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Review

The Economic Value of Fuel Treatments: A Review of the Recent Literature for Fuel Treatment Planning

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Abstract: This review synthesizes the scientific literature on fuel treatment economics published since 2013 with a focus on its implications for land managers and policy makers. We review the literature on whether fuel treatments are financially viable for land management agencies at the time of implementation, as well as over the lifespan of fuel treatment effectiveness. We also review the literature that considers the broad benefits of fuel treatments across multiple sectors of society. Most studies find that fuel treatments are not financially viable for land management agencies based on revenue generated from forest products, biomass, or carbon credits at the time of implementation. Fuel treatments also tend to not be financially viable based on future management costs savings (fire suppression and rehabilitation costs) or averted losses in forest products from wildfire over the lifespan of treatment effectiveness. Similarly, most studies that consider benefits beyond those accruing to land management agencies find that the benefits from any single category (e.g., damage to structures and infrastructure, critical watersheds, air quality, or ecosystem values) are not sufficient to offset treatment costs. Overall, the recent literature suggests that fuel treatment projects are more likely to have benefits that exceed costs if they generate benefits in multiple categories simultaneously. The literature also documents tremendous variability in benefits and costs across regions and between projects within regions, which poses a challenge to reaching general conclusions about the benefits and costs of fuel treatments at programmatic scales, and suggests that practitioners should proceed with caution when trying to extrapolate the benefits and costs for a prospective fuel treatment project from estimates reported in the previous literature.

Keywords: prescribed fire; thinning; net benefits; wildfire; ecosystem services; wildland urban interface

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1. Introduction

For several decades, federal land management agencies have been investing in fuel treatments, or the manipulation of live and dead vegetation to improve ecosystem health and reduce wildfire ignitions, intensity, and resulting damage to valued resources. Numerous studies have demonstrated that fuel treatments are effective in improving ecosystem conditions, reducing the intensity of wildfires, and reducing the wildfire damages to human communities, infrastructure, and natural resources [1,2]. However, despite these investments, the past several decades have seen steady increases in wildfire size, intensity, and accompanying suppression costs and damage due to factors including climate change, expanding wildland urban interface (WUI), and the existing backlog of area in need of fuel treatments [3–5]. This trend of increasing wildfire activity and damages has prompted some to question what has been accomplished with fuel treatment investments and, if previous efforts have not been sufficient, what level of investment is needed to significantly reduce wildfire size and intensity, suppression costs, and damaging wildfire effects [6]. While the economic literature on fuel treatments can help to address these questions by identifying when fuel treatments are likely to generate benefits that exceed their costs, the use of these concepts in fuel treatment planning is not widespread [7].

Estimating net benefits of fuel treatments is complicated because several factors must be considered. These include the cost of treatment, the benefits of treatment both in the presence and absence of wildfire, and the probability of wildfires encountering the treated area. Fuel treatment costs can include not only the direct financial costs of implementing treatments, but also indirect costs, such as the health implications of exposure to prescribed fire smoke. Fuel treatment benefits in the absence of wildfire can include the sale of merchantable materials, improved wildlife habitat, and enhanced recreational opportunities [7]. Fuel treatment benefits when wildfire encounters or spreads through fuel treatment can include avoided damages to communities and infrastructure, savings in wildfire suppression costs, reduction in the human health impacts from exposure to wildfire smoke, and enhanced ability of ecosystems to recover post-fire [2]. Previous reviews of fuel treatment economics found that research has focused heavily on the potential for fuel treatments to reduce wildfire suppression costs and that few studies had examined the full benefits and cost from fuel treatments [6,7].

Many factors make estimating net benefits from fuel treatments challenging. For example, many of the direct and indirect costs of wildfire, such as health impacts of smoke exposure, evacuation costs, and long-term community economic decline, have not been sufficiently quantified [8] and there is uncertainty in the effectiveness of fuel treatments in mitigation some of these costs [1,2]. In addition, many of these factors are not easily monetized. Fuel treatment costs and opportunities for revenue generation can also vary significantly by region [9] as does the probability of wildfire encountering fuel treatments [10] and the longevity of fuel treatment effectiveness [11]. Finally, while the costs fuel treatments are generally incurred by land management agencies at the time of implementation, the benefits of fuel treatments can be borne over longer time horizons and incurred by land management agencies as well as other sectors of society. Given this complexity, it is perhaps not surprising that most investigators have focused on one category of fuel treatment benefits (e.g., suppression costs avoided, watershed services) and, as such, often are providing an incomplete accounting of and the net economic benefits from treatments [12–14].

While this review is not intended to evaluate methodologies for studying fuel treatment economics, it is important to note that investigators have taken several different approaches to assessing the net benefits of fuel treatments. For example, several studies use fire behavior models to assess the potential for damage to mapped resources under different landscape fuel treatment scenarios. This approach typically requires assumptions for the relationship between modeled fire behavior and damage to valued resources. For example, some assume damage to resources when wildfire intersects the resource [15–18] while others assume a range of modeled flame length or intensities at some distance to resources are associated with resource damage [19–21]. Others link fire behavior modeling output to other ecosystem process models that predict soil erosion [22], smoke production and dispersion [23], or wildlife habitat and populations [21,23]. A second approach entails developing statistical models of past wildfire and fuel treatment interactions and outcomes in terms of damage or loss to valued resources [24,25]. Other efforts include the use of production possibility frontiers [15,16,26,27], success odds [28], willingness to pay models [29], or other comparisons of fuel treatment effort to outcomes [13] to evaluate the effectiveness of fuel treatment investments in meeting multiple objectives.

This review synthesizes research findings related to the benefits and costs of fuel treatments since 2013, to capture findings since the last reviews on the topic were published [6,7]. Specifically, we examined the evidence in the scientific literature that addresses three questions related to the net benefit of fuel treatments:

(1) Are revenues generated from fuel treatments greater than the costs of implementation?

(2) Are averted wildfire related costs (borne by land management agencies) attributed to fuel treatments greater than the costs of fuel treatment implementation?

(3) Are the broad benefits of fuel treatments across multiple sectors of society greater than the costs of fuel treatment implementation?

The above questions are designed to incorporate and compartmentalize some of the complicated aspects of understanding fuel treatment economics. These include the different time scales over which costs and benefits can occur, the difficulty in monetizing some costs and benefits, and the fact that costs and benefits associated with fuel treatments are often unequally distributed among land management agencies and other sectors of society. We also review some of the factors that can influence answers to the above questions.

2. Materials and Methods

To describe advancements in the science of fuel treatment economics in recent years, we conducted a review of the scientific literature published since 2013, to capture studies not included in previous reviews of the topic [6,7]. Studies published before 2012 were used in certain instances to provide a frame of reference for a given topic. The key words 'fuel treatment' and 'economics' were used in Google Scholar to find relevant studies. We also 'chased' compiled studies forward and backward in time by examining their references cited and by using the 'cited by' feature in Google Scholar to find references that cite the compiled articles [30] including key syntheses on the topic previously published [6,7]. Studies were compiled that in some capacity addressed the questions the three questions above related to the benefits and costs of fuel treatments.

Are revenues generated from fuel treatments greater than the costs of implementation? For the first study question, we considered whether or not the costs of planning and implementing fuel treatment could be offset by revenue from forest or rangeland products, including for example timber products, biomass energy, and carbon credits. In this case, the direct cost and benefit of fuel treatments occur during the implementation phase and are incurred largely by land management agencies responsible for planning and implementing fuel treatments. We included carbon credits in this analysis, because even though the actual impacts of fuel treatments on carbon generally occur after a future encounter with wildfire, we assume that carbon credits are estimated based on modeling and incurred at the time of treatment implementation. In summarizing the relevant scientific literature, we considered the answer to this question to be 'yes' when the full costs of a fuel treatment program were less than the revenue generated from forest or rangeland products and 'no' when the costs of a fuel treatment program were more than revenue generated. We considered the answer to this question to be 'both' when the costs of a fuel treatment program can be more or less than the revenue generated depending on different fuel treatment scenarios or other study assumptions.

Are averted wildfire related costs (borne by land management agencies) attributed to fuel treatments greater than the costs of fuel treatment implementation? For the second study question, we also considered other potential benefits that could be incurred by land management agencies over the lifespan of effectiveness of a fuel treatment project. For example, fuel treatments might become financially viable for land management agencies if they result in significant cost savings from avoided fire suppression or fire rehabilitation costs or averted loss of forest or rangeland products from wildfire. In this case, the costs and benefits of fuel treatment programs are still largely borne by land management agencies responsible for planning and implementing fuel treatments, but the time spans over which benefits occur extend beyond the implementation phase and only if wildfire encounters the treated area within the lifespan of its effectiveness. In summarizing the literature that addressed this question we considered the answer to be 'yes' when the costs of a fuel treatment program were less than estimated cost savings in wildfire suppression, rehabilitation costs, or averted losses in forest and rangeland products during the lifespan of a fuel treatment. We considered the answer to be 'no' when the costs of fuel treatments were greater than potential cost savings and 'both' when fuel treatment costs can be more or less than potential cost savings depending on fuel treatment or wildfire scenarios or other study assumptions.

Are the broad benefits of fuel treatments across multiple sectors of society greater than the costs of fuel treatment implementation? For the third question, we examined studies that addressed the net benefit of fuel treatments based on averted wildfire losses borne by multiple sectors of society over the lifespan of fuel treatment effectiveness. For example, this could include communities benefiting from fewer structures destroyed from wildfire or utilities benefiting from averted water treatment costs as a result of fuel treatment programs. We considered the answer to this question to be 'yes' when the costs of a fuel treatment program were less than the estimated value of wildfire-induced damages averted due to fuel treatments and 'no' when the costs of a fuel treatment program were greater. We considered the answer to this question to be 'both' when the costs of a fuel treatment program were more or less than the value of lost or damaged resources and assets, depending on the fuel treatment or wildfire scenario or other study assumptions. For each of these studies, we also documented the types of values and assets considered (e.g., structures, infrastructure, watershed impacts).

3. Results

3.1. Are Revenues Generated from Fuel Treatments Greater than the Costs of Implementation?

We found nine studies that examined the costs of a fuel treatment program relative to revenue generated from forest products, such as timber and biomass energy, at the project implementation phase (Table 1). Studies were generally conducted in the western United States and found that the revenue generated by fuel treatment programs in forest products and biomass energy is typically not enough to offset implementation costs (Table 1; Appendix A).

Table 1. Studies that document the net benefits of fuel treatments for land management agencies at the implementation phase. 'Yes' indicates the study found that net benefits (benefits minus costs (were positive, and 'no' indicates they were not. 'Both' indicates the study found that net benefits were positive in some circumstances but not in others. The 'Net Benefits' column reports results from studies that consider both the economic benefits (averted losses) and costs. 'Averted losses' refers to whether or not studies report averted loss of carbon due to fuel treatment, independent of fuel treatment costs.

Studies	Net Benefits			Averted Losses		
	Yes	No	Both	Yes	No	Both
Forest Product Revenue						
Ager et al., 2017 [16]		x				
Ager et al., 2021 [31]			x			
Alcasena et al., 2022 [32]		x				
Belavenutti et al., 2021 [33]			x			
Buckley et al., 2014 [34]		x				
Campbell & Anderson 2019 [35]		x				
Shreshtha et al., 2021 [36]	x					
Taylor et al., 2013 [37]		x				
Zhou and Hemstrom 2014 [38]			x			
Carbon Offset Revenue						
Alcasena et al., 2021 [12]		x		x		
Buckley et al., 2014 [34]		x		x		
Huang et al., 2013 [39]		x		x		
Pacheco & Claro 2021 [40]	x			x		
Penman et al., 2020 [41]						x

Fuel treatments, which target areas of high wildfire hazard, can often have higher implementation costs and lower revenues from the sale of forest products than treatments whose primary objective is generating revenue. Studies that included fuel treatment scenarios with variability in treatment costs and revenue found that revenue generated from fuel treatments can fully offset implementation costs under certain conditions [31,33,38]. For example, Ager et al. [31] found that a fuel treatment strategy in northern Arizona that balances objectives associated with wildfire hazard and revenue generation can result in net benefits. Across Oregon and Washington, the ability for fuel treatments to result in net revenue can vary greatly by planning unit [33] and with stumpage price [38].

Another potential stream of revenue from fuel treatments could come from the generation and marketing of carbon credits. Studies in Arizona [39], Australia [41], California [34], and Spain [12] found loss of carbon during wildfire could be averted due to fuel treatments, leading to justification of carbon credits. However, only one study in southern Europe [40] found that the potential revenue from carbon credits could be sufficient to fully offset the cost of fuel treatments. While still at a nascent stage, it is possible that the generation of marketable carbon credits could help offset the cost of fuel treatments in the future and, as a result, expand the total acreage of wildland receiving treatment.

3.2. Are Averted Wildfire Related Costs (Borne by Land Management Agencies) Attributed to Fuel Treatments Greater than the Costs of Fuel Treatment Implementation?

In addition to the potential of generating revenues from the sale of forest products in the implementation phase, land management agencies may have greater justification for fuel treatment costs if, on average, treatments reduced future management costs associated with wildfire suppression and rehabilitation and avert losses of revenue-generating forest products from wildfire on public land. These benefits will only be realized, of course, if wildfire encounters the fuel treatment over the lifespan of its effectiveness. Several studies in the United States and Australia found that while fuel treatments can result in lower wildfire suppression and rehabilitation costs, the expected cost savings are not typically enough to fully offset the cost of fuel treatments (Table 2). Only two studies examined the averted wildfire-induced loss of forest products because of fuel treatments and similarly found that the cost savings from preserved forest products do not fully offset the cost of fuel treatments [34,39]. We found no studies that examined the potential for fuel treatments to reduce future fire rehabilitation costs.

Table 2. Studies that document the net benefits of fuel treatments for land management agencies over the lifespan of their effectiveness. Studies examined benefits in terms of avoided suppression costs and avoided loss of forest products from wildfire. 'Yes' indicates the study found that net benefits (benefits minus costs) were positive, and 'no' indicates they were not. 'Both' indicates the study found that net benefits were positive in some circumstances but not in others. The 'Net Benefits' column reports results from studies that consider both the economic benefits (averted losses) and costs. 'Averted losses' refers to whether or not fuel treatments resulted in averted losses in an economic resource during wildfire, independent of fuel treatment costs. 'Yes' indicates the study found that fuel treatments resulted in averted fire suppression costs or loss of forest products. 'No' indicates the opposite and 'both' indicates the study found both positive and negative responses depending on assumptions.

Studies	Net Benefits			Averted Losses		
	Yes	No	Both	Yes	No	Both
Suppression costs						
Belval et al., 2019 [42]		x				
Buckley et al., 2014 [34]		x				
Fitch et al., 2018 [14]				x		
Florec et al., 2019 [43]	x					
Huang et al., 2013 [39]		x				
Jones et al., 2022 [44]				x		
Loomis et al., 2019 [45]						x
Penman and Cirulis 2020 [46]				x		
Sanchez et al., 2019 [47]						x
Taylor et al., 2013 [37]			x			
Taylor et al., 2015 [48]		x				
Thompson et al., 2017 [49]		x				
Forest products						
Buckley et al., 2014 [34]		x				
Huang et al., 2013 [39]		x		x		

3.3. Are the Broad Benefits of Fuel Treatments across Multiple Sectors of Society Greater than the Costs of Fuel Treatment Implementation?

Several studies have examined the economic benefits of fuel treatments in relation to averted losses to valued resources from wildfire that can impact multiple sectors of society other than the land management agency performing treatment. Benefits include averted damage or loss to roads, powerlines or other infrastructure; averted damage or loss to structures; averted impacts to watershed resources; averted damage to wildlife habitat; averted loss of life; and averted loss of opportunities for recreation (Table 3). As with the studies that consider the benefits from revenues at implementation phase and the cost-averted for land management agencies discussed above, most studies find that averted losses to society vary substantially by region [41] and are not sufficient, on their own, to cover the cost of implementation (Table 3). However, when multiple values are considered, the averted losses from wildfire are more likely to be sufficient to cover the costs of fuel treatment implementation (Table 3).

3.4. Factors Influencing Whether Fuel Treatment Benefits Are Likely to Exceed Costs

The literature summarized above utilized a variety of methods to estimate the costs and benefits of fuel treatments, incorporating different factors, assumptions, and scenarios. As such, there is a wide range in estimates of net benefits of fuel treatments, both within and across studies (Appendix A), making it difficult to draw broad conclusions about net benefits of fuel treatments. In this section we summarize how some factors influence fuel treatment economics as a practical guide to land managers and policy makers in determining when fuel treatments are likely to have benefits that exceed costs.

3.4.1. Treatment Costs

Rummer [51] reviewed the existing literature on the costs of fuel treatments and concluded that investigators generally use three different approaches for evaluating and assigning costs to fuel treatment programs: expert opinion, cost of past fuel treatment operations, or applying unit production costs, and often differ in which costs are included in analyses (e.g., direct costs, fixed costs). Previous studies also demonstrate a wide range in fuel treatment costs for different localities (e.g., \$25–\$500/acre for prescribed fire; \$250–\$2480/acre for thinning) [51–53]. Even given the wide range in fuel treatment costs, general trends are evident, such as costs increasing with amount of biomass removed, distance to sawmills or biomass facilities, proximity to WUI, degree of ecological departure from historical condition, and slope steepness [7,16,51,54,55]. In addition, direct cost of mechanical treatments generally exceeds that of prescribed fire [52] although the indirect costs associated with prescribed fire smoke are not well understood [56]. Further, due to the fixed costs association with fuel treatments (e.g., planning, equipment maintenance, and transportation to the treatment site) there are economies of scale with large treatment areas generally having a lower per acre cost than small treatment areas [7,51]. Existing studies do not entirely explain the wide range in treatment costs among regions and localities [51]. Differences in fuel treatment costs among regions and localities are likely in part responsible for different benefit–cost outcomes of fuel treatment scenarios for different studies [44]. Further, the variability in fuel treatment costs suggest that when assigning costs to a proposed fuel treatment project for benefit–cost analyses and other purposes, practitioners should use cost-estimates from highly similar projects, preferably in the same region, to ensure accuracy.

3.4.2. Wildfire Regimes

For fuel treatments to be effective in mitigating the effects of wildfire, and, hence, avert costs, they need to intersect with wildfires within the lifespan of their effectiveness. Thus, the rate of encounters between fuel treatments and wildfire is an important component of estimates of the economic benefits of fuel treatments. Investigators focusing on encounter rates between fuel treatments and wildfires have generally found that results vary widely by region. In examining recorded wildfires greater than 200 to 405 ha and fuel treatments between 1999 and 2012, Barnett et al. [10] found that across the United States, fuel treatment and wildfire encounters over this period were relatively rare (6.8% encounter average rate), but also varied significantly by region (0 to >25%).

Table 3. Studies that document the net benefits of fuel treatments for society. Benefits include averted wildfire-induced losses to infrastructure, life, structures, watershed services, and multiple combinations of these and other values. The 'Net Benefits' column reports results from studies that consider both the economic benefits (averted losses) and costs. 'Yes' indicates the study found that net benefits (benefits minus costs) were positive, and 'no' indicates they were not. 'Both' indicates the study found that net benefits were positive in some circumstances but not in others. The 'Averted losses' column reports whether or not the fuel treatments considered in the study resulted in averted losses to one or more economic resource, independent of treatment costs. 'Yes' indicates the study found that fuel treatments averted losses to infrastructure, life, structures, watershed services, or multiple values. 'No' indicates the opposite and 'both' indicates the study found both positive and negative responses depending on assumptions.

Studies	Net Benefits			Averted Losses		
	Yes	No	Both	Yes	No	Both
Infrastructure						
Buckley et al., 2014 [34]		x		x		
Cirulis et al., 2020 [19]				x		
Penman et al., 2020 [41]				x		
Life						
Cirulis et al., 2020 [19]				x		
Huang et al., 2013 [39]		x		x		
Penman & Cirulis 2020 [46]				x		
Penman et al., 2020 [41]				x		
Structures						
Ager et al., 2017 [16]				x		
Alcasena et al., 2022 [32]				x		
Belavenutti et al., 2014 [33]				x		
Buckley et al., 2014 [34]		x		x		
Cirulis et al., 2020 [19]				x		
Elia et al., 2016 [13]				x		
Florec et al., 2019 [43]	x			x		
Huang et al., 2013 [39]		x		x		
Jones et al., 2022 [44]				x		
Loomis et al., 2019 [45]				x		
Penman & Cirulis 2020 [46]				x		
Penman et al., 2014 [20]				x		
Penman et al., 2020 [41]				x		
Sanchez et al., 2019 [47]				x		
Watershed						
Buckley et al., 2014 [34]		x		x		
Gannon et al., 2020 [50]		x		x		
Huang et al., 2013 [39]		x		x		
Jones et al., 2017 [22]			x			x
Jones et al., 2022 [44]			x	x		
Penman & Cirulis 2020 [46]				x		
Multiple values						
Buckley et al., 2014 [34]	x			x		
Campbell and Anderson [19]		x				
Florec et al., 2019 [43]	x			x		
Huang et al., 2013 [39]			x	x		
Jones et al., 2022 [44]			x	x		
Penman et al., 2020 [41]			x	x		

Previous studies have estimated treatment 'leverage'—defined as reduction in area burned in wildfire resulting from a unit area of fuel treatment—by examining the slope of the relationship between previous area treated and wildfire area [57]. A high leverage value shows potential for high fuel treatment benefits as it indicates that a relatively small area treated can result in a significant reduction in wildfire area, presumably by providing firefighters greater opportunities to limit fire size. Global analyses of fuel treatment leverage show that while fuel treatments can be associated with lower area burned in wildfire, leverage tends to be low and highly variable across locations [17,58,59]. Given its importance in determining the economic benefits of treatment, land managers should consider the encounter rate or potential leverage of any proposed treatment project.

3.4.3. Fuel Treatment Longevity

Treatment effectiveness diminishes over time as vegetation grows and fuels accumulate. The longevity of fuel treatment effectiveness is highly variable and can be influenced by several factors, including the biophysical characteristics of the site (vegetation, slope, aspect, etc.), treatment approach, and treatment size [11]. Further, the frequency with which fuel treatments need to be maintained and characteristics of maintenance treatments will ultimately influence the cost of fuel treatment programs. Maintenance treatments that require greater frequency, or that utilize mechanical methods as opposed to prescribed fire, will increase the cost of fuel treatment programs. Costs of fuel treatment programs may be lower if maintenance treatments focus on prescribed fire or using low intensity wildfire when feasible [10,53].

3.4.4. Fuel Treatment Scale

Few studies have evaluated how fuel treatment scale influences the benefits and costs of fuel treatments [7]. As mentioned above, the fixed costs associated with fuel treatments imply economies of scale, with per acre implementation costs declining with the size of the project. Further, using statistical modeling or wildfire simulation methods, several studies have examined how fuel treatment area influences wildfire patterns and losses over time. Generally, increased treatment area leads to reductions in wildfire area burned, burn probability, and wildfire-induced damages and losses [19,23,49,58,60]. However, since fuel treatment leverage varies widely based on ecosystem and fuel type [59], the scale of treatment at which cost effectiveness is optimized also varies by region [19]. Even when wildfire-induced damages and losses to valued resources was considered, increasing treatment area does not necessarily lead to greater cost-effectiveness [49]. For example, Stevens et al. [23] found that reductions in high severity wildfire across a landscape in California were similar in simulations where 13% and 30% of the landscape was treated. Some have been able to describe optimal treatment area [22,61] and others have shown that treatment optimization strategies vary by spatial and temporal scale of analysis [16,62].

3.4.5. Fuel Treatment Spatial Configuration

The spatial placement of fuel treatments on a landscape can also be an important factor determining averted losses and net benefits. For example, studies in Australia have demonstrated that fuel treatments can be effective in reducing fire-induced damages to structures, especially when treatments are placed near the WUI [19,20,41,43,46]. Further, Penman et al. [41] found that fuel treatments were less effective in protecting WUI and infrastructure when such assets were scattered throughout a vegetated landscape compared to landscapes where there was a clearer demarcation between urban and vegetated areas. Spatial placement is, of course, already a primary consideration for land managers contemplating fuel treatments. In this regard, the literature confirms their intuition that fuel treatments are likely to have greater economic benefits if they are placed near housing and infrastructure or areas that are highly valued by recreationalist and conservationists.

4. Discussion and Conclusions

Our review of the literature indicates that while the costs of fuel treatments are largely incurred by land management agencies, both land management agencies and other sectors of society can benefit from these investments. Land management agencies can benefit financially through forest products, biomass energy, carbon credits, and a reduction in wildfire suppression and rehabilitation costs [6]. In addition, fuel treatments can be critical for meeting agency missions of preserving functioning ecosystems, wildlife habitat, forest and rangeland products, and opportunities for recreation [1,2]. Other sectors in society can benefit by reductions in loses in structures and infrastructure from wildfire, reduced negative health effects from smoke, preservation of ecosystem function, and other benefits. It is rare, however, that any one of these categories of benefits on their own can offset the full cost of fuel treatments, which can be most expensive in the areas where they may be needed most (e.g., WUI, areas of high wildfire hazard). These results suggest that fuel treatment projects are more likely to have benefits that exceed costs if they generate benefits in multiple categories simultaneously.

A full accounting of the costs and benefits of fuel treatments is likely to remain elusive for years to come, as a full understanding of the various costs of wildfire to society are not well documented [8]. Indeed, the studies in this review failed to consider multiple potential fuel treatment benefits, such as averted post-fire rehabilitation or restoration costs, smoke exposure, or long-term impacts to rural economies. Only two studies consider the economic considerations of private landowners [32,36]. Future studies examining fuel treatment economics will likely continue to underestimate the full benefits of fuel treatments. Nonetheless, incorporating economic studies into fuel treatment planning can be useful for increasing program efficiencies, effectiveness, and impacts. For example, the previous literature indicates revenue generated for land management agencies can enhance fuel treatment effectiveness by extending budgets and allowing projects to treat larger areas [63] and target more expensive areas with high wildfire hazard [31,33]. Economic studies can also support alternative models of paying for fuel treatments, such as utility or community payment for watershed services, which can also increase the scale of fuel treatments across landscapes [64].

Methodologies and tools to estimate the benefits and costs of fuel treatments have advanced considerable since 2013 and are being applied in multiple settings [49,65,66]. The variable nature of fuel treatment costs and benefits, however, means that results from any one study are not transferable to other localities, and that it is difficult to reach general conclusions about where on the landscape to perform treatments to maximize net benefits at programmatic scales. In order to better address fuel treatment planning at programmatic scales, the available tools and methods need to be applied in multiple setting and at multiple scales. A collection of studies using similar methodologies could inform budgeting of fuel programs on regional to national levels. Such efforts should include sensitivity analyses to determine how estimates of net benefits vary with different estimates of fuel treatment costs, wildfire probability, and wildfire costs [7].

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Appendix A

Detailed information on studies included in the synthesis, including study location, fuel treatments considered, and estimates of the net benefit of fuel treatments for those studies that provide it. Fuel treatments included mechanical fuels reduction (M), which can include timber harvest, thinning, and mastication, and prescribed fire (Rx), which can include broadcast burning and pile burning. Other fuel treatments included use of herbicide (H), wildfire (W), and seeding (S).

Study	Study Site	Fuel Treatments	Net Benefit
Ager et al., 2017 [16]	Oregon and Washington, USA	M	−$4190 to $14,826 per hectare
Ager et al., 2021 [31]	Arizona, USA	M	−$3626 to $2700 per hectare
Alcasena et al., 2021 [12]	Catalonia, Spain	M, Rx	−34,127 to 465,968 Euros per year
Alcensena et al., 2022 [32]	Idaho, USA	M, Rx	−$15.58 to −$0.78 million per year
Belavenutti et al., 2021 [33]	Oregon and Washington, USA	M; Rx	−$107.7 to $46.1 million
Belval et al. [42]	Western states, USA	W	
Buckley et al., 2014 [34]	California, USA	M; Rx	$26 to $48 million
Campbell and Anderson 2019 [35]	Colorado, USA	M; Rx	−$116.33 to −$25.19 million
Cirulis et al., 2020 [19]	Capital Territory and Tasmania, Australia	Rx	
Elia et al., 2016 [13]	Apulia, Italy	M	
Fitch et al., 2018 [14]	Arizona, USA	M; Rx	
Florec et al., 2019 [43]	Southwestern Australia	Rx	$163 to $835 million (Australian)
Gannon et al., 2020 [50]	Colorado, USA	M; Rx	−$9301 to −$2439 per hectare
Huang et al., 2013 [39]	Arizona, USA	M; Rx	−$3458 to $5029 per hectare
Jones et al., 2017 [22]	Colorado, USA	M	−$60 to $60 million
Jones et al., 2022 [44]	Colorado, USA	M; Rx	0.12 to 2.58 benfit-cost ratio
Loomis et al., 2019 [45]	USA	M; Rx	
Pancheco and Claro 2021 [40]	Meditteranean countries	Rx	36,695 to 116,457,800 Euros
Penman et al., 2014 [20]	Sydney Basin, Australia	Rx	
Penman and Cirulis 2020 [46]	Southeast Australia	Rx	
Penmen et al., 2020 [41]	Eastern Australia	Rx	
Sánchez et al., 2019 [47]	USA	M; Rx	
Shrestha et al., 2021 [36]	Mississippi, USA	Rx	
Spies et al., 2017 [21]	Oregon, USA	M; Rx	
Taylor et al., 2013 [37]	Great Basin, USA	M; Rx; H; S	0.06 to 13.3 benefit–cost ratio
Taylor et al., 2015 [48]	Arizona, USA	M; Rx	−$2095 to $1722 net present value
Thompson et al., 2017 [49]	California, USA	M; Rx	
Zhou and Hemstrom 2014 [38]	Washington, USA	M; Rx	

References

1. Hunter, M.E.; Robles, M.D. Tamm review: The effects of prescribed fire on wildfire regimes and impacts: A framework for comparison. *For. Ecol. Manag.* **2020**, *475*, 118435. [CrossRef]
2. Kalies, E.L.; Yocom Kent, L.L. Tamm review: Are fuel treatments effective at achieving ecological and social objectives? A systematic review. *For. Ecol. Manag.* **2016**, *375*, 84–95. [CrossRef]
3. Ingalsbee, T.; Raja, U. The rising costs of wildfire suppression and the case for ecological fire use. In *The Ecological Importance of Mixed-Severity Fires: Natures' Phoenix*; DellaSala, D.A., Hanson, C.T., Eds.; Elsevier Inc.: Amsterdam, The Netherlands, 2015; pp. 348–371. [CrossRef]
4. Radeloff, V.C.; Helmers, D.P.; Kramer, H.A.; Mockrin, M.H.; Alexandre, P.M.; Bar-Massada, A.; Butsic, V.; Hawbaker, T.J.; Martinuzzi, S.; Syphard, A.D.; et al. Rapid growth of the U.S. wildland-urban interface raises wildfire risk. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 3314–3319. [CrossRef]
5. Westerling, A.L.; Hidalgo, H.G.; Cayan, D.R.; Swetnam, T.W. Warming and earlier spring increase western U.S. forest fire activity. *Science* **2008**, *313*, 940–943. [CrossRef]
6. Ecological Restoration Institute. *The Efficacy of Hazardous Fuel Treatments: A Rapid Assessment of the Economic and Ecological Consequences of Alternative Hazardous Fuel Treatments: A Summary Document for Policy Makers*; Northern Arizona University: Flagstaff, AZ, USA, 2013.
7. Milne, M.; Clayton, H.; Dovers, S.; Cary, C.J. Evaluating benefits and costs of wildland fires: Critical review and future applications. *Environ. Hazards* **2014**, *13*, 114–132. [CrossRef]

8. Thomas, D.; Butry, D.; Gilbert, S.; Webb, D.; Fung., J. *The Costs and Losses of Wildfires: A Literature Review, NIST Special Publication 1215*; National Institute of Standards and Technology: Gaithersburg, MD, USA, 2017. [CrossRef]
9. Calkin, D.; Gebert, K. Modeling fuel treatment costs on forest service lands in the western United States. *West. J. Appl. For.* **2006**, *41*, 217–221. [CrossRef]
10. Barnett, K.; Parks, S.A.; Miller, C.; Naughton, H.T. Beyond fuel treatment effectiveness: Characterizing interactions between fire and treatments in the US. *Forests* **2016**, *7*, 237. [CrossRef]
11. Yocom, L. *Fuel Treatment Longevity: Ecological Restoration Institute Working Paper 27*; Ecological Restoration Institute: Flagstaff, AZ, USA, 2013.
12. Alcasena, F.; Rodrigues, M.; Gelabert, P.; Ager, A.; Salis, M.; Ameztegui, A.; Cervera, T.; Vega-Garcia, C. Fostering carbon credits to finance wildfire risk reduction forest management in Mediterranean landscapes. *Land* **2021**, *10*, 1104. [CrossRef]
13. Elia, M.; Lovreglio, R.; Ranieri, N.A.; Sanesi, G.; Lafortezza, R. Cost-effectiveness of fuel removals in Mediterranean wildland-urban interfaces threatened by wildfires. *Forests* **2016**, *7*, 149. [CrossRef]
14. Fitch, R.A.; Kim, Y.S.; Waltz, A.E.M.; Crouse, J.E. Changes in potential fire suppression costs due to restoration treatments in northern Arizona ponderosa pine forests. *For. Policy Econ.* **2018**, *87*, 101–114. [CrossRef]
15. Ager, A.A.; Day, M.A.; Volger, K. Production possibility frontiers and socioecological tradeoffs for restoration of fire adapted forests. *J. Environ. Manag.* **2016**, *176*, 157–168. [CrossRef]
16. Ager, A.A.; Volger, K.C.; Day, M.A.; Bailey, J.D. Economic opportunities and trade-offs in collaborative forest landscape restoration. *Ecol. Econ.* **2017**, *136*, 226–239. [CrossRef]
17. Oliveira, T.M.; Barros, A.M.G.; Ager, A.A.; Fernandes, P.M. Assessing the effect of a fuel break network to reduce burnt area and wildfire risk transmission. *Int. J. Wildland Fire* **2016**, *25*, 619–632. [CrossRef]
18. Scott, J.H.; Thompson, M.P.; Gilbertson-Day, J.W. Examining alternative fuel management strategies and the relative contribution of National Forest System land to wildfire risk to adjacent homes—A pilot assessment on the Sierra National Forest, California, USA. *For. Ecol. Manag.* **2016**, *362*, 29–37. [CrossRef]
19. Cirulis, B.; Clarke, H.; Boer, M.; Penman, T.; Price, O.; Bradstock, R. Quantification of inter-regional differences in risk mitigation from prescribed burning across multiple management values. *Int. J. Wildland Fire* **2020**, *29*, 414–426. [CrossRef]
20. Penman, T.D.; Bradstock, R.A.; Price, O.F. Reducing wildfire risk to urban developments: Simulation of cost-effective fuel treatment solutions in southeastern Australia. *Environ. Model. Softw.* **2014**, *52*, 166–175. [CrossRef]
21. Spies, T.A.; White, E.; Ager, A.; Kline, J.D.; Bolte, J.P.; Platt, E.K.; Olsen, K.A.; Pabst, R.J.; Barros, A.M.G.; Bailey, J.D.; et al. Using an agent-based model to examine forest management outcomes in a fire-prone landscape in Oregon, USA. *Ecol. Soc.* **2017**, *22*, 25. [CrossRef]
22. Jones, K.W.; Gannon, J.B.; Saavedra, F.A.; Kampf, S.K.; Addington, R.N.; Cheng, A.S.; MacDonald, L.H.; Wilson, C.; Wolk, B. Return on investment from fuel treatments to reduce severe wildfire and erosion in a watershed investment program in Colorado. *J. Environ. Manag.* **2017**, *198*, 66–77. [CrossRef]
23. Stevens, J.T.; Collins, B.M.; Long, J.W.; North, M.P.; Prichard, S.J.; Tarnay, L.W.; White, A.M. Evaluating potential trade-offs among fuel treatment strategies in mixed-conifer forests of the Sierra Nevada. *Ecosphere* **2016**, *7*, e01445. [CrossRef]
24. Butry, D. Fighting fire with fire: Estimating the efficiency of wildfire mitigation programs using propensity scores. *Environ. Ecol. Stat.* **2009**, *16*, 291–319. [CrossRef]
25. Gibbons, P.L.; van Bommel, L.; Gill, A.M.; Cary, G.J.; Driscoll, D.A.; Bradstock, R.A.; Knight, E.; Moritz, M.A.; Stephens, S.L.; Lindenmayer, D.B. Land management practices associated with house loss in wildfires. *PLoS ONE* **2012**, *7*, e29212. [CrossRef]
26. Ager, A.A.; Houtman, R.M.; Day, M.A.; Ringo, C.; Palaiologou, P. Tradeoffs between US national forest harvest targets and fuel management to reduce wildfire transmission to the wildland urban interface. *For. Ecol. Manag.* **2019**, *437*, 99–109. [CrossRef]
27. Alcasena, F.J.; Ager, A.A.; Salis, M.; Day, M.A.; Vega-Garcia, C. Optimizing prescribed fire allocation for managing fire risk in central Catalonia. *Sci. Total Environ.* **2018**, *621*, 872–885. [CrossRef]
28. Barros, A.M.; Ager, A.A.; Day, M.A.; Palaiologou, P. Improving long-term fuel treatment effectiveness in the National Forest System through quantitative prioritization. *For. Ecol. Manag.* **2019**, *433*, 514–527. [CrossRef]
29. Bhuiyan, T.H.; Moseley, M.C.; Medal, H.R.; Rashidi, E.; Grala, R.K. A stochastic programming model with endogenous uncertainty for incentivizing fuel reduction treatment under uncertain landowner behavior. *Eur. J. Oper. Res.* **2019**, *277*, 699–718. [CrossRef]
30. Jahangirian, M.; Eldabi, T.; Garg, L.; Jun, G.T.; Nassar, A.; Patel, B.; Stergioulas, L.; Young, T. A rapid review method for extremely large corpora of literature: Applications to the domains of modelling, simulation, and management. *Int. J. Inf. Manag.* **2011**, *31*, 234–243. [CrossRef]
31. Ager, A.A.; Day, M.A.; Waltz, A.; Nigrelli, M.; Volger, K.C.; Lata, M. *Balancing Ecological and Economic Objectives in Restoration of Fire-Adapted Forests: Case Study from the Four Forests Restoration Initiative*; Gen. Tech. Rep. RMRS-GTR-424; USDA Forest Service Rocky Mountain Research Station: Fort Collins, CO, USA, 2021. [CrossRef]
32. Alcasena, F.; Ager, A.A.; Belavenutti, P.; Krawchuk, M.; Day, M.A. Contrasting the efficiency of landscape versus community protection fuel treatment strategies to reduce wildfire exposure and risk. *J. Environ. Manag.* **2022**, *309*, 114650. [CrossRef]
33. Belvanutti, P.; Chung, W.; Ager, A.A. The economic reality of the forest and fuel management deficit on a fire prone western US national forest. *J. Environ. Manag.* **2021**, *293*, 11285. [CrossRef]

34. Buckley, M.; Beck, N.; Bowden, P.; Miller, M.E.; Hill, B.; Luce, C.; Elliot, W.J.; Enstice, N.; Podolak, K.; Winford, E.; et al. *Mokelumne Watershed Avoided Cost Analysis: Why Sierra Fuel Treatments Make Economic Sense*; Report prepared for the Sierra Nevada Conservancy, The Nature Conservancy, and USDA Forest Service; Sierra Nevada Conservancy: Auburn, CA, USA, 2014.
35. Campbell, R.M.; Anderson, N.M. Comprehensive comparative economic evaluation of woody biomass energy from silvicultural fuel treatments. *J. Environ. Manag.* **2019**, *250*, 109422. [CrossRef]
36. Shrestha, A.; Grala, R.K.; Grado, S.C.; Roberts, S.D.; Gordon, J.S.; Adhikari, R.K. Nonindustrial private forest landowner willingness to pay for prescribed burning to lower wildfire hazards. *For. Pol. Econ.* **2021**, *127*, 102451. [CrossRef]
37. Taylor, M.H.; Rollins, K.; Kobayashi, M.; Tausch, R.J. The economics of fuel management: Wildfire, invasive plants, and the dynamics of sagebrush rangelands in the western United States. *J. Environ. Manag.* **2013**, *126*, 157–173. [CrossRef] [PubMed]
38. Zhou, X.; Hemstrom, M.A. Chapter 4: Overview of the vegetation management treatment economic analysis module in the integrated landscape assessment project. In *Integrating Social, Economic, and Ecological Values across Large Landscapes*; Halofsky, J.E., Creutzburg, M.K., Hemstrom, M.A., Eds.; Gen. Tech. Rep. PNW-GTR-896; USDA Forest Service Pacific Northwest Research Station: Portland, OR, USA, 2014. [CrossRef]
39. Huang, C.H.; Finkral, A.; Sorensen, C.; Kolb, T. Toward full economic valuation of forest fuels-reduction treatments. *J. Environ. Manag.* **2013**, *130*, 221–231. [CrossRef] [PubMed]
40. Pancheco, A.P.; Claro, J. Prescribed burning as a cost-effective way to address climate change and forest management in Mediterranean countries. *Annals. For. Sci.* **2021**, *78*, 1–11. [CrossRef]
41. Penman, T.D.; Clarke, H.; Cirulis, B.; Boer, M.M.; Price, O.F.; Bradstock, R.A. Cost-effective prescribed burning solutions vary between landscapes in eastern Australia. *Front. For. Glob. Chang.* **2020**, *3*, 79. [CrossRef]
42. Bevel, E.J.; O'Connor, C.D.; Thompson, M.P.; Hand, M.S. The role of previous fires in the management and expenditure of subsequent large wildfires. *Fire* **2019**, *2*, 57. [CrossRef]
43. Florec, V.; Burton, M.; Pannell, D.; Kelso, J.; Milne, G. Where to prescribe burn: The costs and benefits of prescribed burning close to homes. *Int. J. Wildland Fire* **2019**, *29*, 440–458. [CrossRef]
44. Jones, K.W.; Gannon, B.; Timberlake, T.; Chamberlain, J.L.; Wolk, B. Societal benefits from wildfire mitigation activities through payment for watershed services: Insights from Colorado. *For. Pol. Econ.* **2022**, *135*, 102661. [CrossRef]
45. Loomis, J.; Sánchez; González-Cabán, A.; Rideout, D.; Reich, R. Do fuel treatments reduce wildfire suppression costs and property damages? In *Analysis of Suppression Costs and Property Damages in U.S. National Forests*; Gen. Tech. Rep. PSW-GTR-261; USDA Forest Service Pacific Southwest Research Station: Albany, CA, USA, 2019.
46. Penman, T.D.; Cirulis, B.A. Cost-effectiveness of fire management strategies in southern Australia. *Int. J. Wildland Fire* **2020**, *29*, 427–439. [CrossRef]
47. Sánchez, J.J.; Loomis, J.; González-Cabán, A.; Rideout, D.; Reich, R. Do fuel treatments in the U.S. national forests reduce wildfire suppression costs and property damage? *J. Nat. Resour.* **2019**, *9*, 42–67. [CrossRef]
48. Taylor, M.H.; Sanchez Meador, A.J.; Kim, Y.S.; Rollins, K.; Will, H. The economics of ecological restoration and hazardous fuel reduction treatments in the ponderosa pine forest ecosystem. *For. Sci.* **2015**, *61*, 988–1008. [CrossRef]
49. Thompson, M.P.; Riley, K.L.; Loeffler, D.; Haas, J.R. Modeling fuel treatment leverage: Encounter rates, risk reduction, and suppression cost impacts. *Forests* **2017**, *8*, 469. [CrossRef]
50. Gannon, B.M.; Wei, Y.; MacDonald, L.H.; Kampf, S.K.; Jones, K.W.; Cannon, J.B.; Wolk, B.H.; Cheng, A.S.; Addington, R.N.; Thompson, M.P. Prioritising fuels reduction for water supply protection. *Int. J. Wildland Fire* **2019**, *28*, 785–803. [CrossRef]
51. Rummer, B. Assessing the cost of fuel reduction treatments: A critical review. *For. Pol. Econ.* **2008**, *10*, 355–362. [CrossRef]
52. Hartsough, B.R.; Abrams, S.; Barbour, R.J.; Drews, E.S.; McIver, J.D.; Moghaddas, J.J.; Schwilk, D.W.; Stephens, S.L. The economics of alternative fuel reduction treatments in western United States dry forests: Financial and policy implications from the National Fire and Fire Surrogate Study. *For. Pol. Econ.* **2008**, *10*, 344–354. [CrossRef]
53. Hunter, M.E.; Shepperd, W.D.; Lentile, L.B.; Lundquist, J.E.; Andreu, M.G.; Butler, J.L.; Smith, F.W. *A Comprehensive Guide to Fuel Treatment Practices for Ponderosa Pine in the Black Hills, Colorado Front Range, and Southwest*; Gen. Tech. Rep RMRS-GTR-198; USDA Forest Service Rocky Mountain Research Station: Fort Collins, CO, USA, 2007. [CrossRef]
54. Fitch, R.A.; Kim, Y.S. Incorporating ecosystem health and fire resilience within the unified economic model of fire program analysis. *Ecol. Econ.* **2018**, *149*, 98–104. [CrossRef]
55. Nielsen-Pincus, M.; Charnley, S.; Mossley, C. The influence of market proximity on national forest hazardous fuel treatments. *For. Sci.* **2013**, *59*, 566–577. [CrossRef]
56. Navarro, K.M.; Schweizer, D.; Balmes, J.R.; Cisneros, R. A review of community smoke exposure from wildfire compared to prescribed fire in the United States. *Atmosphere* **2018**, *9*, 185. [CrossRef]
57. Price, O.F.; Russell-Smith, J.; Watt, F. The influence of prescribed fire on the extent of wildfire in savanna landscapes of western Arnhem Land, Australia. *Int. J. Wildland Fire* **2012**, *21*, 297–305. [CrossRef]
58. Boer, M.M.; Sadler, R.J.; Wittkuhn, R.S.; McCaw, L.; Grierson, P.F. Long-term impacts of prescribed burning on regional extent and incidence of wildfires—Evidence from 50 years of active fire management in SW Australian forests. *For. Ecol. Manag.* **2009**, *259*, 132–142. [CrossRef]
59. Price, O.F.; Pausas, J.G.; Govender, N.; Flannigan, M.; Fernandes, P.M.; Brooks, M.L.; Bliege Bird, R. Global patterns of fire leverage: The response of annual area burned to previous fire. *Int. J. Wildland Fire* **2015**, *24*, 297–306. [CrossRef]

60. Addington, R.N.; Hudson, S.J.; Hiers, K.J.; Hurteau, M.D.; Hutcherson, T.F.; Matusick, G.; Parker, J.M. Relationships among wildfire, prescribed fire, and drought in a fire-prone landscape in the south-eastern United States. *Int. J. Wildland Fire* **2015**, *24*, 778–783. [CrossRef]
61. Mercer, D.E.; Prestemon, J.P. Economic analysis of fuel treatments. In *Cumulative Watershed Effects of Fuel Management in the Eastern United States Gen Tech. Rep. SRS-161*; LaFayette, R., Brooks, M.T., Potyondy, J.P., Audin, L., Krieger, S.L., Trettin, C.C., Eds.; USDA Forest Service Southern Research Station: Asheville, NC, USA, 2012. [CrossRef]
62. Warziniack, T.; Sims, C.; Haas, J. Fire and the joint production of ecosystem services: A spatial-dynamic optimization approach. *For. Pol. Econ.* **2019**, *107*, 101926. [CrossRef]
63. Kreitler, J.; Thompson, M.P.; Vaillant, N.M.; Hawbaker, T.J. Cost-effective fuel treatment planning: A theoretical justification and case study. *Int. J. Wildland Fire* **2020**, *29*, 42–56. [CrossRef]
64. Bennett, D.E.; Gosnell, H.; Lurie, S.; Duncan, S. Utility engagement with payment for watershed services. *Ecosyst. Serv.* **2014**, *8*, 56–64. [CrossRef]
65. Rideout, D.B.; Ziesler, P.S.; Kernohan, N.J. Valuing fire planning alternatives in forest restoration: Using derived demand to integrate economics with ecological restoration. *J. Environ. Manag.* **2014**, *141*, 190–200. [CrossRef]
66. Rideout, D.B.; Kernohan, N.; Epps, J.R. Large-scale fire risk planning for initial attack and fuels: The U.S. state of Idaho. *Int. J. Saf. Secur. Eng.* **2019**, *9*, 26–37. [CrossRef]