considered: structures
Study location: San Diego County, California and Boulder County, Colorado

Alexandre, P.M., S.I. Stewart, N.S. Keuler, M.K. Clayton, M.H. Mockrin, A. Bar-Massada, A.D. Syphard, and V.C. Radeloff. 2016b. **Factors related to building loss due to wildfires in the conterminous United States** Ecological Applications 26: 2323-2338.

Summary: The research questions and methods used in this study are similar to Alexandre et al. (2016a). The scale, however, is at a national-level. Investigators examined 9,236 structures that were destroyed and 105,296 structures that survived within the perimeters of all wildfires in the conterminous United States recorded in the Monitoring Trends Burn Severity dataset from 2000-2010 (fires greater than 300 acres). The findings were also similar to Alexandre et al. 2016a, with topography, spatial arrangement of buildings, and vegetation influencing structure loss. Vegetation categories however, were very coarse and did not reflect whether or not fuel treatments had been conducted. The study did not consider fire behavior or fire suppression actions.

Values considered: structures
Study location: conterminous United States

Gibbons, P., L. van Bommel, A.M. Gill, G.J. Cary, D.A. Driscoll, R.A. Bradstock, E. Knight, M.A. Moritz, S.L. Stephens, and D.B. Lindenmayer. 2012. **Land management practices associated with house loss in wildfires**. PLoS ONE 7, e29212.

Summary: Using a random sample of 499 homes exposed to the 2009 wildfires in Victoria, Australia, the investigators developed a logistic regression model to predict house loss with explanatory variables representing fuels, topography, and weather. A greater proportion of houses were lost where there was higher native vegetation cover within 40 m of the structure. Applying the model, investigators estimated that application of prescribed fire within 0.5 km of structures would have reduced number of structures lost by 15%. Treatments within 40 m of structures had much more significant impacts on the ability of structures to survive the wildfires. This is contrary to current land management practices, in which prescribed fires are implemented a mean of 8.5 km away from houses. The investigators suggest shifting fuels management strategies to intensive fuels treatments in close proximity to houses would be more effective in protecting property. The study does not include any information about firefighting efforts.

Values considered: structures
Study location: Victoria, Australia

Gonzalez-Caban, A., J.B. Loomis, R. Reich, D.B. Rideout, and J. Sanchez. 2017. **Do fuel treatment costs affect wildfire suppression costs and property damages? Analysis of costs, damages avoided, and return on investment.** JFSP Final Report #14-5-01-12. Available at https://www.firescience.gov/projects/14-5-01-12/project/14-5-01-12_final_report.pdf (last accessed 5/2/2018).

Summary: This study represents the only national-level analysis of data on wildfire, fire suppression costs, damaged property, and fuel treatments. The investigators used these data across all US Forest Service lands, excluding Alaska and Hawaii, to develop statistical models that elucidate the relationships between the acreage of previous fuel treatments within a wildfire footprint, wildland fire suppression costs, and fire-induced property damage. The dataset included all wildfires over 300 acres and fuel treatments recorded in the Forest Service Activity System from 2010-2014. Only in the Southern and Northern California Geographic Area

Coordination Centers (GACC) was there a significant negative relationship between areas within a wildfire footprint treated with mechanical fuel treatment and fire suppression costs. In all other GACCs there was no significant relationship between fire suppression costs and area previously subject to fuel treatments (prescribed fire or mechanical treatment). In four GACCs, the relationship between prescribed fire acreage and structures damages was negative and significant, indicating that prescribed fire can result in reduced property damage from wildfire. Results were more mixed with mechanical fuel treatments, with negative relationships between mechanical treatment acreage and property damage seen in only two GACCs. This is one of the first studies that documents a correlation between fuel treatments and reduced property damage from wildfire.

Values considered: Fire suppression costs, structures
Study location: USFS lands in lower 48 states

Price, O.F. and R.A. Bradstock. 2012. **The efficacy of fuel treatment in mitigating property loss during wildfires: Insights from analysis of the severity of catastrophic fires in 2009 in Victoria, Australia.** Journal of Environmental Management 113: 146-157.

Summary: Using data from the 2009 wildfires in Victoria Australia, investigators examined the relationships between fire behavior (crown fire vs. understory fire), and several dependent variables including: weather class (catastrophic, very high, moderate, and low), time since prescribed fire, time since logging, forest type, and various measures of topography. Under catastrophic burning conditions (Forest Fire Danger Index > 100), previous prescribed fire and logging were ineffective in mitigating fire behavior. Given that under catastrophic conditions the fire destroyed a majority (67%) houses within the fire perimeter, the investigators conclude that fuel treatments are unlikely to decrease the probability of home loss from wildfires burning under catastrophic conditions. Although this study did not include a robust investigation into factors that contribute to structure loss, a companion study using the same dataset provides more insights (Price and Bradstock 2013).

Values considered: structures
Study location: Victoria, Australia

Price, O. and R. Bradstock. 2013. **Landscape scale influences of forest area and housing density on house loss in the 2009 Victorian brushfires**. PLoS ONE 8(8): e73421.
Summary: Using a dataset of over 3,000 homes effected by a portion of the 2009 wildfires in Victoria, Australia, investigators develop a statistical model to determine the influence of surrounding vegetation (up to 5 km from structures), housing density, topography, and fire behavior on the probability of a house being destroyed in a wildfire. They found that proportion of houses lost was positively related to slope and housing density. They also found proportion of houses lost positively related to both area of adjacent forest and the proportion of land burned in crown fire within the adjacent forest. These relationships were strongest up to 1 km from houses, indicating that treatments to reduce flammable vegetation within 1 km of structures would significantly reduce wildfire risk to communities. They speculate that while vegetation condition closer to homes likely influences exposure of structures to radiant heat, vegetation condition

further from structures (up to 1 km) likely influences exposure of structures to ember rain and thus relates to wildfire risk. This study presents a unique methodology for addressing the relationship between fuel treatments and property loss, which could be adapted to other areas.

Values considered: structures
Study location: Victoria, Australia

Return on investment – modeling studies

Buckley, M., N. Beck, P. Bowden, M.E. Miller, B. Hill, C. Luce, W.J. Elliot, N. Enstice, K. Podolak, E. Winford, S.L. Smith, M. Bokach, M. Reichert, D. Edelson, and J. Gaither. 2014. **Mokelumne watershed avoided cost analysis: Why Sierra Nevada fuel treatments make economic sense.** A report prepared for the Sierra Nevada Conservancy, The Nature Conservancy, and U.S. Department of Agriculture, Forest Service. Available at https://www.researchgate.net/publication/301676614_Mokelumne_watershed_avoided_cost_analysis_Why_Sierra_fuel_treatments_make_economic_sense_A_report_prepared_for_the_Sierra_Nevada_Conservancy_The_Nature_Conservancy_and_US_Department_of_Agriculture_For (last accessed 5/2/2018).

Summary: In an 885 km^2 watershed in the central Sierra Nevada Mountains in California, investigators examined the potential economic benefit of fuel treatments in terms of avoided losses to valued resources in the event of a wildfire. Using a collaborative process with multiple stakeholders, researchers modeled potential wildland fire behavior and post-fire erosion under current conditions and under a fuel treatment scenario in which 29% of the watershed is subject to fuel treatments. Wildfire behavior and erosion models (FSim, FlamMap5, GeoWEPP) were used to quantify changes in wildland fire risk and sediment production resulting from this fuel treatment scenario and a no treatment scenario. These data were then used to quantify the economic benefit of fuel treatments in this watershed in terms of infrastructure saved, avoided fire suppression and rehabilitation costs, carbon sequestered, timber saved, and avoided sediment delivered to reservoirs. Investigators estimated that the fuel treatment scenario would cost roughly $68 million, while benefits from the fuel treatments would total between $126 and $224 million. This study is unique in that it presents a thorough investigation of the economics of fuel treatments for a particular watershed. The calculated return on investment, however, is not likely to be applicable outside this watershed. The investigators present a detailed methodology for their study, which could be adapted to other settings.

Values considered: infrastructure (power lines, roads), structures, timber, carbon, water supply, and fire suppression and rehabilitation costs.
Study location: Central Sierra Nevada Mountains, California

Hartwell, R., S.Kruse, and M. Buckley. 2016. **San Juan-Chama headwaters return on investment study for the Rio Grande Water Fund**. Available at http://riograndewaterfund.org/wp-content/uploads/2017/01/rgwf_roi_sjcp_report_exec_20161229.pdf (last accessed 5/2/2018).

Summary: In this study, investigators use fire behavior and erosion models to calculate theoretical return on investment for fuel treatments in the San Juan – Chama Project area in southwestern Colorado, part of the Rio Grande Water Fund. The investigators use a 'representative fire' approach, in which potential fire behavior is assessed for modeled wildfires representative of past wildfires in the area. Comparing modeled fire behavior and post-fire erosion under current conditions and under proposed fuel treatments, they determine the implications of burning under each scenario for damage to structures, roads, power lines, and water diversions. In addition, they consider fire suppression costs, public health costs, reservoir water storage capacity, change in property values, and opportunities for recreation under each scenario. Considering all these potential benefits of fuel treatments, they estimate a return on investment for fuel treatments of 246-375%, depending on the wildfire modeled. Some drawbacks of this study include the fact that wildfire modeling was not treated in a probabilistic manner and many simple assumptions were used regarding the costs associated with public health, recreation opportunities, and fire suppression.

Values considered: fire suppression costs, structures, infrastructure (roads, power lines, water diversions), public health, recreation, water storage and allocation.
Study location: southwestern Colorado

Jones, K.W., J.B. Cannon, F.A. Saavedra, S.K. Kampf, R.N. Addington, A.S. Cheng, L.H. MacDonald, C. Wilson, and B. Wolk. 2017. **Return on investment from fuel treatments to reduce severe wildfire and erosion in a watershed investment program in Colorado**. Journal of Environmental Management 198: 66-77.

Summary: In this study, investigators quantify return on investment of fuel treatments in two watersheds in the Colorado Front Range. Specifically, they consider the benefit of fuel treatments in terms of reducing the cost of dredging sediment from a downstream reservoir, as this represented a significant cost to Denver Water following previous wildfires in the region. Investigators modeled potential wildfire behavior under different landscape fuel treatment scenarios using FlamMap and the consequences for post-fire runoff and erosion using AGWA-KINEROS2. The return on investment for fuel treatments varied by watershed, with the watershed closest to the reservoir having a higher return on investment. Return on investment was generally positive for 10- and 100-year storm events, but not for 1-year storm events. Return on investment also generally increased as percentage of the landscape treated increased, with diminishing returns after about 50-80% of landscape treated. A limitation of this study is that it does not consider potential fire behavior and erosion in a risk context. Instead, in the modeling exercise it is assumed that the entire watersheds burn and that storms occur one-year post-fire. In addition, other economic benefits of fuel treatments are not considered. Thus, the calculated return on investment is not likely an accurate reflection of the actual return on investment. The study, however, provides information and a methodology that would be useful for informing landscape treatment prioritization.

Values considered: costs associated with dredging downstream reservoir from fire-induced erosion
Study location: Front Range, Colorado

Kruse, S., R. Hartwell, and M. Buckley. 2016. **Taos County return on investment study for the Rio Grande water fund**. Available at http://riograndewaterfund.org/wp-content/uploads/2017/01/rgwf_roi_taos_report.pdf (last accessed 5/2/2018).

Summary: Using a methodology very similar to that in Hartwell et al. (2016), investigators calculated return on investment for fuel treatments in Taos County, New Mexico, as part of the Rio Grande Water Fund. Comparing modeled fire behavior and effects for representative wildfires both with and without fuel treatments, they calculated a return on investment of fuel treatments ranging from 57-118%. Like in Hartwell et al. 2016, several simplified assumptions were made about the economic value of factors that could benefit from fuel treatments.

Values considered: fire suppression costs, structures, infrastructure (roads, power lines), public health, recreation, and water quality and storage.
Study location: northern New Mexico

Literature reviews

Clode, D. and M.A. Elgar. 2013. **Fighting fire with fire: Does a policy of broad-scale prescribed burning improve community safety?** Society and Natural Resources 27: 1192-1199.

Summary: In this review and commentary, the authors summarize available literature on the influence of prescribed fire on community safety in Australia and argue that community protection is best achieved by focusing fuel treatments directly adjacent to communities and enacting measures to make structures more fire resistant. They conclude that very few studies have examined whether or not broad-scale prescribed fire programs are effective in protecting communities or saving lives. Instead, most studies have focused on the ecological effects of prescribed fire.

Values considered: structures
Study location: Australia

Ecological Restoration Institute. 2013. **The efficacy of hazardous fuel treatments: A rapid assessment of the economic and ecologic consequences of alternative hazardous fuel treatments: A summary document for policy makers**. Northern Arizona University. 28 pp. Available at https://nau.edu/eri/banner/the-efficacy-of-hazardous-fuel-treatments/ (last accessed 5/2/2018).

Summary: This paper summarizes the challenges associated with quantifying the economic effectiveness of fuel and restoration treatments in terms of reducing fire suppression costs, decreasing fire risk to communities, and averting resource damages. This document summarizes numerous studies the Ecological Restoration Institute has conducted to address persistent

questions regarding the economic efficiency of fuel treatments. Some of these studies are completed and published as of 2018 (e.g., Kalies and Yocom-Kent 2016), while others are ongoing. While much of the report deals with the effects of fuel treatments on fire suppression costs, it also addresses the influence of fuel treatments on fire risk to communities. Based on a review of the existing literature, the investigators conclude that there is a significant research gap in empirical studies on the effectiveness of fuel treatments in terms of protecting communities, watershed services, and recreation and cultural values.

Values considered: Fire suppression costs, community protection, property value
Study location: United States

Hakes, R.S.P., S.E. Caton, D.J. Gorham, and M.J. Gollner. 2017. **Wildland urban interface part II: Response of components, systems, and mitigation strategies in the United States.** Fire Technology 53: 475-515.

Summary: In this review paper, the authors summarize published research regarding the pathways of wildfire spread into the wildland urban interface. The authors conclude that most of the research on fuel treatment effectiveness has focused on wildlands and very little research has been conducted in the wildland urban interface. Thus, very little is known about the effectiveness of fuel treatments with regard to reducing structure ignition.

Values considered: Structures
Study location: United States

Kalies, E.L. and L.L. Yocom Kent. 2016. **Tamm Review: Are fuel treatments effective at achieving ecological and social objectives? A systematic review**. Forest Ecology and Management 375: 84-95.

Summary: Investigators conducted a systematic evidence-based review of the existing literature regarding effectiveness of fuel treatments in achieving ecological and social objectives. The literature review was limited to empirical studies in which wildfires burned through areas previously treated with mechanical treatments, prescribed fire, or both. The investigators also limited the scope of the review to studies in long-needle pine and dry mixed conifer forests in the western U.S. and Canada and only considered studies in which fire behavior and effects in treated areas were compared to untreated areas. The investigators found several studies that evaluated fuel treatment effectiveness in terms of tree mortality, wildlife habitat, carbon storage, and understory vegetation. There were few studies, however, that dealt with fuel treatment effectiveness in terms of human values, such as property saved, firefighter safety, and suppression effectiveness. They found no studies that addressed hydrology (water yield and water quality), forest uses (recreation, timber, etc.), or rehabilitation effort (seeding, mulching, etc.). This study demonstrates significant research gaps regarding fuel treatment effectiveness in achieving social objectives.

Values considered: rehabilitation effort, carbon storage, water yield, water quality, property damage, evacuation effectiveness, firefighter safety, and forest uses.

Study location: long-needle pine and dry mixed conifer forests in the western U.S. and Canada

Literature cited in Background

Ager, A.A., N.M. Vaillant, and M.A. Finney. 2010. A comparison of landscape fuel treatment strategies to mitigate wildland fire risk in the urban interface and preserve old forest structure. Forest Ecology and Management 259: 1556-1570.

Ecological Restoration Institute. 2013. The efficacy of hazardous fuel treatments: A rapid assessment of the economic and ecologic consequences of alternative hazardous fuel treatments: A summary document for policy makers. Northern Arizona University. 28 pp.

Kalies, E.L. and L.L. Yocom Kent. 2016. Tamm Review: Are fuel treatments effective at achieving ecological and social objectives? A systematic review. Forest Ecology and Management 375: 84-95.

Moghaddas, J.J. and L. Craggs. 2007. A fuel treatment reduces fire severity and increases suppression efficiency in a mixed conifer forest. International Journal of Wildland Fire 16: 673-678.

Scott, J.H., M.P. Thompson, and J.W. Gilbertson-Day. 2016. Examining alternative fuel management strategies and the relative contribution of National Forest System lands to wildfire risk to adjacent homes – A pilot assessment on the Sierra National Forest, California, USA. Forest Ecology and Management 362: 29-37.

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