

Nonmarket Benefits of Reducing Environmental Effects of Potential Wildfires in Beetle-Killed Trees: A Contingent Valuation Study

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We estimated Colorado households' nonmarket values for two forest management options for reducing intensity of future wildfires and associated nonmarket environmental effects wildfires. The first policy is the traditional harvesting of pine beetle-killed trees and burning of the slash piles of residual materials on-site. The second involves harvesting but moving the residual material off-site and converting it into biochar, thus reducing some of the risk and environmental effects associated with burning on-site. A contingent valuation method mail survey was used to evaluate these two management options. The survey achieved a 47% response rate. We used a nonparametric Turnbull estimator to calculate the willingness to pay (WTP) for burn on-site and off-site biochar conversion. The calculated WTP for burn on-site and off-site biochar conversion options (beyond the cost of the status quo level of forest treatment) is \$411 and \$470 per household per year, respectively.

KEYWORDS *nonparametric Turnbull estimator, willingness to pay, contingent valuation, forest management, beetle-kill, fuel treatments, biochar*

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INTRODUCTION

During the last 27 yr, forests of the intermountain western USA have seen two serious threats, one of which has worsened the other: invasion by mountain pine beetles (*Dendroctonus ponderosae*) and large high intensity fires. The mountain pine beetle (MPB) invasion in the intermountain western USA has left 23 million acres of dead trees since 2000 (United States Department of Agriculture [USDA] Forest Service, 2013). MPB, and other bark beetles, are native to the intermountain west. An abundance of large-diameter trees in dense stands and periodic drought have led to a large increase in bark beetle populations in general, and MPB in particular. When beetle populations are low, healthy and vigorous trees can produce enough resinous pitch to drown or “pitch out” attacking adult insects. As trees become stressed, such as by increasingly dense stand conditions and drought, pitch production declines and the number of successful beetle attacks increases. During large bark beetle outbreaks, even healthy trees can be overwhelmed by many adult beetles attacking the tree in mass (USDA Forest Service, 2012). In addition to damage created by bark beetles and their offspring, many bark beetles carry fungi that further limit the tree’s ability to transport nutrients and water. It is such fungi that result in the characteristic “blue stain” seen in MPB-killed trees.

Dead trees with red needles are more flammable than live trees. Once the needles have fallen, however, standing dead trees no longer increase wildfire risk. As trees drop to the ground the addition of downed woody material—i.e., increased fuel loading—does increase fire intensity and severity. In Colorado, the thousands of acres of dead trees was a significant contributing factor to the intensity and rapid spread of fires during the summer of 2012. Forests that burned in Colorado contained upwards of 70% beetle-killed pine trees (Massey, 2012); resulting in an excessive buildup of fuel in advance of the fires. For example, the extensive amounts of beetle-killed trees fueled the very large and long lasting (3 weeks) High Park fire near Fort Collins, Colorado. This high intensity fire burned an estimated 87,284 acres (Mitchell, 2012), closing roads, burning USDA Forest Service recreation sites, and resulting in sedimentation and debris flows into the Poudre River that shut down Fort Collins’ main water supply for more than a month during the summer. In total, Colorado had 1,498 forest fires in 2012 that burned 246,445 acres of forest (from National Interagency Fire Center, 2012).

Once insects have entered the bark there are no effective treatments to keep the tree alive. All one can do is take steps to prevent successful attacks on uninfested trees. Land managers understand tree and stand characteristics that increase susceptibility to many bark beetle species; and they are called upon by the public to do something. One management option is to develop silvicultural treatments to reduce stand densities, increase tree species and

age diversity, and remove bark beetle-killed and infested trees. Thinning reduces competition between trees for limited sunlight, water, and nutrients. The remaining trees are better able to produce pitch to defend against bark beetle attacks. Increased age and species diversity enhances stand resistance to bark beetle attacks and reduces the effects of tree mortality when attacks occur. Regardless of any silvicultural treatments managers might design, bark beetle outbreaks are not preventable (USDA Forest Service, 2012). Treatment can only mitigate the impacts. Protection of individual, high-value trees can be accomplished with insecticide and pheromone treatments; but such treatments are not feasible for large areas of public forestland.

Treatments to thin the forests, decrease fuel loads, and clear out insect and disease-killed trees are expensive. Many timber sales are judged by potential bidders to be infeasible due to economic conditions and a lack of available markets for the mostly small trees that can be harvested. Forest thinning projects not part of a timber sale are equally expensive and limited by agency budgets. Treatments that do get accomplished are left with an expensive disposal problem because there is no market for residual material—i.e., the limbs, tops, and branches—that are left after any usable/marketable material is removed. These “slash piles” are often burned on-site where they contribute to smoke, air pollution, and greenhouse gas emissions.

Being able to utilize woody biomass to produce value-added products, especially from residual materials of biomass removal and wood processing, would enhance the feasibility of accomplishing biomass removal and forest treatment projects. One way to utilize woody biomass is through pyrolysis, a process in which organic matter is heated with limited or no oxygen. Products that can be produced from woody biomass using pyrolysis include: (a) biochar (shortened from “biological charcoal”) which has potential as a solid fuel, soil amendment, and precursor for secondary carbon products including activated carbon; (b) syngas (“synthesis gas”) which has potential for energy production and as feedstock for liquid fuels and chemical production; and (c) bio-oil which has potential for use as heating oil or transportation fuel, or as chemical feedstock (Lehmann & Joseph, 2009b).

As a soil amendment, biochar attracts and holds water, increases cation exchange capacity, makes the soil more porous, and enhances sorption of organic compounds. Such properties enhance soil productivity and facilitate plant growth to reduce erosion, and restore compacted, oxidized, and degraded soils (Lehmann & Joseph 2009a; Sohi, Krull, Lopez-Capel, & Bol, 2010; Jeffery, Verheijen, van der Velde, & Bastos, 2011). Biochar is a stable form of carbon that is highly resistant to further decay and remains in the soil for hundreds or thousands of years, implying uses for carbon sequestration (Lehmann, Gaunt, & Rondon, 2006; Lehmann, 2007; Laird, 2008; Meyer, Glaser, & Quicker, 2011). As a precursor to activated carbon, biochar has potential for use in filters; such as those used in water treatment facilities.

The purpose of this study is to estimate Larimer County, Colorado households' nonmarket values for two alternative forest management options aimed at reducing the intensity of future wildfires and associated nonmarket environmental effects of wildfires by removing additional dead and dying trees to reduce the fuel load in the forest compared to the status quo. The first alternative management option (which we call Option 2) is to remove more standing dead and downed trees from the forest using manual and mechanical harvest methods, removing any marketable material, and burning residual material on-site. Residual material is biomass left over after any usable or marketable material has been removed. Generally, this consists of tree tops, limbs, and branches. But it could include material of any size if local conditions are such that it is not economically feasible to transport and process the material. The second management alternative (referred to as Option 3) involves the same increased harvesting and removal of marketable material, but moving the residual material off-site and converting it into biochar, thus reducing some of the environmental effects associated with burning residuals on-site.

The second objective of the study is to test whether there is an incremental willingness to pay (WTP) for the added environmental benefits associated with off-site burning of residuals (using a carefully controlled pyrolysis process) and conversion into biochar. These two options are compared to the current level (status quo) of limited harvest of dead and downed trees only from high priority areas such as around roads and campsites with on-site of residual materials. The status quo is referred to as Option 1.

Economists use WTP as a measure of the benefits a person receives from a particular good or service (McCollum, Peterson, & Swanson, 1992; Freeman, 1993). For nonmarket goods and services, two broad types of techniques of techniques are used to estimate WTP: (a) revealed preference; and (b) stated preference (Champ, Brown, & Boyle, 2003). Revealed preference methods such as the travel cost method for estimating recreation demand and WTP, relies on visitors' actions and behaviors—e.g., trading money and travel time for a recreation experience (Freeman, 1993; Loomis & Walsh, 1997). However, for some people the benefits of protecting forests, downstream water quality, and fisheries are unrelated to their own on-site use and are referred to as passive use or nonuse benefits (McCollum et al., 1992). These benefits include existence value (Krutilla, 1967; Krutilla & Fisher, 1975) to know self-sustaining forests exist in their area and that they will be available to future generations (bequest value). When an individual places value on knowing that a resource exists independent of any personal use of the resource; and bequest value, when an individual places value on knowing the resource will be available to future generations (Krutilla & Fisher, 1975). In order to measure such passive use values, economists must rely on what people state in a carefully constructed hypothetical market, hence the name stated preference.

In order to estimate the WTP of the general population for the reduction in the amount of standing and downed pine beetle-killed trees, the extent of forest fires, and pollution associated with fires, our study used the contingent valuation method (CVM), a commonly used stated preference method. While the method has been used for more than four decades by academic and government economists, some fundamental concerns regarding the accuracy and validity of the resulting WTP estimates remain. In the Methods and Data section, we provide more detail on CVM and review the issue of hypothetical bias. Specifically, that some respondents state they would pay more than they actually would just because the valuation exercise is hypothetical and actual payment is not required (Loomis, 2014). Then we discuss the degree to which our study is susceptible to hypothetical bias, and how we attempted to minimize this problem. Mitchell and Carson (1989), Boyle (2003), and Alberini and Kahn (2006) provide a thorough presentation of the CVM.

LITERATURE REVIEW

While there are no economic studies of the public's value of off-site conversion of residual forest materials into biochar, there have been several nonmarket valuation studies of reducing the intensity and spread of wildfires. One of the earliest studies was a phone-mail-phone CVM survey of households in Florida, California, and Montana (Loomis & Gonzalez-Caban, 2009). The study compared WTP for prescribed burning and mechanical harvesting to achieve fuel reductions in the three states. The calculated mean WTP of Caucasian households for prescribed burning for California, Florida, and Montana was 460, 392, and \$323, respectively. The calculated mean WTP of Caucasians for mechanical fuel reduction was 510, 239, and \$186, respectively.

Walker, Rideout, Loomis, and Reich (2007) used CVM to estimate WTP for two methods of fuel reduction: mechanical thinning versus prescribed burning for urban and wildland-urban interface (WUI) regions in northern Colorado, a geographic area similar to our study. The annual WTP for the prescribed burning method by Larimer County and Boulder County urban respondents was 140 and \$213, respectively. For WUI respondents, WTP for prescribed burning was 150 and \$202 per household, respectively. The WTP for thinning in Larimer County and Boulder County by urban respondents was 289 and \$412, respectively; and by WUI respondents WTP was 311 and \$493, respectively. Talberth, Berrens, McKee, and Jones (2006) used an induced-value experiment and a CVM survey to examine the simultaneous effects of wildfire insurance and private/public averting behavior of households in the mountainous areas of eastern New Mexico along the WUI. They concluded that households take averting behavior with regard to forest fires regardless of whether they have full home insurance. WTP values per

household for private risk reduction activities, neighborhood risk reduction activities, public land risk reduction activities, and private wildfire insurance were 240.04, 94.45, 64.12, and \$184.42, respectively. Talberth et al. (2006) also estimated a total WTP of \$583 by summing WTP for private, neighborhood, and public land risk reduction activities and private wildfire insurance. Our study builds on these previous studies by comparing the value for mechanical fuel reduction treatment with residuals disposed of by burning on-site to that for mechanical fuel reduction with residual materials moved off-site and converted to biochar.

METHODS AND DATA

Stated Preference Valuation Method

Carson and Louviere (2011) discussed different stated preference methodologies that have been used to elicit WTP for public goods. Two of those stated preference methods are relevant to our study: CVM and discrete choice experiment studies. In both those methods, information about a public good is presented to a group of people in order to elicit their WTP. In the traditional dichotomous choice CVM, the dollar amounts that households are asked to pay are varied across the sample to allow calculation of mean WTP. The advantage of the dichotomous choice format is that it is similar to price taking behavior of consumers in a market and to voting in a referendum. To capitalize on these advantages we adopted the dichotomous choice WTP question format in our study.

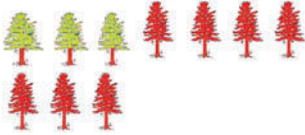
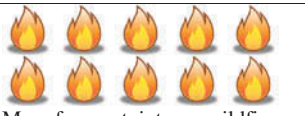
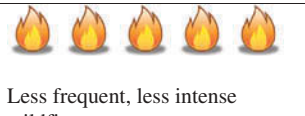
In a discrete choice experiment, respondents choose between different management options characterized as bundles of attributes related to the management activities and the outcomes of those activities—e.g., number of acres treated or number of high air pollution days resulting from the treatment. The attributes have different levels—e.g., 100 or 1,000 acres of land treated. Attribute levels in a choice set presented to respondents will vary between the status quo management option and the alternative management options. Respondent A might see an Option 2 alternative comprised of 3,000 acres treated resulting in 4 high pollution days at an additional cost of \$50 per household versus the status quo in which 1,000 acres are treated resulting in 14 high pollution days at an additional cost of \$0—because that is the level of management activity for which they currently pay. Respondent B might see an Option 3 alternative comprised of 4,000 acres treated with 3 high pollution days at an additional cost of \$95 versus the same status quo. Respondents choose either the alternative or the status quo based on the different attributes and levels of each bundle, where one attribute is the cost. This way the respondents can express their WTP by choosing the alternative that best represents their preferences. Our dichotomous choice CVM is a special case of the discrete choice experiment in which the group of attributes

only vary between the three options, and just the cost of the option is varied across respondents. Being binary the respondents only choose between the status quo and one of the other options in each WTP question. Separate CVM exercises are conducted for Option 2 and Option 3.

Public Goods Being Valued

As described above, the goods being valued are increases in the level of harvest and removal of beetle-killed trees compared to the status quo (Option 1). The primary difference between on the ground management actions in Option 2 and Option 3 is in how residual materials are handled. Option 2 burns the residual material on-site and Option 3 moves the residual material off-site to produce biochar in a controlled environment. Seven nonprice attributes and a cost variable were selected as the bases for comparison of the three options: (a) acres of pine beetle-killed trees remaining after the management treatments; (b) percent of the forest that burns over a 10-yr period; (c) frequency and intensity of wildfires; (d) level of air pollution; (e) level of greenhouse gas emissions; (f) water quality in streams; (g) number of months recreation sites would be closed due to fire and cleanup operations; and (h) annual (additional) cost to taxpayers. Percentage of the forest that burns every 10 yr was specified for the three alternatives. The frequency of large wildfires represented the number and intensity of forest fires that occur. Air pollution was represented by the number of unhealthy days—i.e., days on which people are likely to experience undesirable health effects and on which people with existing conditions such as respiratory problems are advised to avoid going outside. Water quality in streams as a consequence of forest fires had two levels: it could be muddy, or rarely muddy. In rarely muddy conditions, there are possibilities for fishing and kayaking, and minimal additional water treatment is required.

The levels of these attributes varied between Current Management (Option 1) and the two alternatives—Management Option 2 (harvest and burn residual material on-site) and Management Option 3 (harvest and convert residual material to biochar). Only three nonprice attributes (air pollution, greenhouse gas emissions, and recreation site closure) varied across all three management alternatives, and the levels were fixed for each alternative. The other four nonprice attributes only changed from current management (Option 1) to identical levels for Options 2 and 3. Focus groups indicated that it did not make sense for all the attributes in Options 2 and 3 to vary independently as changes in forest fire frequency should be the same since both of those options involved the same amount of mechanical thinning. [Figures 1](#) and [2](#) illustrate the choice sets seen by respondents and the specified nonprice attributes. The cost attribute also varied across all three options. One of 12 different cost amounts ranging from 5 to \$700 for Option 2 and 10 to \$900 for Option 3 was inserted into the spaces shown in

	Option 1: Current management	Option 2: Burn beetle-killed trees on-site
Pine beetle-killed trees (acres infested)		
% Forest burned every 10 yr	20%	10%
Forest fire frequency	 More frequent, intense wildfires	 Less frequent, less intense wildfires
Air pollution from fire smoke (# average days)	High air pollution  10 unhealthy days	Low air pollution  4 unhealthy days
Greenhouse gas emissions	High	Medium
Water quality in streams and lakes in areas burned	 Frequently muddy	 Rarely muddy
# of months recreation areas are closed	 6 months	 2 months
Annual cost to taxpayers	\$0	5–\$700 (the bid varies from 5 to \$700)

1. Using the information provided in the Figure above, which option would you choose?
(Check one box).

Option 1

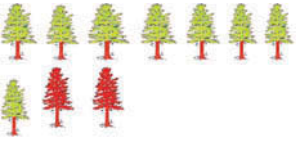
☐

Option 2

☐

FIGURE 1 Current management versus burn on-site scenarios.

Figures 1 and 2 for “annual cost to taxpayers.” Over half of the cost amounts for both options were under \$125. While the format of the CVM questions in Figures 1 and 2 resemble a binary choice experiment, we could not conduct an orthogonal main effects design due to budget limits and the logic of the environmental effects. As indicated, focus groups felt it was ecologically sensible for all the attributes in Options 2 and 3 to vary independently as reductions in forest fire frequency were identical since both Options 2 and 3 involved the same amount of mechanical thinning.

	Option 1: Current management	Option 3: Convert beetle-killed trees to biochar
Pine beetle-killed trees (acres infested)		
% forest burned every 10 yr	20%	10%
Forest fire frequency	 More frequent, intense wildfires	 Less frequent, less intense wildfires
Air pollution from fire smoke (# average days)	High air pollution  10 unhealthy days	Very low air pollution  2 unhealthy days
Greenhouse gas emissions	High	Low
Water quality in streams and lakes in areas burned	 Frequently muddy	 Rarely muddy
# of months recreation areas are closed	 6 months	 1 month
Annual cost to taxpayers	\$0	10–\$900 (the bid varies from 10 to \$900)

1. Using the information provided in the Figure above, which option would you choose?
(Check one box).

Option 1
☐

Option 3
☐

FIGURE 2 Current management versus biochar scenarios.

Payment Vehicle

Respondents were told that because of the large amount of federal lands in Colorado, such as National Parks and National Forests, the cost of management treatments to reduce the wildfire hazard would be shared between all U.S. taxpayers and Colorado taxpayers. Combined federal and state taxes

would increase, with the amount depending on the management option. The federal tax would be in the form of an increase in income tax. Colorado state taxes would be an increase in sales tax and state income tax. These annual tax increases would be for 10 yr taking effect in 2014 and expiring in 2024. The money would go into a dedicated fund for forest treatments and removal of pine beetle-killed trees that would be monitored by a citizen advisory panel. The cost varied from a low of \$5 annually to as much as \$900, with most bids less than \$125.

Addressing Fundamental Concerns About CVM in Our Survey Instrument

While CVM has been used by environmental economists for decades, the Exxon Valdez oil spill in 1992 brought CVM under intense scrutiny. A series of articles in the *Journal of Economic Perspectives* in 1994 summarized the concerns about CVM surveys of the general public at the time (see Portney, 1994 for an overview). Nearly 20 yr later, the same journal reexamined the state of progress in CVM. The overview paper attempted to provide a neutral assessment of the progress that had been made, what has been learned, and continuing concerns with CVM (Kling, Phaneuf, & Zhao, 2012). Hausman (2012) revisited his original criticisms (Diamond & Hausman, 1994), and continued to find long-standing fundamental problems: (a) hypothetical bias whereby stated values exceeded objective measures of actual values—often cash payments; (b) WTP exceeding willingness to accept compensation; and (c) a lack of “scope”—i.e., a concern that CVM estimates are not responsive to the magnitude of a change in quantity or quality of a public good. These are serious concerns and ones that have been well-researched over the last 20 yr. Numerous strategies have been developed to minimize these effects (Kling et al., 2012).

As is the case for other CVM studies, hypothetical bias was a concern for this study. We followed literature guidelines in designing our survey to minimize hypothetical bias (see Loomis, 2014 for a summary of strategies to minimize hypothetical bias). For example, we cast the household's WTP decision in a dichotomous choice binary format (status quo versus Option 2, then another binary choice with status quo versus Option 3 (Carson & Groves, 2007)). We stressed the consequentiality of the respondent's choice in terms of: (a) payment of taxes—a compulsory payment vehicle rather than as a voluntary donation (Carson & Groves, 2007); (b) the results would be used by federal and state forest management officials in their decisions regarding how to address the pine beetle-kill problem. Vossler and colleagues have shown that consequential surveys do in fact reduce or even eliminate hypothetical bias in some cases in nonmarket valuation field experiments using stated preference methods such as CVM (Vossler & Kerkvliet, 2003; Vossler,

Doyon, & Rondeau, 2012; Vossler & Watson, 2013). Further, the population in Colorado is very aware of both wildfires and beetle-killed forests. Thus, the survey should have a high level of salience to respondents. High salience is expected to both increase response rate and the seriousness with which respondents take the survey (Heberlein & Baumgartner, 1978).

A shortage of funding prevented us from including a scope test in this study. While it is possible that our respondents valued a program larger than just the state of Colorado, evidence from our focus groups suggests otherwise. In particular, discussions in the focus groups indicated that respondents were focusing on the benefits just in Colorado (and even more locally to where they lived in Northern Colorado) rather than the entire western USA, for example.

As noted above, we conducted two focus groups in the geographic area where the survey would be mailed (i.e., Larimer County, Colorado). Respondents read each page of the survey, specifically noting anything that was not clear. The page was discussed as a group to gain additional insight on their responses. Surveys were revised after each focus group to address the suggestions of the focus group. A pretest of the resulting mail survey was conducted by handing the survey out at one of the local grocery stores, and having respondents mail it back. Part of the intent at this phase was to test whether the bid (or cost amount) distribution was realistic. These steps helped to ensure face validity—i.e., that respondents understood the WTP question as intended by the researchers.

SURVEY IMPLEMENTATION

To implement the CVM we created a color mail survey that was sent to a random sample of 500 residents of Larimer County, Colorado (which contains Fort Collins). We used the Dillman repeat mailing method (Dillman & Sallant, 1994) as follows: the first mailing of the survey and cover letter was sent to 500 residents of Larimer County in May of 2013 with a \$1 bill and a postage paid return envelope included. We included a \$1 bill in our first mailing in an attempt to increase our response rate, as discussed by Dillman and Sallant (1994). The postage paid return envelope was a further attempt to increase response rate. A postcard reminder was sent 2 weeks after the initial mailing. A second survey mailing was sent to nonrespondents 1 month after the first mailing. Again, that was followed by a reminder postcard. A third survey mailing was sent in late June of 2013, followed up with postcard reminders. A fourth mailing in August was sent to remaining nonrespondents. Accounting for undeliverable addresses, nonusable data, and ineligible data (people who had moved out of state), the usable response rate was 47%.

ANALYSIS OF DATA

Nonparametric Model Versus Parametric Model

There are two choices for estimating WTP from dichotomous choice data: a parametric or nonparametric model. In a fully parametric model, the data generating process includes two parametric components. One is the probability density function (PDF); the other is the conditional mean of the dependent variable. The PDF shows the relationship between the dependent variable and the independent variables. Assumptions about the PDF and conditional mean of the dependent variable in a fully parametric model affect the type of estimator needed to make inferences about population parameters. For example, assuming a normal distribution leads to the corresponding statistical model being a probit, while assuming a logistic distribution gives rise to the logit model.

Nonparametric methods do not impose a specific distribution or functional form; instead these methods are data-driven. With a nonparametric model, no assumptions are made about either the conditional mean of the dependent variable or about the exact PDF of the dependent variable (Racine, 2008).

A nonparametric “Turnbull estimator” was used to smooth the empirical WTP distribution associated with proposed management options. Nonparametric methods such as the Turnbull have been used extensively in CVM studies (Haab & McConnell, 2002, pp. 65–66).

Nonparametric Smoothing Method: Turnbull Estimator

In the case of the discrete choice CVM for estimating WTP, if the respondent chooses an alternative management option over the current management option, it means their WTP is greater than or equal to the price the respondent is asked to pay for the alternative management option. On the other hand, if the respondent says “No” to the alternative management option and chooses their status quo, their WTP is less than the alternative management options’ price. In most dichotomous choice surveys that do not have large sample sizes at each bid amount, the probability of getting a “No” response does not necessarily monotonically increase as bid amounts increase, as economic theory would suggest. The advantage of using the Turnbull estimator is that one can estimate WTP even though the proportion of “No” responses did not increase monotonically as the dollar bid amount increased. It is important to note that Turnbull estimators provide a lower bound estimate for WTP. The process involves calculating the proportion of “No” responses associated with increasing bid amounts. For bid amounts that do not follow the monotonicity restriction, we pool the number of “No” responses to bid amount j (N_j) and N_{j+1} together, and then we drop the bid amount that does

not follow the monotonic trend in “No” responses (N_{j+1}). Then we calculate a weighted average of the prior bid (B_{nj}) and subsequent bid (B_{nj+2}). This procedure is followed until all cells are pooled sufficiently to derive the monotonically increasing cumulative distribution function (CDF) in the “No” response (Haab & McConnell, 2002).

RESULTS

Descriptive analysis of the data indicates that 39.1% of respondents were female, 27.6% live in a rural area, 40% seniors (over 65 yr old), and 86.9% visited some forest for recreational activities such as hiking, mountain biking, skiing, camping, etc., in the previous 12 months. Sixty-eight percent of respondents reported higher education (bachelor’s degree or higher), and 33% of our participants fell into the middle income range. The high education level reflects the fact that Larimer County is home to one college and one university as well as being a high tech hub (e.g., Hewlett Packard, Intel, and AMD are major employers in Larimer County).

We calculated the percentage of respondents who chose different management options such as burn residual material on-site management option (Option 2) and move residual materials off-site and convert into biochar (Option 3) rather than the status quo option (Option 1). These results are shown in Table 1. In Scenario 1 shown in Figure 1, respondents chose current management 32.6% of the time and Option 2, 63.5% of the time. In Scenario 2 shown in Figure 2, respondents chose the current management option 41.7% of the time versus Option 3, 54.4% of the time. And 3.9% of respondents did not choose any of the management options. It should be noted that Option 3 asked respondents to pay a higher range of dollar amounts than Option 2, since Option 3 would be more expensive to implement.

TABLE 1 Respondent Choice by Management Options; Burn On-Site Versus Biochar for Repeated Contingent Valuation Method (CVM) Survey

	WTP Scenario 1*	WTP Scenario2**
Current management	32.6%	41.7%
Burn on-site (Option 2)	63.5%	NA
Convert beetle-killed trees to biochar (Option 3)	NA	54.4%
No response	3.9%	3.9%

Note. *Scenario 1 asked respondents to choose one management option between current management option (Option 1) and burn on-site (Option 2). **Scenario 2 asked respondents to choose one management option between current management option (Option 1) and convert beetle-killed trees to biochar (Option 3). Scenario 2 asked respondents to pay higher dollar amounts for Option 3 than were asked for Option 2, due to the higher cost of implementing Option 3.

Using the nonparametric Turnbull estimator, we calculated WTP for the burn on-site option (Option 2) as \$411 per household per year. The WTP estimate for the biochar option (Option 3) was \$470 per household per year. The mean WTP for the mechanical thinning with the burn off-site with biochar option is about 15% higher than the burn on-site option. This indicates there could be a small incremental value for achieving the additional reductions in air pollution, greenhouse gas emissions, and months of recreation-site closure. As noted earlier, both of these WTP estimates, like some of those originating from a CVM study, may exhibit overstatement of WTP amounts—i.e., reflect a degree of hypothetical bias.

DISCUSSION, IMPLICATIONS, AND CONCLUSIONS

Table 2 presents estimates of WTP per household from the studies most similar to ours along with the forest acreage that burned during the year of the respective study. Loomis and Gonzalez-Caban (2009) calculated the mean annual WTP for forest fire reduction activities using mechanical thinning in another intermountain state, Montana, to be \$186 per household. The WTP number for Montana is lower than what we calculated for both burning on-site and off-site conversion to biochar. However, in the year of the Montana study about 50,000 acres burned in Montana, roughly a quarter of the acreage that burned in Colorado during the year of our study. These differences in acreage burned may have influenced WTP year.

Walker and her colleagues calculated WTP of urban and WUI residents of Larimer County for thinning versus prescribed burning. The WTP for thinning in Larimer County was 289 and \$311 for urban and WUI respondents, respectively (Walker, Rideout, Loomis, & Reich, 2007). Most (72%) of our

TABLE 2 Comparison of CVM Studies for Reducing Wildfire Risks in the Wildland-Urban Interface

Author	State/Region of study	Calculated WTP	# Fires at time of survey	Acres burned at time of survey	Survey response
Loomis and Gonzalez-Caban (2009)	Montana	\$186	1,731	48,912	34–50%
Walker, Rideout, Loomis, and Reich (2007)	Northern Colorado	\$311	3,914	26,515	27–41%
Talberth, Berrens, McKee, and Jones (2006)	New Mexico	\$583 total WTP	2,636	607,802	27.3%
Current study	Northern Colorado	\$411	1,134	195,082	47%

respondents were from urban areas, and our WTP for thinning and burning residual material on-site was \$411 for Larimer County. Our WTP estimate is higher than the Walker et al. (2007) estimate, which could be due to multiple years of large forest fires that occurred in Colorado after the time of the Walker et al. study. The study with mean values substantially larger than ours (Talberth et al., 2006) occurred in NM, where nearly three times the forest acreage burned in the year of the study. We suspect that the acreage burnt at the time of survey leads to higher WTP. The studies in Table 2 have been used to calculate the correlation among WTP and acreage burned. The result presented is the *R* correlation coefficient. We preferred using simpler *R* correlation than *R*-squared for this particular study with only four observations. The calculated correlation coefficient between WTP and acreage burnt at the time of survey is .92.

In terms of our first objective, Larimer County households have a substantial annual WTP to lessen the nonmarket environmental effects of wildfires. In particular they are willing to pay to increase the removal of pine beetle-killed trees to reduce the frequency and intensity of wildfires, decrease the amount of air pollution from wildfires, decrease the amount of time recreation sites are closed, and to reduce postfire sedimentation in streams.

In terms of our second objective, there could be a small difference in the public's evaluation of whether it is worth additional cost to move the residual material from forest treatments off-site and convert it to biochar as opposed to just burning the residual material on-site. Mean WTP was 15% greater for Option 3 (residual material used for off-site production of biochar) than for Option 2 (burning residual materials on-site). There might be some economic justification for implementing the biochar option if (a) there is not a large cost differential between Options 2 and 3; and (b) the sale or use of the biochar product (which we did not evaluate) can provide further benefits or value. The jury is still out; more research could better inform the debate.

This study reinforces the results of previous studies by illustrating that the public appears to support the need for more active forest management of dead and dying beetle-killed trees to reduce the risk that lightning or human-caused wildfire could quickly spread into a massive wildfire threatening air quality and postfire water quality, along with other effects of wildfire. They appear willing to pay for harvesting more dead timber and allow the trees to be burned on-site. There seems to be diminishing returns to subsequent reductions in air pollution and greenhouse gas emissions that would come from moving the burning out of the forest and burning the residual material in a controlled environment. We purposely did not emphasize any benefits of the biochar product itself so as to keep the focus on the nonmarket environmental aspects of forest management. Providing information on biochar and adding biochar use for soil restoration and carbon sequestration as outcomes of the management alternative could be a next step.

The generalizability of our results to other areas merits further study. Given the widespread exposure to information about the extent of beetle-killed forest and the frequent severe wildfires in Colorado, we believe our results are generalizable from Larimer County to other counties along Colorado's wildland-urban interface. Further research is needed to investigate the values for these forest management activities in other states affected by mountain pine beetles, or other bark beetles, and wildfires.

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