Changing Perceptions and Actions in Response to Forest Disturbance by Mountain Pine Beetles in North Central Colorado

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Abstract

Forest disturbances caused by insects, pathogens, and fire continue to increasingly occur within forests across the U.S. and around the world. Given the dynamic nature of these forest disturbances and the role played by local residents in risk management, it is valuable to explore how the human experience, attitudes, and behaviors associated with these ecological processes may evolve over time. In this paper we assess temporal changes in local residents' perceptions and actions in response to the mountain pine beetle outbreak that affected large swaths of forests in north central Colorado. Through analyses of secondary and household survey data from 2007 and 2018, we note significant changes in these aspects and identify factors consistently associated with individual and community activeness. The study contributes to knowledge of dynamic socio-ecological considerations of forest disturbances and improves understanding of how social sciences can help to identify opportunities and barriers to effective forest ecosystem management.

Study Implications: This study focuses on the dynamic social processes related to forest disturbance by mountain pine beetles (MPB) in north central Colorado. Evidence demonstrates that local risk perceptions and actions in response to the MPB outbreak change over time. Understandings of such dynamics and their influencing factors can inform management strategies that support both forest health and community well-being. Communities' biophysical and socioeconomic vulnerability contexts also play an important role in shaping changes in local perceptions and actions. Successful forest ecosystem management thus relies on approaches that explicitly attend to social complexity and temporal effects.

Keywords: forest insect disturbance, community vulnerability, human response, temporal dynamics, local context, community variations

Ecological disturbances including those associated with forest ecosystems are occurring with increased frequencies, durations, and magnitudes because of changing climate parameters at different spatial scales (Bentz et al. 2010; Morris et al. 2018; Wolken et al. 2011). Insect, pathogen, and fire outbreaks are among the most significant agents of forest disturbances and related risks in the United States and across the world (Dale et al. 2000; McCollum and Lundquist 2019; Vose et al. 2018). Anthropogenic factors such as forest management and amenity migration further compound such ecological issues. Growing research on the sociocultural and economic dimensions of forest insect disturbance has emerged during the past two decades. Scholars have particularly examined different aspects of human perceptions and experience related to forest insect outbreaks, including community risk concerns and responses (e.g., Flint and Haynes 2006; Qin and Flint 2017), knowledge and attitudes of forest visitors (e.g., Arnberger et al. 2018; Müller and Job 2009), and public opinions on forest management and industry options (e.g., Kooistra and Hall 2014; Urquhart et al. 2017). Despite the inherently dynamic nature of forest insect disturbance, temporal changes in related perceptions and behaviors are not often studied.

Whereas existing longitudinal analyses of the human dimensions of forest disturbances mainly focus on wildfire and fuel management (e.g., Champ and Brenkert-Smith 2016; Gordon et al. 2013; Shindler and Toman. 2003; Toman et al. 2014), several studies have explored changing perceptions and actions in response to forest insect disturbance over time. Using national survey data collected in 2013 and 2016, Urquhart et al. (2017) detected a general decline in the British public's knowledge and concern about tree health issues as well as willingness to adopt biosecure actions. Elsewhere, McFarlane and Watson (2008) found that perceived risk to ecosystems consistently contributed to support for controlling beetle outbreaks by surveying Canadian national park visitors' ecological risk perceptions related to mountain pine beetles (MPBs; *Dendroctonus ponderosae*) at two points in time (2003 and 2005). A series of sociological studies of the spruce bark beetle (SBB; *Dendroctonus rufipennis*) outbreak in Kenai Peninsula, Alaska (2003–2008), also suggested that the evolvement of community risk perception and response was more complicated than a simplistic issue-attention cycle would predict (Flint 2007; Qin et al. 2015a). Building on the existing literature, particularly the Kenai study, we further examined dynamic beetle-related perceptions and responses over a longer time span and in another biophysical and socioeconomic context – the forest disturbance by MPBs in north central Colorado. Our research objectives were mainly two-fold: (1) to assess temporal changes in local residents' perceptions and actions in response to the MPB outbreak, and (2) to identify factors consistently associated with individual and community activeness (level of actions) related to beetles.

The Mountain Pine Beetle Outbreak in Colorado

American coniferous forests have seen increasing disturbance by insects in recent years. Since 1996, a massive MPB outbreak has killed nearly 3.4 million acres of lodgepole (*Pinus contorta*) and ponderosa pine (*Pinus ponderosa*) trees in northern Colorado, leaving many large swaths of grey-casted dead forests throughout this region. Although MPBs are native species to Colorado, the outbreak occurring during this period was unprecedented in terms of its scope and intensity. In particular, the forests of Summit, Eagle, Routt, Grand, and Jackson counties in north central Colorado were heavily impacted (CSFS 2007). The extreme severity of this MPB outbreak was mainly caused by years of warm winter temperatures, serious drought conditions immediately prior to and during the outbreak, and overstocks of mature, homogenous pine forests (Negrón and Cain 2019). The MPB infestation in Colorado reached its peak around 2008, and there has been limited new beetle activity since 2014 (CSFS 2016). This beetle outbreak has brought substantial impacts on various sectors of local socio-ecological systems including forest stand structure, water yields and quality, wildlife habitat, economic opportunities, property values, and recreation activities (Negrón and Cain 2019). The MPB disturbance may also interact with a series of other forest risks, such as forest fire, soil erosion, and invasive plant species. Meanwhile, like many others regions in the western US, Colorado has experienced significant socioeconomic restructuring and change during the past decades: declined timber production, tourism and recreation development, expanding wildland-urban interface (WUI) areas, inflows of amenity-seeking migrants, etc. As the MPB activities spread across the mountainous areas of

Colorado, state and federal management officials contended that there was no practical approach to curb the infestation (CSFS 2006; Flint et al. 2009). However, regional and local forest management is often complicated by the multifaceted human dimensions of the MPB disturbance.

Methods and Data

Study Communities

Based on initial information collected from regional US Forest Service (USFS) representatives and other sources (e.g., the US Census data), nine communities were purposively selected from a five-county study area in north central Colorado (Figure 1; also see Figures S1–S4 in the supplemental materials). Together the study communities represent a wide array of socioeconomic characteristics and local experience with the beetle disturbance (Flint et al. 2012). They include both small towns/cities oriented to amenity development (Breckenridge, Dillon, Frisco, Silverthorne, Vail, and Steamboat Springs) and rural communities with deeper roots in resource extraction sectors such as ranching and logging (Granby, Kremmling, and Walden). Local landscapes in the six resort towns are heavily forested and represent typical WUI communities. By contrast, Granby, Kremmling, and Walden are situated in open park-like valleys and thus are generally further from forests infested with beetles. However, these communities have still been directly impacted by the MPB outbreak, as the forests around them have seen high magnitudes of tree mortality.

(Figure 1 about here)

Data Collection

In this paper, we focused on the quantitative component of a larger study that used a mixed-methods design for data collection and analysis (Creswell 2018). This part relied on secondary data to understand the local context and survey data to examine changing perceptions and actions related to the beetle disturbance.[1] Biophysical and socioeconomic data from the 2006–2017 aerial insect surveys conducted by the USFS Rocky Mountain Region, the National Land Cover Database (NLCD) 2001 and 2011, and the US Census were used to construct indicators of local contextual characteristics for two study periods: 2006–2007 (Phase I) and 2017–2018 (Phase II). In 2007, survey questionnaires were mailed to 4027 households randomly selected from a mailing address database purchased from the direct marketing firm USADATA. Among them, 1,346 surveys were completed and returned, yielding a response rate of 38.9% after accounting for undeliverable surveys. Findings from the 2007 survey provided baseline information for a longitudinal analysis of the dynamic perceptions and actions in response to local forest disturbance by beetles (Flint et al. 2012; Qin and Flint 2010).

We replicated mail surveys with the 1,346 original respondents in the summer of 2018. Contact information of these respondents was validated using updated data from USADATA and local telephone directories. To represent current community-wide perspectives, the surveys were sent to an additional random sample of 3000 households obtained from the new USADATA database. Similar to the 2007 survey, the resurvey adopted a modified tailored design method (Dillman et al. 2014) consisting of three waves of survey mailing with different cover letters, prenotice and thank you/reminder postcards, announcements in local newspapers, and reminder

[1] Qualitative findings of the 2017–2018 restudy are published elsewhere (Vickery et al. 2020).

phone calls to non-respondents.[2] In 2018, there were 1130 completed surveys in total, which resulted in an aggregate response rate of 32.4% after accounting for those undeliverable. Among these respondents, 460 also participated in the 2007 survey.

Measurement of Variables

We used identical secondary data sources and survey questions to track temporal changes in community experience with and response to the MPB impacts. Two community-level indicators were developed to represent local socioeconomic and environmental contexts of forest risks. The first was a measure of *community biophysical vulnerability* indicating the percentage of affected trees within a 15-mile radius around the census designated place boundary of each study community. The second community context indicator was a *community social vulnerability* index created based on sociodemographic, income, employment, and housing data from the 2009 and 2017 American Community Surveys. We adopted the analytical framework described in Cutter et al. (2003) and collected information about relevant variables for all census places in Colorado. The variable values were then normalized and aggregated into an index of social vulnerability.[3]

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[2] See Qin and Flint (2010) for further details of survey administration and measurement of major variables. In Phase II, pre-notice postcards were first sent out to those original respondents from the 2007 survey. The first survey packets sent to these respondents also included a two-dollar bill as a token reward.

[3] The construction of this composite indicator used the dominant variables of the 11 dimensions of social vulnerability identified in Cutter et al. (2003): per capita income (directionality reversed), median age, number of commercial establishments per square miles, percent employed in extractive industries, percent housing units that are mobile homes, percent African American, percent Hispanic, percent Native American, percent Asian, percent employed in service occupations, and percent employed in transportation, communication and public utilities. All variable values were transformed to a range of 0 – 1 using the formula [(actual value – minimum value)/(maximum value – minimum value)]. The four normalized variables related to race and ethnicity were first combined into one average value. The final index was then obtained by computing the mean of this weighted race/ethnicity measure and the other seven variables.

Two variables reflected the perception of beetle disturbance severity. A survey question asked respondents to describe tree mortality in and around their communities (*perceived tree mortality*), while another addressed the perceived amount of local natural growth of new trees (*perceived tree regrowth*). Both variables used a 5-point scale ranging from 1 (no pines are dead/no natural regrowth) to 5 (almost all pines are dead/much natural regrowth).

Perception of beetle-related risks was measured by asking how concerned respondents were about a series of forest risks for their community, such as forest fire, falling trees, increased erosion and runoff, loss of forests as an economic resource, loss of tourism and recreation opportunities, and loss of community identity tied to the forest (response options ranged from 1, not concerned, to 5, extremely concerned). A general indicator of *forest risk perception* was built by taking the mean of responses to these items.[4]

A series of sixteen agree-disagree statements on forest resources measured respondents' perceptions of how they related to forests in local landscapes (response options ranged from 1, strongly disagree, to 5, strongly agree). Based on the results of exploratory factor analysis, a composite measure of *faith in forest industry* was created by calculating the average value of responses to relevant statements (e.g., "forests should be managed to meet as many human needs as possible"). Answers to several other items, such as "forest management does a good job of including environmental concerns," were included in a measure of *trust in forest management*. Respondents were also asked to indicate their level of support on a 1–5 scale (strongly oppose to strongly support) for several industry options, including biomass/biofuels power generation, large- or small-scale timber processing, and niche marketing/production of wood products.

[4] The alpha reliability coefficients of major composite indicators in the analysis were all within a normally accepted range (>.65).

Relationship with land managers was measured by respondents' satisfaction with how the MPB issue was handled by a number of relevant management entities: private individuals and landowners, local fire departments, private logging companies, developers, homeowner associations, city government, county government, Colorado State Forest Service, Bureau of Land Management, and USFS (response options ranged from 1 very dissatisfied, to 5, very satisfied). Exploratory factor analysis revealed two factors based on these variables: *satisfaction with local entities* and *satisfaction with governmental entities*. Two new variables were created accordingly by calculating the mean response value for each land manager cluster.

Regarding experience with emergencies, survey respondents were asked to indicate whether or not they themselves and their community experienced a series of hazards, including wildland fire, avalanche or landslide, flooding, and toxic contamination. Aggregate measures of *personal and community emergency experience* were generated by summing responses (0 for no and 1 for yes) to these questions. This summation approach was also used in the construction of two variables representing community interaction and communication in the analysis. The first was a composite indicator of a respondent's level of community participation and interaction, and the second was a measure of the multiplicity of information sources about forest risks. Respondents were asked to indicate whether they participated in any of a list of community activities (e.g., attending a local community event or any public meeting in the community) during the prior 12 months, and whether they relied on specific sources of information about forest issues, such as newspaper, radio, local fire department, city government, and Colorado State Forest Service. Dichotomous responses (0 for no and 1 for yes) to these questions were summed as the *community participation* measure and the *total number of information sources*.

Local responses to forest disturbance also included informal or formal actions taken by community residents to reduce risks from the MPB outbreak. Respondents were asked if they had taken any of a series of actions listed in the survey. Similarly, two composite activeness measures were created by summing answers (0 for no and 1 for yes) to relevant questions: (1) *individual activeness* (e.g., spraying trees on personal property with chemicals, clearing vegetation near structures), and (2) *community activeness* (e.g., attending a public informational meeting, helping with clearing or maintaining public trails).

Additionally, several sociodemographic indicators were included in the analysis to control for possible influences of respondents' personal characteristics on perceptions and actions in response to the beetle disturbance. These variables are *age* (in years), *gender* (male = 0, female = 1), *length of residence* (years lived in community), *educational attainment* (six categories ranging from "less than a high school degree" to "advanced degree"), and *total household income* in the previous year of the survey (eight levels ranging from "less than $15,000" to "$150,000 or more").[5]

Data Analysis Procedures

The full survey datasets for Phases I and II were used for a trend analysis of community perspectives and experience related to the beetle outbreak. The two aforementioned research objectives generally structured the data analysis and reporting of findings. We first examined the characteristics of the study communities and respondents using a descriptive analysis of community vulnerability indices and major sociodemographic variables. Next, considering the

[5] The surveys also included a question on race and ethnicity. This variable was not statistically significant in the analysis as a vast majority of the respondents in both phases were white (96.6% and 96.3% in 2007 and 2018, respectively).

partial correlations within the longitudinal survey data, the corrected *z*-test was used to determine whether local perceptions and actions changed between the two study phases. This statistical technique was particularly suitable for the analysis because the two survey samples included both paired and independent observations (Qin et al. 2017). Finally, we checked the correlations between major variables (both Pearson's *r* and Spearman's rho) and ran regressions of the two activeness measures using the Phase I and the Phase II datasets respectively, and then compared results across the two study periods. The multivariate analysis used multilevel Poisson regression modeling, because the dependent variables consisted of count data and individual respondents were nested within the nine study communities. We first included all the independent variables and sociodemographic controls in the full regression models. The final reduced models were then obtained by systematically removing the non-significant variables until all remaining variables in the models were statistically significant.[6]

Results

Major sociodemographic characteristics of survey respondents in Phases I and II are summarized in Table 1. Compared to respondents in 2007, those of the 2018 survey were relatively older, wealthier, more educated, and had longer time of residence in their communities. Female and male respondents accounted for similar proportions in both surveys. The two survey samples were generally comparable with each other considering the fact that 40.7% of the respondents in 2018 also participated in the 2007 survey. Secondary data analysis indicated that Walden, Kremmling and Granby (higher vulnerability cluster) had larger percentages of local forests killed by beetles and relatively higher social vulnerability than the other six study communities

[6] Each round of this systematic variable selection process involved removing the most insignificant variable (with the highest *p*-value) from a regression model and rerunning the analysis.

(lower vulnerability cluster) in both study periods (see Table 2). There was a substantial increase of biophysical vulnerability in all study communities, particularly those in Summit County (Breckenridge, Dillon, Frisco, and Silverthorne). The social vulnerability index values also increased in the nine communities to different extents. Frisco had the lowest level of social vulnerability in Phase I, but was among the more vulnerable study communities in Phase II. Overall, the two community clusters based on risk context were largely stable across the two study stages.

(Tables 1 and 2 about here)

Changes in Major Variables

We examined temporal changes in beetle-related perceptions and actions for both the total survey samples and different community clusters in terms of biophysical and social vulnerability (see Table 3). Confirming the trend shown in the secondary biophysical data, the survey respondents in Phase II indicated significantly higher levels of perceived tree mortality and regrowth compared to Phase I. However, they were less concerned about all forest risks except for falling trees and forest fire. Perceived risk of falling trees increased significantly across the study communities. Concern about forest fire remained high in the study area as a whole but became relatively lower in the more vulnerable community cluster. There was also no major change in the perception of impacts on livestock grazing for this subgroup of communities.

The analysis indicated little change in the level of faith in forest industry, but there was an increase in the trust in forest management (albeit still near the neutral level). In all, local support increased for niche marketing of wood products, but reduced for biomass/biofuels power generation to an extent. Community perspectives on small- and large-scale timber processing generally stayed unchanged. Further analysis revealed respondents in the higher vulnerability community cluster showed declined faith in forest industry but no significant change in opinions on biomass/biofuel or niche production industry options. Those from the less vulnerable study communities also voiced weaker opposition against large-scale timber production in Phase II.

Compared to respondents in 2007, those from the follow-up survey were more satisfied (or less dissatisfied in some cases) with nearly all local and governmental entities regarding how the beetle issue was managed. There was no significant change in the overall level of dissatisfaction with developers, though this sentiment was relatively mitigated among respondents in the lower vulnerability cluster. Additionally, residents from those more vulnerable communities indicated largely the same levels of satisfaction with private logging companies and homeowner associations in both study stages.

Although the reported level of personal experience with emergencies remained mostly the same, respondents indicated decreased community emergency experience in Phase II. The 2018 survey also found respondents were relatively less engaged in general community activities. In contrast, the total number of information sources about forest issues and both individual and community actions related to beetles increased significantly over time. The higher vulnerability community cluster was again different from the aggregate data and the other cluster regarding some of these temporal trends. Results for this subsample show less personal experience with emergencies and limited change in the use of information sources and community activeness.

(Table 3 about here)

Bivariate Correlations

As shown in Table 4, in terms of bivariate correlations between major variables, perceived tree mortality, personal and community experience with emergencies, community participation, and the number of information sources were consistently and positively related with both individual and community actions in responses to the beetle outbreak. Biophysical and social vulnerability contexts were negatively related with individual activeness but had positive correlations with community activeness in Phase I. However, only the community social vulnerability index was negatively correlated with individual activeness in Phase II. Perceived tree regrowth became positively related with both individual and community activeness in the resurvey. In comparison, forest risk perception had a positive relationship with individual and community activeness in Phase I, but was only related with individual activeness in Phase II. The composite indicators of faith in forest industry and trust in forest management were significant or almost significant in their bivariate relationships with both action measures only in 2007 (positive and negative correlations, respectively).[7] Moreover, satisfaction with governmental entities largely corresponded with community actions in both surveys.

(Table 4 about here)

It is also worth noting the significant correlations among those independent variables relevant to forest risk and management. In both Phases I and II, community biophysical and social vulnerability indices, perceived tree mortality, faith in forest industry, personal emergency experience, and reliance on information sources showed positive correlations with forest risk perception. The opposite (negative correlation) was the case for perceived tree regrowth, trust in forest management, and satisfaction with governmental land managers. Faith in forest industry

[7] We include marginally significant results in the presentation of findings in order to explore similar patterns across study phases.

was positively and negatively related with satisfaction with local entities and satisfaction with governmental entities, respectively. Not surprisingly, respondents with more trust in forest management also reported higher levels of satisfaction with both local and governmental land managers. In addition, the two community vulnerability indicators were positively associated with faith in forest industry and satisfaction with local management entities, and negatively correlated with trust in forest management and satisfaction with governmental entities.

Regression Models

Results of the final multilevel regression models of individual and community actions are summarized in Table 5. The likelihood ratio test indicated that there was a significant random component of the intercept in all four models. Higher perceived tree mortality, personal experience of emergency, community participation, and the total number of information sources consistently contributed to higher levels of individual and community activeness. Perceived tree regrowth was not significant in either model in Phase I, but became a significant explanator of both action measures in Phase II. Forest risk perception had a positive and significant effect in the two Phase I models, with every unit of increase in it being associated respectively with an 8.6% and 9.5% increase [(Exp(B) – 1) × 100%] in the numbers of individual and community actions. However, this variable was no longer associated with individual or community activeness in the multivariate analysis of Phase II, despite its significant bivariate correlation with individual activeness (see Table 4). Faith in forest industry, trust in forest management, and satisfaction with local or governmental land managers were statistically significant or almost significant in one of the two individual activeness models. Trust in forest management was consistently and negatively associated with community activeness, whereas satisfaction with governmental entities was stable in its positive relation with this dependent variable. More specifically, for an increase of one unit in the measures of trust in forest management and satisfaction with governmental land managers in Phase II, the number of community actions is estimated to decrease and increase by 10.6%, respectively.

Community experience of emergency and local vulnerability context initially had significant correlations with both individual and community actions in the bivariate analysis. However, community emergency experience was non-significant in all four models, while community social vulnerability only showed a negative influence on individual activeness. This was mainly due to the fact that community contextual effects were mostly captured in the multilevel modeling (Qin and Flint 2010). Additionally, age, educational attainment, and household income were consistently positive factors in either individual or community activeness models. Likelihood ratio chi-square statistics indicated that these models were all highly significant when compared with their corresponding random intercept-only models.

(Table 5 about here)

Discussion

There is an increasing interest among natural resource social scientists and management professionals in the temporal dynamics of socio-ecological systems in general and of vulnerability and response to hazards in particular. This study further advances this literature by examining the changing perceptions and actions in response to the MPB outbreak in north central Colorado over a 10-year time period. The analysis found that concerns about those forest risks related to personal safety and property (i.e., forest fire and falling trees) had a stronger staying power than other perceived risks, even though the overall level of risk perception declined over time. Results also show significant increases in the satisfaction with local and governmental management entities as well as individual and community activeness. In both study phases, bivariate analysis revealed that forest risk perception was negatively correlated with trust in forest management and satisfaction with governmental land managers, but positively related with individual actions. This apparent discrepancy in the temporal trends and correlations of risk perception and actions suggests that their evolving relationships are rather complicated (also see further discussion on this aspect below).

Vulnerability, perceptions, and actions are interrelated dimensions of responses to environmental hazards including forest insect outbreaks (Flint and Luloff 2005; Qin et al. 2015b). The baseline data of this longitudinal research depicted the linkages between communities' biophysical and social vulnerability contexts and local responses to the beetle disturbance (Qin and Flint 2010; Flint et al. 2012). Compared with those from communities with less tree mortality and higher socioeconomic amenity, respondents from communities with greater loss of trees but less focus on amenities tended to have higher levels of forest risk perception, more support for forest industry, as well as lower trust in forest management and less satisfaction with governmental land managers. The follow-up analysis also suggested that community vulnerability conditions influenced the temporal changes in local perceptions and actions. The higher vulnerability cluster generally presented less salient changes in many aspects of reactions to the MPB issue than the lower vulnerability group. Nevertheless, it demonstrated statistically significant reductions in perceived forest fire risk, personal emergency experience, and faith in forest industry, whereas there was negligible change in these aspects for the less vulnerable cluster and for the aggregate samples. In future research, it would be meaningful to examine the effects of community vulnerability on changing perceptions and actions in other slow-onset environmental change settings, such as drought, land or forest degradation, and sea level rise.

Comparisons of the multilevel Poisson regression models highlighted those shared determinants of individual and community actions in either or both study stages, including perceived mortality of trees, forest risk perception, trust in forest management, satisfaction with governmental entities, community participation, and information sources. Satisfaction with governmental management entities was mostly associated with lower levels of individual actions but higher levels of community actions. Previous research maintains that relationships with local and governmental land managers affect ecological risk perception in different manners (Qin et al. 2015a; Sjöberg 1999). This analysis suggested that while satisfaction with governmental entities reinforced community activeness, it largely limited individual activeness as residents might substitute community and official forest management actions for their own. Nevertheless, public trust in broader forest management regimes was generally found to be negatively associated with local activeness. Both trust in forest management and satisfaction with governmental entities were even more significant in the multilevel modeling than in the bivariate correlation analysis. In contrast, faith in forest industry and satisfaction with local land managers were relatively less important for explaining individual and community actions in response to beetles. Additionally, these two types of local activeness tended to be associated with different sociodemographic factors. Age and income were positively related to individual actions, whereas educational attainment was a strong contributor to community activeness.

Two independent variables were significant in the final reduced models at specific phases. Perceived tree regrowth only had a positive effect on individual and community actions in the restudy, as natural growth of new trees in the study area increased over time. However, forest risk perception became non-significant in its relation with both activeness measures in Phase II. This is likely due to a risk reappraisal effect as risk-related behavior may lower risk perception (Brewer et al. 2004; Siegrist 2013). Further research using panel survey data should shed light on the dynamic relationships between risk perception and actions in the context of forest disturbances. Additionally, although the effects of community emergency experience and local vulnerability conditions were constrained in the multilevel modeling process, the results suggest that community contexts still hold an important role in framing the spatial and temporal variations of local responses. Methodologically, this focus allows us to remind forest managers and policy makers that human behavior and decision-making are embedded in the socioeconomic and biophysical situations of local places (Beckley 1998), and that successful ecosystem management relies on approaches that explicitly attend to social complexity and temporal effects.

To a large extent, findings of this research expand those of an earlier 2003–2008 study of community responses to the SBB outbreak in Kenai Peninsula, Alaska (Flint 2007; Qin et al. 2015a). There were some overlaps in the research designs of these two projects despite their distinct geographic contexts and time spans. The Kenai study also identified lingering concerns about forest and grass fire risks, decreased perceptions of other forest risks not directly related to personal safety or property, and increased satisfaction with local and governmental management entities, but found declined community activeness. Factors having a robust relationship with community actions in response to the SBBs included the scale of trees killed by beetles, perception of broader forest risk, community participation, length of residence, and educational attainment (all except for the tree mortality level were positively associated with community activeness). Taken together, these two comparable longitudinal analyses can improve understanding of temporal transition patterns of the human dimensions of forest insect disturbance.

Conclusions and Implications

USFS management language asserts that since the MPB infestation cannot be halted, managing public perspectives on the epidemic is essential for successful public land management. As such, investigations over time of residents' changing perceptions and actions in response to MPBs, particularly attitudes about its management and related forest industry options, can provide critical insights for successful management moving forward. Through analyses of longitudinal research data from the study communities in north central Colorado, we note significant changes in local residents' responses to the MPB outbreak, and identify both common and different factors associated with individual and community activeness. This study's findings highlight the dynamic and multifaceted nature of human interactions with the environment. Forest risk perception as well as individual and community activeness change over time and are often associated with changing experience and perspectives. Although local residents' emotional feelings toward the beetle outbreak eventually lessen, the temporal dynamics of perceptions and actions related to accompanying forest risks are more complicated than conventionally assumed. To more effectively meet the goals of sustainable natural resource management, it is essential for governmental agencies to proactively adjust strategies and policies in coordination with evolving forest disturbances and human responses. A clear recognition of varied trends in the perceptions of forest risks, engagement in risk-related actions, and support for forest industry options can help to identify both opportunities and barriers to sound forest management. Land management entities may also build on positive changes in the views on forest management to improve relationships with local community residents. Further, evidence reveals that individuals' perceptions, responses, and relevant temporal changes vary, depending in part on the biophysical and socioeconomic contexts of their communities. Importantly, a community's relative vulnerability conditions play a structural role in dynamic perceptions and actions in response to the MPB outbreak. Differences across communities stress the need for taking local context into account in policy and management practices. Overall, linking such community variations with temporal changes can help better explain complex social response to management approaches and inform more nuanced management decisions.

Supplemental Materials

Supplementary data are available at *Journal of Forestry* online.

Supplement 1. Photos of beetle killed trees from the study area.

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Literature Cited

Arnberger, A., M. Ebenberger, I.E. Schneider, S. Cottrell, A.C. Schlueter, E. von Ruschkowski, R.C. Venette, S.A. Snyder, and P.H. Gobster. 2018. Visitor preferences for visual changes in bark beetle-impacted forest recreation settings in the United States and Germany. *Environmental Management* 61(2):209-223. doi:10.1007/s00267-017-0975-4.

Beckley, T.M. 1998. The nestedness of forest dependence: A conceptual framework and empirical exploration. *Society & Natural Resources* 11(2):101-120. doi:10.1080/08941929809381066.

Bentz, B.J., J. Régnière, C.J. Fettig, E.M. Hansen, J.L. Hayes, J.A. Hicke, R.G. Kelsey, J.F. Negrón, and S.J. Seybold. 2010. Climate change and bark beetles of the western United States and Canada: Direct and indirect effects. *BioScience* 60(8):602-613. doi:10.1525/bio.2010.60.8.6.

Brewer, N.T., N.D. Weinstein, C.L. Cuite, and J.E. Herrington. 2004. Risk perceptions and their relation to risk behavior. *Ann Behav Med* 27(2):125-130. doi:10.1207/s15324796abm2702_7.

Champ, P.A., and H. Brenkert-Smith. 2016. Is seeing believing? Wildfire risk perceptions after a catastrophic fire. *Risk Analysis* 36(4):816-830. doi:10.1111/risa.12465.

Colorado State Forest Service (CSFS). 2006. *2005 Report on the Health of Colorado's Forests*. Colorado State Forest Service, Fort Collins, CO.

Colorado State Forest Service (CSFS). 2007. *2006 Report on the Health of Colorado's Forests*. Colorado State Forest Service, Fort Collins, CO.

Colorado State Forest Service (CSFS). 2016. *2015 Report on the Health of Colorado's Forests*. Colorado State Forest Service, Fort Collins, CO.

Creswell, J.W. 2018. *Research Design: Qualitative, quantitative, and mixed methods approaches*, 5th ed. SAGE Publishing, Thousand Oaks, CA. 304 p.

Cutter, S. L., B. J. Boruff, and W.L. Shirley. 2003. Social vulnerability to environmental hazards. *Social Science Quarterly* 84(2):242-261. doi:10.1111/1540-6237.8402002.

Dale, V. H., L. A. Joyce, S. McNulty, and R.P. Neilson. 2000. The interplay between climate change, forests, and disturbances. *Science of The Total Environment* 262(3):201-204. doi:10.1016/s0048-9697(00)00522-2.

Dillman, D.A., J.D. Smyth, and L.M. Christian. 2014. *Internet, phone, mail, and mixed-mode surveys: The tailored design method*, 4th ed. John Wiley & Sons, Hoboken, NJ. 528 p.

Flint, C.G. 2007. Changing forest disturbance regimes and risk perceptions in Homer, Alaska. *Risk Analysis* 27(6):1597-1608. doi:10.1111/j.1539-6924.2007.00991.x.

Flint, C.G., and R. Haynes. 2006. Managing forest disturbances and community responses: Lessons from the Kenai Peninsula, Alaska. *Journal of Forestry* 104(5):269-275. doi:10.1093/jof/104.5.269.

Flint, C.G., and A.E. Luloff. 2005. Natural resource-based communities, risk, and disaster: An intersection of theories. *Society & Natural Resources* 18(5):399-412. doi:10.1080/08941920590924747.

Flint, C.G., B. McFarlane, and M. Müller. 2009. Human dimensions of forest disturbance by insects: An international synthesis. *Environmental Management*. 43(6):1174-1186. doi:10.1007/s00267-008-9193-4.

Flint, C.G., H. Qin, and J. Ganning. 2012. Linking local perceptions to the biophysical and amenity context of forest disturbance in Colorado. *Environmental Management* 49(3): 553–569. doi:10.1007/s00267-011-9802-5.

Gordon, J.S., J.B. Gruver, C.G. Flint, and A.E. Luloff. 2013. Perceptions of wildfire and landscape change in the Kenai Peninsula, Alaska. *Environmental Management* 52(4):807-820. doi:10.1007/s00267-013-0127-4.

Kooistra, C.M., and T.E. Hall. 2014. Understanding public support for forest management and economic development options after a mountain pine beetle outbreak. *Journal of Forestry* 112(2):221-229. doi:10.5849/jof.13-004.

McCollum, D.W., and J.E. Lundquist. 2019. Bark beetle infestation of western US forests: A context for assessing and evaluating impacts. *Journal of Forestry* 117(2):171-177. doi:10.1093/jofore/fvy041.

McFarlane, B.L., and D.O.T. Watson. 2008. Perceptions of ecological risk associated with mountain pine beetle (*Dendroctonus ponderosae*) infestations in Banff and Kootenay National Parks of Canada. *Risk Analysis* 28(1): 203–212. doi: 10.1111/j.1539-6924.2008.01013.x.

Morris, J., S. Cottrell, C.J. Fettig, W. Hansen, R. Sheriff, V.A. Carter, J. Clear, J. Clement, R. DeRose, J. Hicke, P. Higuera, K. Mattor, A. Seddon, H. Seppa, J. Stednick, and S. Seybold. 2018. Bark beetles as agents of change in social-ecological systems. *Frontiers in Ecology and the Environment* 16(S1):S34-S43. doi:10.1002/fee.1754.

Müller, M., and H. Job. 2009. Managing natural disturbance in protected areas: Tourists' attitude towards the bark beetle in a German national park. *Biological Conservation* 142(2):375-383. doi:10.1016/j.biocon.2008.10.037.

Negrón, J.F., and B. Cain. 2019. Mountain pine beetle in Colorado: A story of changing forests. *Journal of Forestry* 117(2):144-151. doi:10.1093/jofore/fvy032.

Qin, H., and C.G. Flint. 2017. Changing community variations in perceptions and activeness in response to the spruce bark beetle outbreak in Alaska. *Sustainability* 9(1):67. doi:10.3390/su9010067.

Qin, H., and C. G. Flint. 2010. Capturing community context of human response to forest disturbance by insects: A multi-method assessment. *Human Ecology* 38(4):567-579. doi:10.1007/s10745-010-9334-2.

Qin, H., C.G. Flint, and A.E. Luloff. 2015a. Tracing temporal changes in the human dimensions of forest insect disturbance on the Kenai Peninsula, Alaska. *Human Ecology* 43(1):43-59. doi:10.1007/s10745-014-9717-x.

Qin, H., E. Prentice, and K. Freeman. 2017. Analyzing partially correlated longitudinal data in community survey research. *Society & Natural Resources* 31(1):142-149. doi:10.1080/08941920.2016.1264650.

Qin, H., P. Romero-Lankao, J. Hardoy, and A. Rosas-Huerta. 2015b. Household responses to climate-related hazards in four Latin American cities: A conceptual framework and exploratory analysis. *Urban Climate* 14:94-110. doi:10.1016/j.uclim.2015.05.003.

Shindler, B., and E. Toman. 2003. Fuel reduction strategies in forest communities: A longitudinal analysis of public support. *Journal of Forestry* 101(6):8-15. doi:10.1093/jof/101.6.8.

Siegrist, M. 2013. The necessity for longitudinal studies in risk perception research. *Risk Analysis* 33(1):50-51. doi:10.1111/j.1539-6924.2012.01941.x.

Sjöberg, L. 1999. Risk perception by the public and by experts: A dilemma in risk management. *Human Ecology Review* 6(2):1-9. www.jstor.org/stable/24707052.

Toman, E., B. Shindler, S. McCaffrey, and J. Bennett. 2014. Public acceptance of wildland fire and fuel management: Panel responses in seven locations. *Environmental Management* 54(3):557-570. doi:10.1007/s00267-014-0327-6.

Urquhart, J., C. Potter, J. Barnett, J. Fellenor, J. Mumford, C.P. Quine, and H. Bayliss. 2017. Awareness, concern and willingness to adopt biosecure behaviours: Public perceptions of invasive tree pests and pathogens in the UK. *Biological Invasions* 19(9):2567-2582. doi:10.1007/s10530-017-1467-4.

Vickery, J., H. Brenkert-Smith, and H. Qin. 2020. Using conjoint constitution to understand responses to slow-moving environmental change: The case of mountain pine beetle in north-central Colorado. *Environmental Sociology* 6(2):182–193. doi:10.1080/23251042.2019.1706263.

Vose, J.M., D.L. Peterson, G.M. Domke, C.J. Fettig, L.A. Joyce, R.E. Keane, C.H. Luce, J.P. Prestemon, L.E. Band, J.S. Clark, N.E. Cooley, A. D'Amato, and J.E. Halofsky. 2018.

Forests. P. 232-267 in *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D.R. Reidmiller, C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.). U.S. Global Change Research Program, Washington, DC.

Wolken, J.M., T.N. Hollingsworth, T.S. Rupp, F.S. Chapin, S.F. Trainor, T.M. Barrett, P.F. Sullivan, A.D. McGuire, E.S. Euskirchen, P.E. Hennon, E.A. Beever, J.S. Conn, L.K. Crone, D.V. D'Amore, N. Fresco, T.A. Hanley, K. Kielland, J.J. Kruse, T. Patterson, E.A.G. Schuur, D.L. Verbyla, and J. Yarie. 2011. Evidence and implications of recent and projected climate change in Alaska's forest ecosystems. *Ecosphere* 2(11):art124. doi:10.1890/ES11-00288.1.

Figure

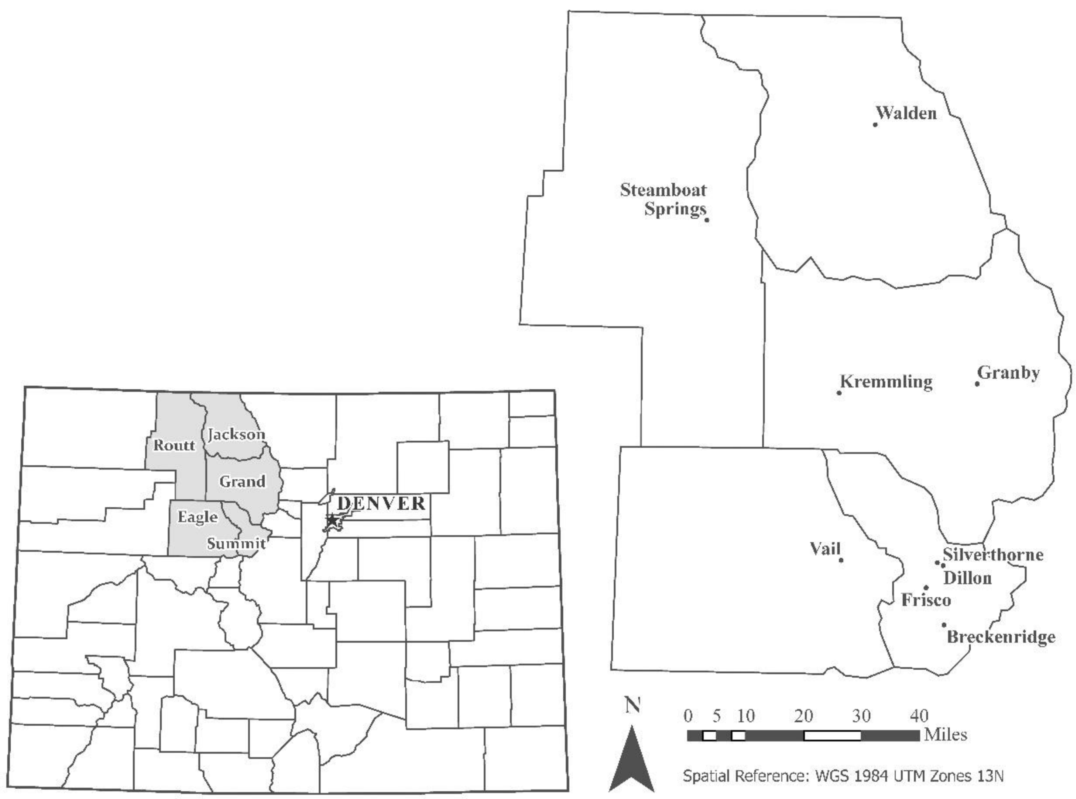

Figure 1. Map of north central Colorado and the study communities. (cartography by Martha Bass).

Tables

Table 1. Sociodemographic characteristics of survey respondents

Variable	Phase I (Mean or Percent)	Phase II (Mean or Percent)
Age	52.0	59.7
Gender		
Female	44.3%	46.7%
Male	55.7%	53.3%
Years in community	19.0	25.9
Educational attainment[a]		
High school degree or lower	10.9%	7.6%
Some college training or technical/associate degree	30.1%	23.9%
Bachelor's degree or higher	58.9%	68.4%
Total household income[a]		
Less than $35,000	14.1%	13.4%
$35,000 to $74,999	39.1%	30.6%
$75,000 to $149,999	33.0%	39.1%
$150,000 or more	13.8%	16.9%
N	1346	1130

[a] Some original categories of educational attainment and total household income were combined in the summary of results.

Table 2. Biophysical and social vulnerability of the study communities

Community	% of Forests Affected		Social Vulnerability Index[a]	
	Phase I	Phase II	Phase I	Phase II
Breckenridge	20.8%	70.8%	0.202	0.218
Dillon	25.2%	73.4%	0.175	0.234
Frisco	23.8%	70.0%	0.171	0.255
Silverthorne	25.4%	70.9%	0.210	0.233
Steamboat Springs	22.6%	53.3%	0.196	0.215
Vail	21.2%	61.7%	0.180	0.212
Granby	41.0%	84.1%	0.224	0.239
Kremmling	45.2%	82.1%	0.234	0.283
Walden	83.4%	100.0%	0.310	0.354

[a] The social vulnerability indexes for Phases I and II have a statewide range of 0.088–0.402 and 0.115–0.453, respectively (minimum/maximum values = least/most vulnerable census places in Colorado).

Table 3. Temporal changes in selected variables[a]

Variable	Aggregate Data[b]		Lower Vulnerability Cluster[c]		Higher Vulnerability Cluster[c]	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
Perceived tree mortality	3.08***	3.38***	2.80***	3.16***	3.55***	3.80***
Perceived tree regrowth	2.21***	2.93***	2.23***	2.95***	2.17***	2.91***
Forest risk perception	3.70***	3.30***	3.62***	3.15***	3.85***	3.59***
Forest fire	4.46	4.41	4.37	4.42	4.61***	4.41***
Falling trees	3.65***	3.92***	3.54***	3.76***	3.85***	4.22***
Impact on livestock grazing	2.68***	2.38***	2.42***	2.03***	3.14	3.03
Faith in forest industry	2.78	2.74	2.52	2.54	3.25**	3.11**
Trust in forest management	2.56***	2.95***	2.75***	3.18***	2.24***	2.53***
Support for biomass/biofuels power generation	3.68**	3.55**	3.51*	3.39*	3.97	3.84
Support for niche marketing of wood products	3.81***	3.96***	3.62***	3.88***	4.14	4.10
Support for large-scale timber processing	2.77	2.83	2.28**	2.45**	3.62	3.52
Support for small-scale timber processing	3.65	3.64	3.31	3.37	4.22	4.14
Satisfaction with local entities	2.92***	3.15***	2.81***	3.11***	3.10*	3.22*
Satisfaction with governmental entities	2.65***	3.22***	2.77***	3.44***	2.46***	2.79***
Personal experience with emergencies	1.21	1.17	1.24	1.26	1.15*	1.01*
Community experience with emergencies	2.25***	2.05***	2.52***	2.26***	1.77*	1.63*
Community participation	4.23***	3.92***	4.17*	3.98*	4.34***	3.79***
Number of information sources	5.76**	6.07**	5.77**	6.17**	5.74	5.87
Individual activeness	2.40***	2.68***	2.51***	2.81***	2.22*	2.44*
Community activeness	1.43**	1.59**	1.39***	1.65***	1.51	1.49
N	1346	1130	851	738	495	392

[a] Given as variable means.
[b] Compared to the corrected *z*-tests for the aggregate data, corresponding paired *t*-tests based on the panel survey dataset ($N = 460$) did not show any significant change in the support for biomass/biofuels power generation or niche marketing of wood products, number of information sources, or community activeness, but identified a decrease in personal emergency experience ($p < 0.01$). Otherwise, the two types of tests produced largely consistent results.
[c] Lower vulnerability cluster: Breckenridge, Dillon, Frisco, Silverthorne, Vail, and Steamboat Springs; higher vulnerability cluster: Granby, Kremmling, and Walden. Further analysis using independent *t*-tests and Mann–Whitney U tests showed that in both Phases I and II the two community clusters were significantly different with respect to all these variables except for perceived tree re-growth, perception of forest fire risk (significant difference only in Phase I), personal experience with emergencies (significant difference only in Phase II), community participation, number of information sources, and community activeness.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 4. Bivariate correlations between independent and dependent variables

Independent Variable	Individual Activeness		Community Activeness	
	Phase I	Phase II	Phase I	Phase II
Perceived tree mortality	.086**	.117***	.102***	.122***
Perceived tree re-growth	-.021	.086**	-.001	.096**
Forest risk perception	.113***	.062*	.108***	.047
Faith in forest industry	.048(*)	-.035	.075**	-.026
Trust in forest management	-.105***	-.010	-.135***	-.029
Satisfaction with local entities	.013	.024	.052(*)	.047
Satisfaction with governmental entities	-.017	.023	.054(*)	.097**
Personal emergency experience	.110***	.148***	.185***	.169***
Community emergency experience	.107***	.118***	.136***	.137***
Community participation	.204***	.179***	.432***	.391***
Number of information sources	.222***	.211***	.405***	.386***
Community biophysical vulnerability	-.070*	-.030	.080**	.032
Community social vulnerability	-.071**	-.091**	.081**	.013

Given as Pearson's *r* correlation statistics. The results were cross-checked with Spearman's rho correlation coefficients. The two types of tests produced consistent results in terms of variable correlations and significance levels.

(*)$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 5. Comparison of the reduced regression models of individual and community activeness[a]

Variable	Individual Activeness		Community Activeness	
	Phase I	Phase II	Phase I	Phase II
Intercept	0.548^{*}	1.303	0.080^{***}	0.102^{***}
Perceived tree mortality	1.059^{*}	1.118^{***}	1.089^{**}	1.149^{***}
Perceived tree regrowth		1.043^{*}		1.081^{**}
Forest risk perception	1.086^{**}		1.095^{*}	
Faith in forest industry	1.065^{*}			
Trust in forest management	0.907^{***}		0.904^{**}	0.894^{**}
Satisfaction with local entities		$1.067^{(*)}$		
Satisfaction with governmental entities[b]		0.918^{**}	1.091^{**}	1.106^{*}
Personal emergency experience	1.066^{***}	1.080^{***}	1.076^{***}	1.082^{**}
Community emergency experience[c]	—	—	—	—
Community participation	1.033^{**}	1.039^{**}	1.239^{***}	1.196^{***}
Number of information sources	1.036^{***}	1.028^{***}	1.091^{***}	1.103^{***}
Community biophysical vulnerability[d]	n.a.		n.a.	
Community social vulnerability	$0.114^{(*)}$	0.055^{*}		
Age	1.011^{***}	1.006^{***}	1.005^{*}	
Gender (Female = 1)		1.104^{*}	1.104^{*}	
Years lived in community[d]	—	—	—	—
Educational attainment			1.085^{***}	1.116^{***}
Household income	1.097^{***}	1.031^{*}		
N	1072	866	1206	1036
Deviance (-2 log likelihood)	2445.574	1776.176	3588.318	3030.356
Likelihood ratio chi-square (df)	820.835 (10) ***	528.530 (11) ***	909.308 (10) ***	596.223 (8) ***

[a] Given as natural exponentials of fixed coefficients [Exp(B)].
[b] In Phase I, satisfaction with governmental management entities had a marginally significant and negative effect in the full model of individual activeness, but became nonsignificant in the reduced model.
[c] Community biophysical vulnerability was removed from the two Phase I models because of the multicollinearity between biophysical and social vulnerability indexes.
[d] Community emergency experience and years lived in community were not statistically significant in any of the reduced models.
$^{(*)}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Supplemental Data

Supplement 1. Photos of beetle killed trees from the study area

Figure S1. Grey-casted beetle killed trees in north-central Colorado, USA (2019); Author: Hua Qin

Figure S2. Beetle killed trees in Arapaho and Roosevelt National Forests, Grand County, Colorado, USA (2017); Author: Jamie Vickery

Figure S3. Beetle killed trees around homes in north-central Colorado, USA (2006); Author: Courtney G. Flint

Figure S4. Red beetle killed trees on hillside in north-central Colorado, USA (2006); Author: Courtney G. Flint