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Exploring How Community Context Informs Variations in Local Perceptions of Forest Disturbance and Land Management in Colorado Over Time

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Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abstract: Placed-based socio-economic and biophysical context has been viewed as an essential driver in shaping perceptions of forest risks and land management. Growing evidence of the importance of diverse community context in forested landscapes sets the stage to further consider how people's understandings of their local environment influence natural resource management preferences. However, research to date largely lacks considerations of how community context informs social responses to long-term environmental change over time. Using the mountain pine beetle (MPB) outbreak in Colorado, we analyze and compare longitudinal interview and survey data collected from nine north-central Colorado communities to understand the relationships between community context and changing perceptions of forest disturbance and engagement with land management. Both qualitative and quantitative findings show that community context framed and continues to inform variations in local perceptions of the MPB outbreak and forest management. Interviews with key informants provided rich narratives on different context-based trajectories in local residents' perceptional responses, while survey data allowed for general patterns of evolving community variations (e.g., stable or clearer community clustering, reduced community differences) to be uncovered. We explore methodological implications for community indication and future directions for understanding differing community responses to slow-moving environmental change. Incorporating knowledge of changing local contexts and variations can also help practitioners advance toward more dynamic and effective management strategies.

Keywords: community context; community differences, environmental change; forest insect disturbance; mountain pine beetle outbreak; forest management; longitudinal research

1. Introduction

Community context is increasingly recognized as an influential factor shaping human responses to forest risks and associated land management approaches. Local cultural, social, economic, and environmental factors overlap and interact to characterize the socio-ecological landscapes of communities. A growing body of research on the diversity of local context and community types in forested landscapes has shown that community context influences individual and community-level responses to forest disturbances, wildfire hazards, forest/land management, and wildfire adaptation planning (Brenkert-Smith, 2011; Brenkert-Smith et al., 2012; Christianson et al., 2014; Krannich and Smith, 1998; McCaffrey et al., 2011; Meldrum et al., 2018; Paveglio et al., 2015, 2019; Qin and Flint, 2017). These studies have used a range of approaches to depict or measure community context (e.g., narrative description, community typologies, community indices/indicators) and to capture relevant contextual effects on perceptions and behaviors related to forest risks (e.g., qualitative case studies, correlation analysis, multi-level modeling). Community context research is also logically related to comparative community analysis examining variations or differences in local reactions to social, economic, and environmental issues (Qin and Flint, 2017). Thus far, the temporal dimension of community processes has been largely overlooked in the study of community and natural resources (McCaffrey et al., 2013; Qin, 2015). As a result, we are left with an incomplete understanding of the evolving effects of community context and how it informs changing

variations in local perceptions of forest and other ecological risks and engagement with land management.

Using the mountain pine beetle (MPB) (*Dendroctonus ponderosae*) outbreak that affected large swaths of the Rocky Mountains, we draw upon longitudinal key informant interview and mail survey data to explore how local context shapes the ways in which communities perceive beetle-related risks and forest management over time. Insect disturbances in forests are inherently dynamic and subject to cascades of connected disturbances, such as fire, pathogens, introduced species, weather events, and landslides (Dale et al., 2001). The scope of these environmental processes may also only be apparent after they have been underway for a substantial period of time and may have varied effects across large landscapes. Therefore, such slow-moving environmental change may garner less immediate public attention and understanding than abrupt environmental impacts. Building on previous research on local perceptions and actions in response to the MPB outbreak (Flint et al., 2012; Qin and Flint, 2010), this work provides additional insights from an extended temporal lens by revisiting the same study communities. Our data analysis and presentation of findings are structured by two research questions: (1) how do community variations in the perceptions of forest risks and land management evolve over time? (2) how are developing local contexts related to differential community perceptions of a shared, landscape-scale environmental event?

In the upcoming sections, we ground the manuscript by highlighting literature concerning the importance of community context in natural resource management and relevant methodological issues. We then describe the study background, including the MPB outbreak and the study communities in north-central Colorado, and the mixed method design used for this research. In the findings section we present comparisons of qualitative and quantitative findings on community differences in perceptions of forest risks, perspectives on forest industry and management, and relationships with land management entities across two study phases. We conclude by discussing how factors comprising community context coalesce to inform varied local responses to the same slow-moving environmental event – and how meaningful attention to and incorporation of changing community contexts and variations can guide more effective management practice.

2. Literature Review

2.1. The role of community context in natural resource management

Research that considers the interaction between humans and the environment commonly places the contexts in which perceptions and actions take place under consideration. Community represents a key scale of analysis in socio-ecological investigations (Beckley, 1998; Field and Burch, 1988; Krannich et al., 2011). Local socio-economic and biophysical vulnerabilities together constitute community risk context in conceptual frameworks of household and community responses to risks and disasters (Flint and Luloff, 2005; Qin et al., 2015b). In a similar vein, a matrix approach to understanding the human dimensions of forest fire emphasizes the intersection of biophysical, demographic, cultural, and socio-economic characteristics forming the backdrop for complex relationships between human communities and natural resources (Gordon et al., 2013; Luloff et al., 2007). Paveglio and colleagues (2009) also posit that local capacity to adapt to wildfire and other hazards are structured by diverse community social context encompassing demographic dynamics, place-based knowledge or experience, access to scientific or technical information, and the interactions and relationships among community residents and decision-makers (e.g., land managers). Such diversity is also evident in

variation in public acceptability of forest management techniques intended to reduce wildfire risk and improve forest health (Brenkert-Smith et al., 2023).

From a broader landscape ecology perspective, the traditional inquiry on landscape heterogeneity may provide a conceptual foundation for the exploration of community context and variations in social-ecological research as well (Flint et al., 2012). To promote successful management of rapidly changing environmental conditions, it is essential to energize multi-disciplinary perspectives to integrate biophysical, social, and economic implications of landscape disturbance (Pickett et al., 1997a). Although landscape heterogeneity is a cornerstone of research on ecological change and disturbance (Wiens, 2000), human perceptual components of landscape heterogeneity are often overlooked creating a missing link for managing disturbances across diverse landscapes. From an ecological standpoint, heterogeneity is "an important principle of conservation" (Ostfeld et al., 1997, 5) and "the root of biological diversity" (Ostfeld et al., 1997, 6) at all levels or scales of ecological organization. Heterogeneity is critical to ecosystem structure and function (Christensen, 1997; Meyer, 1997) and some suggest that management trends toward maximizing homogeneity in forest systems "bodes ill for the long-term biological sustainability and adaptability of the land" (Maser, 1994, 67). Others suggest that efforts to manipulate heterogeneity may or may not produce desired management outcomes depending on the degree to which scale, organism response, and form of spatial heterogeneity have been incorporated appropriately (Wiens, 2000). Natural disturbances are often viewed as important sources of heterogeneity, but there are differences of opinion on the role of anthropogenic disturbances. Wiens (2000) suggested that anthropogenic disturbances, such as land use, development, and resource extraction, tended to homogenize landscape patterns. Others suggest that these human activities alter natural heterogeneity or impose patchiness upon landscapes (Ostfeld et al., 1997; Pickett et al., 1997a). Thus, landscapes influenced by both human and natural processes may reflect competing influences on spatial heterogeneity at different scales.

Academic journals such as *Urban Ecology* and *Landscape Ecology* are increasingly publishing research integrating socio-economic jurisdictions and human settlement patterns in investigations of ecological heterogeneity and outcomes (e.g., Milovanović et al. 2020; Nassauer, 1995; Nassauer and Opdam 2008). Commenting on the need to fully address the political and social dimensions of landscape ecology, Pickett et al. (1997b) argued that more integrative research and a long-term perspective are needed to understand the role of humans in ecosystems and landscape heterogeneity, beyond their basic structural or jurisdictional manifestations. Nassauer (1995) also suggested that in order to improve ecological functions of landscapes, landscape ecologists should understand how culture influences landscape perception and how human values change, conflict, and influence landscapes over time.

Existing literature has provided abundant evidence for the important role of community context and heterogeneity in natural resource use and management. For example, scholars have found that understanding social context is essential for creating effective and appropriate natural resource and land management policies, including how community decision-making occurs (Brunckhorst 2010; Kakovannis et al., 2001; Krannich and Smith, 1998; Nursey-Bray, 2011). In the case of forest risks, research on wildfire mitigation and adaptation has shown that perceived efficacy and appropriateness of various forest management approaches are informed, in part, by the unique political, social, economic, and environmental factors that characterize communities (Brenkert-Smith, 2011; Paveglio et al., 2015, 2016, 2019). Qin and Flint (2010) also found in their study of human responses to forest insect disturbance that biophysical and social

characteristics of communities had significant influences on whether and how residents took actions in response to the MPB outbreak in Colorado.

2.2. Measurement and indications of community context

Community social science has nurtured a range of creative research designs and methods (Luloff, 1999). There have been increasing investigations on the ways to capture community context and analyze its influences on individual perceptions and behavior (Luke, 2005; Qin and Flint, 2010, 2017). Community researchers often rely on qualitative narratives to depict various aspects of local context such as histories, cultures, economies, institutions, and social relations (e.g., Brenkert-Smith, 2011; Bruno et al., 2022; Huntington et al., 2006). Many of these community characteristics can also be quantitatively measured using primary or secondary demographic, socio-economic, and biophysical data (e.g., Dolisca et al., 2009; Flint and Luloff, 2007; Mattarita-Cascante et al., 2017; Scherzer et al., 2019). Such processes often involve the construction of composite community indices broadly representing local conditions within specific sectors (socio-cultural, economic, environmental, etc.) or across multiple dimensions (resilience, vulnerability, sustainability, etc.).

Both qualitative and quantitative contextual information can be readily used to develop community typologies organizing cases and data according to selected criteria. A community typology can be considered as an abstraction of local context that helps to guide research practices and policy making (Luloff et al., 2007). For example, community clusters based on social and biophysical risk context facilitated analysis of local responses to forest insect disturbances in both Kenai Peninsula, Alaska and the north-central Colorado (Flint and Luloff, 2007; Flint et al., 2012; Qin et al., 2021a). To understand wildland urban interface (WUI) communities' adaptive capacity to wildfire, Paveglio and collaborators (2015, 2019; Carroll and Paveglio, 2016) also utilized an archetype scheme to organize the various social contextual factors and characteristics that determine acceptability and relevance of forest management strategies. Each archetype is situated along a series of continua of community-level trust and preferences regarding government and agency collaborations, communication networks, financial resources, and expectations of firefighting services.

2.3. Capturing community contextual effects

Scholars in community science have also developed varied approaches to examine the effects of community contexts on socio-economic and ecological phenomena at individual, household, and community scales. The most straightforward strategy is to conduct detailed comparisons of community case studies using both qualitative and quantitative data (e.g., Brenkert-Smith, 2011; Paveglio et al., 2016; Matarrita-Cascante and Trejos, 2013). Qin et al. (2017) also showcased the potential usage of qualitative comparative analysis (QCA) in an exploratory study of factors influencing the outcomes of community-based natural resource management. More quantitative methods of analyzing community contextual effects often entail the inclusion of community-level social, economic, and/or environmental indicators in bivariate analyses or multivariate statistical models (e.g., Besser, 2009; Dolisca et al., 2009; Flint and Luloff, 2007; Qin and Flint, 2010, 2017). When community sub-datasets are sufficient and balanced, researchers may also organize statistical analyses by community and compare results for individual study sites (e.g., Greider et al., 1991; Qin and Flint, 2010, 2012; Smith et al., 2001).

As not all community features and processes (perspectives, capacities, etc.) can be readily measured, an alternative approach is to collect relevant information from individuals and/or families and then aggregate results at the community level (Luloff, 1999). Meanwhile, the conditional effects of local contexts can be generally evaluated by checking the variations across individual communities regarding particular aspects or areas of interest. Such analyses may involve testing variance statistics across a large set of community units (e.g., Meldrum et al., 2018) or checking specific differences among a relatively small number of participant groups based on study communities (e.g., Brenkert-Smith et al., 2023; Flint, 2006; Krannich and Smith, 1998; Mayagoitia et al., 2012; Paveglio et al., 2019; Parkins and MacKendrick, 2007; Toman et al., 2014).

2.4. Summary

While there is considerable literature on community contexts and related effects, their temporal dimension thus far has been largely understudied in community-focused research. Previous longitudinal studies on community change can provide direct implications on how community context may evolve over time. For example, Luloff and Krannich (2002) reported both persistent and changing patterns of social and economic processes in follow-up research on six rural communities in the classic U.S. Department of Agriculture (USDA) Rural Life Studies. Temporal changes in community contextual effects may be examined in restudies replicating original research designs (particularly data collection and analysis) and comparing results from different study phases. Interestingly, existing work in this area was also mostly carried out by rural and natural resource sociologists. In a series of studies of four boomtowns in the Intermountain West region, Krannich and colleagues (Berry et al., 1990; Brown et al., 2005; Greider et al., 1991; Krannich et al., 1989; Smith et al., 2001) found community variations in perceived impacts of energy development generally became less salient in the post-growth period while the study communities' positions on several social indicators shifted significantly across stages.

In a similar vein, Qin and others (Qin et al., 2015a; Qin and Flint, 2017) used longitudinal survey data from six communities in Kenai Peninsula, Alaska to study changing perceptions and actions related to the spruce bark beetle outbreak. Among other major findings, they discovered both continuity and change in community-level differences in local responses to forest disturbance. In later work on the MPB outbreak in north-central Colorado, community contexts characterized as lower to higher levels of biophysical and social vulnerability (or the lack of amenity) have also been found to differentially influence perceived forest risks, opinions on land management and forest industry options, adoption of beetle-related actions, and temporal changes in varying perspectives and (in)actions (Flint et al., 2012; Qin and Flint, 2010; Qin et al., 2021a). The current paper builds upon previous studies by using longitudinal qualitative and quantitative data to tease apart ways in which local biophysical and socio-economic contexts are linked to variations in perceptual aspects of community response to the MPB outbreak in Colorado over time (see Fig. 1). Importantly, this type of work provides researchers and practitioners with a more nuanced and dynamic understanding of the potential effectiveness and appropriateness of various forest management approaches.

(Fig. 1 about here)

3. Study Background

3.1. The MPB outbreak

The most recent widespread MPB outbreak has affected significant portions of the Rocky Mountain region, including parts of Mexico and British Columbia. It has resulted in the mortality of millions of acres of lodgepole pine (*Pinus contorta*) forests since the late 1990s and early 2000s (National Park Service (NPS), 2018; USFS, 2011, 2024). Although rates of infestation have substantially slowed since 2014 in Colorado, MPBs have killed approximately 3.4 million acres of lodgepole pine forests in the state (CSFS, 2020, 2024; Negrón and Cain, 2019). MPBs are part of the forest ecology of lodgepole pine forests in the region, however same-species, same-age forests coupled with warmer winters and drought caused the outbreak to spread in the manner that it did (BBS, 2015; Carroll, 2010). Within the study region (see Fig.2), which includes the towns of Breckenridge, Dillon, Frisco, Granby, Kremmling, Silverthorne, Steamboat Springs, Vail, and Walden, the outbreak has affected approximately 1.6 million acres (CSFS, 2020, 2024).

(Fig. 2 about here)

3.2. Study communities

In this section of the paper, we use secondary sources to briefly orient the reader to the contextual information (e.g., local histories, economies, impacts resulting from the MPB outbreak) on the study communities. Table 1 presents an overview of these communities, including forests affected at the county and community levels, population sizes, and social vulnerability considerations. The communities represented in this study range in their biophysical, social, and economic characteristics, which provide a broad biophysical and socio-economic backdrop for each of the communities and their variations in vulnerability and response to ecological and social disturbance. The communities can be divided into two overarching clusters based on the percentage of surrounding forests affected by the MPB outbreak as well as a community social vulnerability index. The higher vulnerability cluster includes Granby, Kremmling, and Walden while the lower vulnerability cluster includes Breckenridge, Dillon, Frisco, Silverthorne, Vail, and Steamboat Springs. In the initial study phase, biophysical data on forest cover taken from the National Land Cover Database and the U.S. Forest Service (USFS) were integrated with socio-economic data including demographics, employment, and housing from the US Census and recreational data from USFS maps to create a community-level amenity index (Flint et al., 2012). The index scores were standardized to allow for comparison and ranking across communities. We organized community descriptions and the presentation of findings by local amenity context as community clusters based on the amenity and vulnerability conditions are generally consistent: lower/higher amenity = higher/lower vulnerability.

(Table 1 about here)

Throughout the nine communities, population sizes span from roughly 600 in Walden to over 12,000 in Steamboat Springs (see Table 1). Several towns located within Summit County, Colorado (Breckenridge, Dillon, Frisco, and Silverthorne), Vail, and Steamboat Springs are known for their year-round recreation-based resorts, which drives the local and regional economies in these areas. Other communities (Granby, Kremmling, and Walden) historically have economic foundations in agriculture, ranching, and extractive industries, which continue to play significant roles in their local economies (KCC, 2024; NPA, 2013). However, local

economies in these communities (particularly Granby) are becoming increasingly recreation-based as these areas provide a number of seasonal and year-round recreational opportunities given their proximity to national forests and parks (GCCTB, 2024; North Park CO, 2024). Hunting, fishing, snowshoeing, and cross-country skiing exemplify the growing recreation-based economic dependence of communities that were once considered to have predominantly resource- or extraction-based economies.[1]

Breckenridge is a community located in Summit County, near the base of the Rocky Mountain Tenmile Range. The town's official 1859 founding corresponded with infrastructure developments (e.g., post office, railroads) to support metals prospecting activities that ultimately offered varied levels of economic opportunity until gold dredging ceased in 1942. The town nearly disappeared in the 1950s as the population dwindled and many structures were destroyed by fire or abandonment. By the 1960s, lumber industry had staked the area for its first ski resort development. This, coupled with the westward expansion of the U.S. interstate system, became the impetus for a transition to amenity-centered economic development (Mather, 2024). Today, with a population of over 4,800 residents, parts of the town are architecturally preserved and protected by a National Historic Register designation (NPS, 2024). However, its social-cultural pulse centers on a thriving, year-round outdoor recreation economy (NWCCOG, 2024a).

Dillon is a central Summit County community with a history as a trading post town that "was constantly moving", most recently due to the creation of the Lake Dillon Reservoir in the 1950s-60s. Throughout its history, Dillon's proximity to major transportation hubs supported it emergence as a hub for multiple industries of the day, such as mining, logging, and ranching (Summit Historical Society, 2024). At present, the town's geographical location enables access to multiple ski resorts, trails, and other outdoor recreation. Similar to other Summit County communities, the majority of Dillon's residents are employed by the tourism industry (Dillon Colorado, 2024).

Frisco was incorporated in 1880 with its establishment dating back to the century's gold rush era as mining operations sprawled across the region (Dutta, 2019). It is a community with approximately 2,900 residents. Frisco is also located in central Summit County, economically benefiting from expansive mid-20th century investments in rail, highway, and water systems. It has been labeled the "Main Street of the Rockies" due to a vibrant downtown and locality that places it within 30 minutes of several ski resorts, many of which employ the town's residents (Town of Frisco, 2024).

The Silverthorne area in Summit County experienced early development effects of 1870s and 1880s gold prospecting in Summit County, yet it became more populated when it functioned as a Dillon Reservoir worker camp in the 1960s construction (Silverthorne Colorado, 2024). The town was officially incorporated in 1967, and as of 2020 had 4,402 residents. For much of its recent history, it has been both a stopover locale for broader regional tourism and an entry point to a vast Gore Range trail network (Uncover Colorado, 2024a).

The town of Vail as people know it today was established as a ski community. After it was incorporated in 1966, Vail marketed itself and continued to grow as a ski resort destination (Town of Vail, 2024). The town is home to the first gondola lift in the United States and became

[1] Overall, the three lower-amenity (or higher-vulnerability) communities are transitioning to varying degrees from extractive industries such as ranching and logging to more of a natural resource amenity orientation for retirees, second homeowners, and recreationists. Older traditions die hard among longer term residents in these communities and there is some evidence of the classic "culture clash" between new and longer standing residents (Smith and Krannich 2000).

even more recognized as a ski resort after it made headline news that Gerald Ford, who became president in 1974, owned a home in the town (Town of Vail, 2024). Home to the 2015 Alpine World Championships and the Burton U.S. Open Snowboard Championships, which attracts professional athletes from around the world, Vail is a prominent international destination (Town of Vail, 2024). In addition to the area's characterization as an international ski and snowboard resort, Vail prioritizes environmental health. The town's sustainability initiatives aim to drastically reduce the area's carbon footprint (Town of Vail, 2018, 2024).

A stark majority of businesses in Vail are directly or indirectly connected to the ski and tourism industries, and the area is heavily reliant on tourism-related sales taxes for revenue (Romer, 2016; Town of Vail, 2018, 2024). Notably, however, Vail also houses the world-renowned Steadman Hawkins Clinic where many high-profile athletes receive treatment for various injuries and the renowned Shaw Cancer Center that serves patients in the region and more broadly. Coinciding with the high quality of life in Vail, however, are issues that residents and individuals desiring to move to the area encounter, such as high costs of living, a lack of sustainable job opportunities, healthcare costs, and access to mental health services (Blevins, 2019; Bannow, 2019; Williams, 2019).

Steamboat Springs, with a population of 13,224 as of the 2020 Decennial Census, was incorporated in 1900 by wealthy businessmen drawn to the area's mineral springs. The town is located in the Yampa Valley, an area that has great cultural and spiritual significance to indigenous tribes of the region (City of Steamboat Springs, 2024). By the early 20th century, ranching and related agricultural activities were well-established, and the newly established rail lines facilitated the emergence of coal operations in Routt County (Routt County Colorado, 2024). The first ski resort was developed in 1961. Today, Steamboat Springs is a vibrant community with year-round recreation and diverse industry presence (City of Steamboat Springs, 2024).

Incorporated in 1864 and founded in 1905, Granby, Colorado was built along the Denver, Northwestern, and Pacific railroad (Destination Granby Colorado, 2024; GCCTB, 2024; Woods, N.D.a). Granby's close proximity to Hot Sulphur Springs to the west, Winter Park Ski Resort on the eastern part of the county as well as its own smaller resort, Granby Ranch, affords residents and visitors a number of recreation-based activities. However, industries such as logging and ranching also characterize the local economy and history of the community/region (Destination Granby Colorado, 2024; Town of Granby, 2024). Overall, Granby represents more of the business center of Grand County as it is centrally located within the county.

Granby is in east Grand County that accounts for most of the local tourist-based economy. People who live in the Grand Lake, Winter Park, or Fraser areas represent more resort-based communities, whereas other parts of the county, such as Kremmling and to a lesser extent, Granby, still maintain logging, agriculture, and ranching as key elements of their local economies. Many of Granby's approximate 21,00 residents work for resorts or hotels in surrounding areas (Blevins, 2018). Low crime rates and limited amounts of traffic characterize the area, as it is not as directly accessible to visitors compared to Summit and Eagle Counties, for instance. The population continues to grow and more and more homes are being built to address the demand for housing – especially near the Winter Park area (Golden, 2019; Harford, 2019; Renoux, 2018).

Located in west central Grand County, Kremmling is a community with a population of 1,509 in the most recent census. The town has its earliest history as a general store strategically placed within the bounds of the Colorado River, Blue River, and the Muddy Creek (Woods

N.D.b). The town incorporated in 1904 and has maintained an identity as a western town since its inception. At present, Kremmling is surrounded by Bureau of Land Management (BLM) and USFS lands that are partially accessible for grazing and recreation activities (NWCCOG, 2024b).

With the smallest population (about 600), Walden is unique compared to other areas in the study region given its relative isolation from infrastructure such as chain retail stores, grocery stores, and hospitals. Local residents must travel either to Steamboat Springs, Colorado or Laramie, Wyoming for amenities such as groceries and healthcare. Historically characterized as a resource-dependent community, the local economy in Walden has stagnated over the years, as industries (e.g., mining and forest products) that once characterized the region moved out and the area experienced out-migration of residents (U.S. Census Bureau, 2020). One sawmill in particular, the Michigan River Heights Sawmill (later Louisiana-Pacific Mill), employed roughly half the town (Colorado Encyclopedia, 2024). When this company left the area in the 1980s, Walden experienced an economic downturn. However, recreation activities are becoming more of an economic driver for the area given the amount and varying types of recreation present within and around Jackson County (e.g., hunting, fishing, hiking) (Town of Walden, 2024; Uncover Colorado, 2024b). T*hese shifts represent* a move from a strictly resource-dependent economy to one that is diversifying into more of a recreation-based economy − especially around hunting.

4. Methods

4.1. Data collection

A mixed methodological approach combining both qualitative and quantitative methods was used in this study to investigate the same research question from different viewpoints (Greene, 2007). We draw upon data from key informant interviews and household mail surveys conducted with residents throughout the study region, as part of a larger study that also involved secondary socio-economic and biophysical data analysis and a media analysis of local and regional newspapers. Interviews with key informants provided qualitative data in the form of rich narratives and survey data offered a means of gauging general patterns across larger population samples from the study communities. Altogether, these two approaches allowed the research team to investigate contextual factors across communities and their influences on perceptional responses at household and community levels.

Key informant interviews were conducted early in the study to explore the range of community experiences across the nine study communities. In the summer of 2006, a total of 165 key informant interviews were conducted using a multiple-criteria and snowball sampling methodology (Babbie, 1998; Luloff, 1999). To draw on multiple perspectives in each community, key informants were selected from a wide range of categories: schools, business owners, librarians, government leaders, clergy, fire or police, community service, logging industry, environmental organizations, newspapers, longtime residents, and newcomers. In some cases, informants represented more than one category. State and federal forest managers stationed throughout the region were also interviewed at length and are included in the 165 interviews.

Recruitment and interviews with key informants in the restudy occurred between October 2017 to July 2018. In total, we interviewed 54 key informants and met informally with 10 additional stakeholders throughout north-central Colorado (see [REDACTED] for a more detailed discussion of methodology). Initially, we identified and attempted to reach contacts from the previous 2006-2007 study for recruitment. When unavailable, we focused on recruiting

individuals who filled similar positions throughout the study area, such as law enforcement, fire fighters, fire managers, public officials, and community leaders. Of the 54 people interviewed, 12 had previously participated in the 2006-2007 study. As part of the recruitment process, we informed potential informants about the purpose of the study, why we were contacting them, and formally requested their participation. Importantly, and as we reiterate in the findings, the perspectives and insights we highlight are representative of key community members and leaders who maintained influential roles in shaping community response and community narratives surrounding the outbreak. Recruitment centered on informants who could speak to broader sentiments at the community level and beyond; these individuals predominantly hold influential positions in terms of policy, management of, and response to the outbreak.

Building on the results of the 2006 key informant interviews, a mail survey was developed and administered in spring of 2007 to 4,027 randomly selected households in the nine study communities (see [REDACTED] for a more detailed discussion of survey procedures). The survey was administered using a modified tailored design method and resulted in 1,346 valid responses (a response rate of 38.9% after accounting for undeliverable surveys). A re-survey was sent to the 1,346 original respondents from 2007 and 3,000 additional households randomly selected from a new mailing address database purchased from USADATA Inc. in 2018. This follow-up yielded 1,130 completed surveys (a response rate of 32.4% after accounting for the undeliverable), including 460 returned by those who also participated in the 2007 study. Overall, the two survey samples were largely comparable with each other in terms of basic socio-demographic characteristics such as age and gender compositions, educational attainment, and household income.

4.2. Interview and survey instruments

The 2006 key informant interview instrument revolved around various aspects of local experiences with the MPB outbreak and major components of a conceptual model of community response to forest disturbance by insects, such as perceived MPB impacts, concerns about forest risks, relationships with land managers, and local participation in community activities (Flint and Luloff, 2007; Qin and Flint, 2010). The interview guide in Phase II included questions organized by quality of life and the local economy, changes over time during and following the MPB outbreak, forest management preferences and perception, and forest products industry perceptions. Before every interview, we obtained permission to record. When individuals declined or the location of the interview had noise pollution, we took detailed hand-written notes.

The two surveys used identical questions to gather information on local perceptions of the MPB disturbance and land management. Forest risk perception was measured in the survey by asking the respondents how concerned they were about a series of forest risks, such as forest fire, falling trees, increased erosion and runoff, loss of forests as an economic resource, loss of tourism/recreation, and loss of community identity (responses ranged from “1” not concerned to “5” extremely concerned). Following results of exploratory factor analysis, a general forest risk perception measure was created by calculating the average value of responses to these questions.

The survey also assessed attitudes about a series of statements on forest resources and forest management. The level of agreement or disagreement with the statements were measured on a scale from 1 (strongly disagree) to 5 (strongly agree). Exploratory factor analysis revealed two factors underlying these statements – one for faith in forest industry (including statements such as “forest should be managed to meet as many human needs as possible”) and one for trust in forest management (including statements such as “forests are being managed successfully for

a wide range of uses and values"). Composite index variables were created for both factors by taking the mean of responses to relevant items. Respondents were also asked to indicate their attitudes about a group of four forest industry options: biomass/biofuels power generation, large-scale timber processing, small-scale timber processing, and niche marketing/production of wood products (responses ranged from "1" strongly oppose to "5" strongly support). Additionally, relationship with resource managers was measured by respondents' levels of satisfaction with ten local or governmental forest management entities such as private landowners, local fire departments, county government, and USFS (responses ranged from "1" very dissatisfied to "5" very satisfied). Two composite indicators were created to represent average levels of satisfaction with local and governmental land management entities, respectively.

4.3. Data analysis

While responses could be explored both at individual and community levels, we draw upon individual insights among critical stakeholders situated within particular community contexts. In taking this approach, we intended to show how place-based histories and contexts were inextricably linked to perceptions of forest disturbance and land management. Recordings and hand-written notes were transcribed and analyzed using NVivo11 and NVivo12 qualitative analysis software. Beginning with creation of high-level codes informed by the interview instrument, we sorted initial themes by interview question, which led us to more refined codes pertaining to environmental and social change, community participation, and industry perception (see Appendix 1 in the Supplementary Data) (Berg, 2004, Saldaña, 2009).[2]

Community variation was also the focus of statistical analysis of survey data. Considering the characteristics of key variables in the dataset, we used the Kruskal–Wallis one-way analysis of variance (ANOVA) by ranks test (the non-parametric version of one-way analysis of variance) to examine community differences in perceptual indicators and then compare results across study phases. Moreover, given the partially correlated nature of our longitudinal survey data (a combination of paired and independent observations), we tested temporal changes in major variables for individual communities and the whole study area with the corrected *z*-test instead of an independent samples *t*-test (Qin et al., 2018). All statistical analyses were conducted with SPSS Statistics Version 29.0.1.0. Marginally significant results ($p < 0.10$) were also included in the reporting of relevant results to better indicate temporal changes in the patterns of community variations.

5. Qualitative Findings

5.1. Phase I

Interviews in the initial study revealed strong variations across the nine study communities in terms of perceived MPB impacts and attitudes about forest management. Respondents also expressed considerable awareness of these differences and frequently compared their experiences to other communities. A Walden resident offered the following observation about the need to recognize community differences.

> "*The issues are definitely different in each community. The issues in Steamboat are different than they are here. Although we have the same problem, sometimes a blanket policy is not good because the issues are different. There may be some common themes that some policy decisions can be made on, yes. But each*

[2] Readers may also refer to [REDACTED] for a more detailed description of the qualitative analysis process.

community needs to handle it, you know, that benefits their community. Each one - because each has different values and objectives."

Forest managers recognized the socio-economic differences and related attitudes across the communities, and they readily referenced the amenity versus extractive industry orientations of the study communities. A regional forest supervisor highlighted the dramatic differences between Jackson and Eagle counties:

"*There are a lot of economic things playing in these counties. Jackson County has 1,600 people. They have no ski area. They're still predominantly an ag county. Then you go to Eagle County which has lots of major ski areas, major second homes, lots of wealth, huge tax base. They were saying 2 billion dollars all year. Little Jackson county, not geographically, but population-wise, there's no way they can compete with and/or put the amount of county resources or money into helping the problem. Although they're trying to figure out how they can do it from a people standpoint. It's a different clientele than you'll find necessarily in resort communities.*"

While space does not allow a full reporting of the rich qualitative information obtained, we focus here on the degree to which sentiments were found to vary by amenity and tree mortality community clusters. Thus, findings from Granby, Kremmling, and Walden (lower amenity communities) are compared with the other six higher amenity communities.

Perceived forest risks tied to the MPB outbreak were rather consistent across all nine study communities with some differences based on tree mortality rates or amenity context. Residents from all study communities were highly concerned about negative scenic and aesthetic changes and fire hazard resulting from dying trees. Many described the landscape impacts as "shocking" or "disturbing". A Frisco resident said, "*I hate to see all the brown, red, dead trees. It just kills me – kills my heart.*" A Granby resident highlighted the importance of forest to the region's identity saying, "*It's important to how people live. They love the forest and the mountains and the animals and the birds.*" A Breckenridge resident commented that "*When you're tourist based, it's important to be beautiful.*" Projecting the continued aesthetic impact, a Walden resident said, "*The few things in the community that actually go well, the hunting and the natural beauty around it, are going to be devastated.*" Fire was mentioned as a key concern, by nearly every person interviewed and most perceived a higher fire risk to be an inevitable consequence of the MPB outbreak as exemplified by a Dillon resident who said, "*The primary concern is, above all, the wildfire that follows the beetle. Period.*" Not everyone perceived forest fire risks to be the number one risk and there were some differences in personal risk perception of fire depending on proximity to forest, but in qualitative interviews, fire concern did not vary substantially by community amenity or tree mortality context.

Perceptions of economic ramifications of forest loss ranged from costs associated with removing dead trees to effects on community economies. While interviewees from all study communities had economic concerns, perspectives differed by amenity contexts and levels of financial resources. Respondents from lower amenity communities, where second homeowners and new amenity migrants are mixed with long-time residents with extractive industry orientations, articulated concerns about disparities in ability to absorb costs:

"*It's very different from Eagle County, for instance, which is wealthier. If you have the money to manage it, you may be unhappy about putting $10,000 into cutting down trees, but you can deal with it.*" (Granby)

> "*One of our biggest concerns is our watershed up here. Luckily, we have some very rich people that are logging it for us – very, very, very rich. They're not clearing everything, but they're thinning so that they still have the forest and we still have the watershed.*" (Kremmling)
>
> "*If we were to lose our forests, and the economy that comes along with it, the Walden that we're going to be left with is not necessarily going to be sustainable.*" (Walden)

Not all sentiments from lower amenity communities were negative as respondents also highlighted economic benefits from the MPB experience:

> "*I would say some people view it as an opportunity because there's a lot of new businesses that have cropped up because of it. You know, people that spray and people that are taking the trees down and it's definitely had to have had to help the economy in one way I would imagine.*" (Walden)
>
> "*It's given the lumber people their jobs back.*" (Kremmling)

For higher amenity community participants, perspectives focused on the economic loss and uncertainty from the MPB outbreak. A Dillon resident pointed out that those with means can cut trees, "*It's very costly to harvest trees, but some are doing that, those who can afford it.*" A Breckenridge resident said, "*Our economic base is basically tourism and we're 70% national forest land in the county. Anything that affects 70% of the county is obviously going to be a very important thing in the county.*" Noting that not all people appreciated risks, a Vail resident said, "*There's so many billions of dollars of infrastructure at risk that people don't seem to be aware of although I think they're getting there.*"

The relationship between local communities and resource management agencies varied considerably between lower and higher amenity community clusters. For those in lower amenity communities, considerable distrust and frustration were expressed:

> "*Our roots are in logging and our roots are in timbering. So we feel that the government has ignored this issue to the point where it's gotten to the point of an epidemic and now uncontrollable.*" (Kremmling)
>
> "*Private landowners are doing an excellent job of trying to get their places cleaned up, but a lot of them border onto the Forest Service [lands], and that's where the problem is.*" (Walden)
>
> "*I think if anyone has a black eye (bad reputation), the black hat (someone who acts immorally), unfortunately right or wrong, it's the Forest Service. The feeling is that they're not doing anything and that they're just letting it all die.*"[3] (Granby)

In higher amenity communities, better relationships were described, including more understanding of the limitations faced by local forest managers:

[3] Explanations of selected American slangs are added in parentheses to facilitate understanding (same below).

> "*We have a good collaboration with the Forest Service. They have the technical [knowledge]…they virtually have no dollars to help with actual cutting, but they have helped us a lot with the technical aspects of it.*" (Vail)

> "*No local community will be able to get anything done. I don't even think any single state will be able to get anything done. The only way we will see something done is if the affected western states pull together.*" (Breckenridge)

5.2. Phase II

The findings discussed in this section offer an analysis of the perceptions and perspectives of residents from selected study communities as they pertain to forest management and the forest products industry. The three communities at the focus of this analysis, Granby, Vail, and Walden, vary considerably in terms of their local histories and economies, experiences with the MPB outbreak, and historical perceptions around forest management and the forest products industry. They represent distinct points on a spectrum of biophysical and socio-economic characteristics − making them uniquely and appropriately positioned for a comparative analysis concerning the role of community context on land management perception and engagement. By grounding these perspectives within particular community contexts, we examine if context continues to frame preferences for and opinions on land management and industry in response to the MPB impacts. Below we first explore perceptions of the forest products industry and note differences across these communities regarding how industry preferences have changed or remained the same over time. In subsequent findings sections, we provide an analysis of interview findings across the three communities pertaining to forest management perception and satisfaction. For purposes of anonymity, we mainly reference informants based on their location. Where appropriate, we provide additional detail about the informants, including occupations and years in the community/area. However, in some cases providing additional detail on certain participants would inadvertently reveal their identities due to community size.

5.2.1. Forest products industry perceptions by community

5.2.1.1. Walden

Walden has a long and extensive history with the forest products industry, as it was long considered a critical part of the economic foundation of the area. Therefore, residents in this region, as informants explained, tend to be supportive of most forms of industry given the area's historical reliance on industry for jobs and economic development. For instance, a Jackson County political official (35+ year tenure) explained that,

> "*…basically the inception of the community was all about timber, I don't think they have any hostile thoughts or any reason not to embrace it if it was to come back, but it's just not going to happen… [logging is] definitely ingrained in the community. There's still guys trying to make a living doing it but it's harder and harder all the time.*"

Other interview informants shared that the community generally would support the forest products industry in the area given that it would be done responsibly. A logger and firefighter in Walden (~40 year tenure) explained,

> "*Yes, I think they would support nearly anything. We run a little tiny sawmill here on our place. Some of the logs we cut we saw, and then we build barns out of them. I think anything here ... if you came in and felt that you could do a reasonably clean job, it would be accepted by the community.*"

In sum, while informants acknowledge the minimal likelihood of having a viable, large-scale forest products industry in the area again - many also recognize the attainability of recreation as an increased source of economic capital to the area. Further and despite its decline, given the history of logging in and around Walden, informants noted a continued sense of community support for the forest products industry if it is economically sustainable and environmentally responsible.

5.2.1.2. Granby

Similar to Walden, logging and the forest products industry have historical roots in Granby and Grand County more broadly. One informant in Granby (30+ year tenure) explained that logging is historic to the area: "*It's part of the foundation of the whole county. Whether it's from building the ski areas to German POWs (prisoners of war) that cut way back in (being deeply located within a particular area)…that were over here [pointing toward Fraser and Kremmling], there's a lot of people that have roots in the logging industry*." Support for the forest products industry, according to interview informants, remains strong throughout parts of the county. In an interview with two firefighters in Grand County (20- and 28-year tenures, respectively), they shared the following when asked about residents' support for the industry:

> ***Grand County Informants****: I think they're for it. One of the things that has come out of this is we've got two facilities -- one in Grand County [and] one up in North Park, that do the pellets for pellet stoves and stuff. I think there was kind of a big push here, eight years ago or whatever... And we got another lumber mill moved in over there in Parshall and they seem to be going gangbusters (going with great enthusiasm). I don't think there's any pushback on the logging locally. The only complaint I've heard is when they occasionally pull down a power pole or something because they're stacked too tall or whatever.*
>
> ***Interviewer****: Have these attitudes changed over time, since the beetle outbreak especially?*
>
> ***Grand County Informants****: Grand County traditionally has been really rural and rugged, I'm going to say. I think they've always been supportive as long as I've been here. Logging's part of the way of life and it just happens.*

Notably, logging and the forest products industry, while rooted throughout parts of the county, predominantly characterizes Granby and other towns such as Kremmling. This is in contrast to the eastern part of the county home to Winter Park Ski resort - making Grand County's economic base rather diverse instead of being heavily reliant (one way or the other) on extractive industries or amenity-based services.

5.2.1.3. Vail

Out of all the communities included in the larger study, and especially in relation to Granby and Walden, Vail informants report more hesitancy and aversion in their community toward the forest products industry. Much of this has to do with the image of Vail as a premier resort area. For instance, as one Eagle County-based informant (22-year tenure) who works out of Vail shared,

> "*We have an allergic reaction to [the forest products industry] in [our] resort region. I think this is an impediment to some of the challenges we're talking about. We talked*

about managing the forests… There's still an ethos that's not Gifford Pinchot (the first Chief of the USFS) ethos of managing the forest."[4]

A city-level administrator working on wildfire mitigation in Vail explained that "*Vail has been referred to by many people as Disneyland in the mountains. They want that perfect façade. Logging by far does not fit within that perfect façade*." However, some informants explained that there may be some levels of acceptance for industry given that it is environmentally friendly and sustainable. An employee for the town of Vail (10-year tenure) argued that the industry "*would have to be zero emissions*" for there to be support among residents.

Another Vail informant (12+ year tenure) shared that since the timber and forest products industry does not contribute - and historically has not contributed - to the local economy, conversations around the industry are minimal.

***Interviewer**: Do you think that the community would support a forest products industry here in any form?*

***Vail Informant**: "I don't know. Question mark. Again, it's a tough thing to establish in Vail given all of the other competing interests that are producing a lot more money… it's not like Grand County where you really seem to have potential and an existing forest products industry there. I think it was all pushed out when the tourism boat sailed. It's just that timber value doesn't trump the recreational and land value of Vail.*"

Comparatively speaking, while Granby and Walden have rich histories associated with the forest products industry, Vail has become characterized as a year-round resort destination. The forest products industry and extractive industries more generally do not fit the "mold" of Vail and Vail's environmental values.

5.2.2. Forest Management Perceptions by Community

5.2.2.1. Walden

Walden and the North Park region of Colorado more broadly have a unique history with forest management that continues to color management perceptions today. Given the large amount of federal land located in the county (BLM 2017; USFS 2024), the town of Walden has had decades of interaction with federal land management agencies, such as the USFS and BLM. Informants shared that many community members feel that the forest has not been managed properly for some time, which they attribute to bureaucratic constraints and a general lack of acknowledgement and receptiveness among federal land management agencies to community needs and desires. In particular, what residents perceive as a lack of recognition of and care toward community preferences of forest management over time (e.g., constraints around allowing timber sales to local loggers and companies) has produced increased levels of distrust toward federal land management agencies among residents (this is also reflected in the survey report for Walden and nearby towns (Rand, Coalmont, and Cowdrey) [REDACTED]).

While in the field in Walden, we frequently heard of negative community perceptions of forest management among informants. One person exemplified this sentiment, stating that local people are not "*fond of Smokey Bear (the symbol for forest fire prevention in the United States) in this part of the country*." Compared to Vail, for example, informants in Walden shared that the community places a substantial amount of blame on federal land agencies for mismanagement

[4] Gifford Pinchot is referred to as "the Father of American Forestry." He promoted conservation and sustainable land-use as an approach for managing public lands. More information is available via U.S. Department of the Interior 2017.

and overgrowth that allowed the outbreak to flourish. As a result, many informants report low levels of satisfaction toward forest management - the lowest throughout the study region (also see [REDACTED]). A few Walden community members, including two Jackson county-level officials that we interviewed (70- and 8- year tenures, respectively), explained that dissatisfaction with forest managers is also a "*lack of listening to your community*" and that "*we don't think we have any influence on forest management decisions*." Expressing the sense of self-reliance in Walden, one of them who was based in that community shared,

> "*We as a community don't like the government, including us, including the ones that we actually elect. We're just very, I don't know what to call it. It's like "code of the West (a set of unwritten, informal principles shaping the American frontier and cowboy culture)." We're just a very self-sufficient, self-sustaining community.*"

Another community informant (20-year tenure) detailed his community's disdain toward federal forest management:[5]

> ***Walden Informant****: We feel that [forest management agencies] have public hearings because the law requires them to have public hearings. But it has no impact or influence on decisions at all.*
>
> ***Interviewer****: And why do you think that is? Do you think it has something to do with your location, the area's location in the state?*
>
> ***Walden Informant****: No, I don't think it has anything to do with location. I think it's just ... The Forest Service, BLM, Fish and Wildlife, they're just huge bureaucracies. They rely on studies and expert opinions from people living in New Hampshire.*

Some informants from Walden argued that they also feel overlooked in part because of the relative size of their community compared to others, such as Steamboat Springs and Vail. Given the low number of residents in the community, informants explained that community members feel overlooked and as "not important" due to a lack of weight their opinions carry. This unique history and context culminate into a community culture that emphasizes individual efforts toward mitigation rather than a reliance on/trust in land management agencies to accomplish mitigation.

5.2.2.2. Granby

Informants from Granby generally report relatively higher levels satisfaction with forest management compared to initial findings from 2007, although some report feeling as though forest management was poorly executed due to a "hands-off" approach that allowed for overgrowth and contributed to the decline of the forest products industry in this region. Relatedly, some informants report perceptions of poor or a lack of communication among forest managers regarding work conducted (or not) in the forests, and why, or a sense that managers do not listen to community concerns and desires. For instance, as a logger in Granby (25-year tenure) argued, "*Our forest managers are supposed to be subservient to the public that lives here, but they really aren't. I think at least on a federal level*." In addition to these sentiments, concerns continue to focus on the lack of available resources for federal land management agencies to address an increasing number of forest hazards, largely in reference to the MPB outbreak. Given the significance of logging and forest products to Granby's (and Grand County's more broadly) economic base, multiple informants shared that it seemed easier in the past for

[5] Despite these perceptions, some informants reported increased levels of satisfaction with forest management now that they have a new forest manager for their region. They felt that the previous manager did not listen to their concerns and was largely unavailable.

industry to work with forest managers to ask for timber sale contracts or permits. Several informants from across the entire study area acknowledged the predicament of extracting lodgepole pine, explaining that the cost for extraction and transport to a processing facility outweighs the benefits. For instance, lodgepole pine is not a lucrative resource given its relatively small diameters compared to larger trees used in construction.

Multiple informants throughout Granby reported that the outbreak sparked a general shift in thinking that recognized the need for proactive forest management, acknowledging that preexisting conditions in the forest (e.g., overgrowth, same-species, same-age forests) exacerbated the effects of the outbreak. Before the MPB outbreak, as two state-level forest managers (26- and 8-year tenures, respectively) working within Grand County explained, it was a tough "sell" to implement proactive forest management strategies: "*So people have learned to accept forest management, in general, in this county*." A former newspaper editor (roughly 50-year tenure) based in Grand County stated, "*People have become more receptive toward thinning and clear cutting as a way to control risk from wildfire than before*."

5.2.2.3. Vail

Vail informants overwhelmingly reported higher levels of satisfaction with forest management compared to Granby and Walden area informants , explaining via interviews that they feel that forest managers have been communicative and taken time to form good relationships. Several recognized the constraints that forest managers face due to a lack of funding, resources, and human power. For instance, as a county-level elected official based out of Vail (24-year tenure) expressed, "*we love our local forest rangers and forest managers. We think they do a good job*," adding an acknowledgement that more funding is going toward fighting fires than to mitigation. Another informant (10-year tenure) working for the town of Vail explained that,

> "*So, [forest managers] have got their hands full, and I think that they're doing a really good job. I would say the community, you know, really respects the Forest Service's role, and the folks that are there, but they're just understaffed. Could we do better? Yeah, maybe. But I think there's good partnerships with the town and the Forest Service.*

This was a common sentiment among many informants, although it is unclear to what extent and whether the general public and residents of these communities are also aware of these constraints.

Historically, Vail represented the opposite end of the spectrum in terms of historical support for forest management compared to Granby and Walden. Before the outbreak, as some forest managers and wildland fire experts explained, it was difficult to get anything done in the forests given community pushback. However, as with other communities throughout the study area, Vail informants reported a shift in thinking about forest management from one that used to be more "hands-off" to increased support for proactive forest management following the outbreak ([REDACTED]). Although hesitation remains for management activities that are "in sight" or clearly visible to the public, there is a sense that the Vail community has increasingly recognized the need for forest management.

To sum up, sentiments around logging and the forest products industry varied clearly among the three areas, with Granby and Walden reporting higher levels of support for this sector compared to Vail where there is not a recent history of large-scale logging. Informants from across Granby, Vail, and Walden also reported varying levels of satisfaction (both personally and at community levels) with forest managers in their respective regions. Taken together, the

findings demonstrate how local histories and context coalesce to explain unique trajectories across communities in response to the same slow-moving environmental event.

6. Quantitative Findings

We here present survey results on evolving community variations in local perspectives on the MPB beetle disturbance. Table 2 summarizes community differences in forest risk perceptions at the two study stages. Overall, although perceived forest risk declined across the study area (corrected *z*-test = 13.3, $p < .001$), the general pattern of community differentiations remained stable and even became further reinforced to some degree. Walden respondents indicated the highest level of forest risk perception in both phases while Kremmling became similar to Walden and more different from some of the communities in the higher amenity cluster over time. This trend of increased community clustering was also observed for the perceptions of several specific forest risks including falling trees (see Fig. 3a), the impact on livestock grazing, the loss of forests as an economic resource, the loss of scenic/aesthetic quality, the loss of tourism/recreation, and the impacts on property values. Concerns about the decline in wildlife habitat, increased erosion and runoff, and the loss of community identity continued to be more elevated in Walden than in some or all of the other study communities. There was largely no significant difference among the nine communities in the perceived risk of invasive plant species in either phase. Additionally, the re-survey data demonstrated a convergence of forest fire risk perception at a rather high level as those community differences identified in Phase I mostly disappeared (see Fig. 3b).

(Table 2 about here)

(Fig. 3 about here)

Results on the changing variations in community perspectives on forest industry and management show a generally consistent pattern across individual variables (see Table 3). Compared to the more amenity-based communities, those in the lower amenity cluster (particularly Kremmling and Walden) still exhibited more support for forest industry in general and specific industry options while indicated less trust in forest management (see Figs. 3c and 3d). In Phase II, although respondents from Granby continued to voice relatively strong support for large- and small-scale timber processing, they became more like those from the higher-amenity communities and differed from Kremmling and Walden participants in attitudes about forest/forestry-related issues.

(Table 3 about here)

Furthermore, as shown in Table 4, there were fewer community differences in the aggregate satisfaction with local entities in the re-study. Nevertheless, the clustering of individual communities still existed or became relatively clearer regarding opinions on private logging companies, local fire departments, and homeowner associations (see Fig. 3e). This pattern of temporal changes is even more obvious for community variations in the satisfaction with governmental land managers at different scales. While views on these entities became more positive across the board, satisfaction levels were still generally lower in communities of the lower-amenity cluster, especially Kremmling and Walden (see Fig. 3f).

(Table 4 about here)

The survey data also demonstrate detailed evolvement of perceptional responses in individual study communities during the study period (see Tables 2–4). While the aggregate levels of most of these perceptions changed significantly over time, the extents of temporal adjustments within communities varied considerably across major variables in the analysis.

There were significant changes with respect to some aspects (e.g., concerns on increased erosion/runoff and the impact on property values, trust in forest management, satisfaction with the USFS in all or most of the nine communities. In contrast, such outcomes in several other indicators were only manifested in a specific community cluster (e.g., concern on the impact on livestock grazing, support for niche marketing of wood products) or a few communities (e.g., support for biomass/biofuels power generation, satisfaction with private logging companies). For specific variables (e.g., concern on forest fire, support for large scale timber processing), communities might exhibit deviations from the overall trend observed across the study area. Compared to other study sites, two of the lower-amenity communities (Kremmling and Walden) showed relatively fewer significant changes in local perceptions of forest risks and management.

7. Discussion

Community context remains a critical area of exploration for understanding local responses to long-term environmental change. As we presented through interview data, key informants across communities within the study area expressed differing views on MPB impacts and risks, forest industry, and forest management (including relationships with land managers), which were linked to the unique local histories, economies, and cultures of their respective communities. Residents' perceptions were based on past experiences with forest management, but are also closely related to communities' ties to and levels of support for the forest products industry. For instance, compared to resort communities, the towns of Granby and Walden have a history and generally positive pre-existing relationships with or sentiments toward the forest products industry. Conversely, informants in these higher-amenity communities reported more positive community relationships with forest management than informants from other study communities. However, in asking informants to reflect on change over time with regard to their community's thoughts about forest management and the forest products industry, we are able to note similarities and shifts across time − and how community context framed and continues to inform differential local perceptions of the MPB outbreak and forest management. We have not only shown that these variations are shaped by community context, but that such context and its influences are dynamic.

Qualitative findings on different trajectories in local residents' perceptional responses were substantiated by survey findings, but the ability to explore perceptions quantitatively allowed for general patterns to be uncovered. Findings from both interviews and surveys with residents from the nine study communities provide insights into variations in forest risk perceptions, attitudes about forest industry and management, as well as satisfaction with land managers. Survey results also suggest several possible scenarios of evolving community variations in local perspectives on the MPB disturbance: (1) stable community clustering based on vulnerability context (views on forest industry and forest management); (2) relatively clearer subgrouping of communities aligned with vulnerability conditions (e.g., perceptions of forest risks such as falling trees and the impact on property values, satisfaction with governmental land management entities); (3) reduced differences (or increased convergence) across communities (forest fire risk perception); and (4) no significant community variation in either phase (concern on invasive plant species and satisfaction/dissatisfaction with developers). Despite substantial temporal changes in most of these perceptual factors across the study area, the overall pattern of community variations and their linkages with local amenity contexts stayed mostly consistent.

The continuity and reinforcement of previous community differences can be mainly attributed to specific community changes in correspondence with original and/or developing

local contexts or the relative lack of temporal changes across study communities. For example, while the level of perceived falling tree risk rose in most study communities, respondents from lower amenity communities (Granby, Kremmling, and Walden) reported larger increases than those from other communities. In contrast, there were smaller drops in most other forest risk perceptions (except for perceived forest fire risk) for this community cluster than for those higher-amenity communities. Similarly, general trust in forest management and satisfaction with governmental land managers improved across the study area and particularly in the six amenity communities. As a result, initial patterns of community variations in these aspects were largely retained. Nevertheless, as Granby moved closer to the alternative community subgroup in terms of socio-economic context, it differed from the other two lower-amenity communities in the temporal trends and subsequent outcomes of some forest risk perceptions and forest views, including concern on the loss of forests as an economic resource, faith in forest industry, trust in forest management, and support for selected forest industry options (e.g., large- and small-scall timber processing).

Initial household survey data from the nine north-central Colorado communities suggested local residents' responses to the outbreak vary, in part, because of their biophysical and socio-economic risk contexts (Flint et al., 2012). Earlier analysis showed that there were notable differences between two community clusters (lower tree mortality–higher amenity vs. higher tree mortality–lower amenity communities) with respect to residents' reported perceptions of forest risks, forest management, and forest industry options related to the MPB outbreak. In the re-study of local perceptions and actions in response to forest disturbance, while we adjusted the criteria for community clustering to focus more on biophysical and social vulnerability considerations, the compositions of the two community subsets were mostly identical across study phases (Qin et al., 2021a). Among other key findings from the longitudinal data, the higher amenity (lower vulnerability) cluster continued to report relatively lower levels of forest risk perception and higher levels of support for forest management compared to communities in the other cluster, while both subgroups showed reduced concerns on most forest risks and increased trust in forest management and satisfaction with land managers over time. Moreover, respondents in the lower amenity (higher vulnerability) communities shared decreased levels of faith in the forest products industry, while perspectives of the more amenity-oriented communities indicated minimal change in this aspect. The current paper builds upon these previous analyses and showcases the value of mixed methods research in understanding the complex and dynamic human dimensions of forest hazards and risks. While our quantitative analysis produced more structured information on changing variations in community responses, the qualitative component helped to disentangle local contexts that influence community perceptions and processes over time.

Existing literature on community context and community variations has shown the importance of longitudinal research work (Brown et al., 2005; Krannich et al., 1989; Qin et al., 2015a; Qin and Flint, 2017; Toman et al., 2014). This study highlights the linkages between evolving community contexts and community variations in coupled socio-ecological systems. Previous longitudinal boomtown research in the Intermountain West region reported that community differences in local impacts of and responses to energy development decreased after periods of rapid growth (Smith et al., 2001). While these study communities were not exposed to a singular development activity, they were largely similar to each other in terms of accompanying demographic and economic changes. More related to the present research, the follow-up study of community responses to the spruce bark beetle outbreak in Kenai Peninsula,

Alaska detected several major trends of changing community variations in relevant perceptual and behavioral indicators: reduced differences or coalescence, increased variations, similar levels of variability (either changed or largely the same patterns), and no significant variation at either time point (Qin and Flint, 2017). Although these changes did not match exactly with a biophysical/socio-economic vulnerability typology of the study communities (including $2 \times 2 = 4$ subcategories), the analysis showed that adjusted community variations in some specific domains (e.g., wildfire experience and perceived beetle impacts) generally mirrored a regional beetle outbreak timeline that was directly related to local biophysical vulnerability context. In contrast, this research suggests that social vulnerability context is relatively more influential than biophysical vulnerability in framing local reactions to the MPB outbreak in north-central Colorado over an extended period. Our longitudinal data revealed increased convergence within two subgroups of communities, sustained differentiations across community clusters, as well as the shifting of community positions associated with local socio-economic restructuring. These findings should contribute to a more complete understanding of the general patterns of evolving community variations. While not implying local socio-cultural, economic, and environmental conditions fully determine subsequent changes in the similarities and differences among communities, we have shown that community contexts can provide a general reference frame for pinpointing potential continuity and/or change of community variations.

This mixed-methods study highlights the value of pursuing interdisciplinary research that treats the integration of social and ecological characterizations as essential for nuanced understanding. It can also provide useful methodological implications for capturing or tracking community contexts and contextual effects in ecological social science. Our data collection and analysis combined multiple established approaches including qualitative narratives, community typology building, and examining indicator variations at the community level. For the most part, the relationships identified between changing community contexts and community differences in this research can help to validate the applicability of examining community contextual effects through analyzing community variations. Thus far, quantitative longitudinal analyses of community contextual effects often entail comparisons of results of statistical analyses (e.g., the Kruskal–Wallis one-way ANOVA tests, multilevel regression models) for different study phases. Future research along this line may directly incorporate temporal dimensions into data analyses with time series models or multivariate analyses involving temporal factors. Furthermore, in addition to the letter superscripts, text strings, and stacked bar charts used in this and several other studies (e.g., Brenkert-Smith et al., 2023; Flint et al., 2012; Romero-Lankao et al., 2014; Smith et al., 2001), researchers may explore additional creative approaches (3D graphs, maps generated by spatial or network analyses, etc.) to indicate or visualize community variations and contextual effects.

8. Conclusions

Previous studies have found that biophysical and socio-economic contexts situate how community members perceive and act on forest risks such as wildfire and insect outbreaks (e.g., Brenkert-Smith, 2011; Flint et al., 2012; Paveglio et al., 2019; Qin and Flint, 2010). In this paper, we demonstrate further evidence that local context matters in influencing how communities differentially respond to the same ecological event over time. By taking into consideration local context and perspectives, a broader look at the community dimension of landscape heterogeneity revealed an alternative pattern than might have been expected based solely on biophysical data. Community-level responses to slow-moving environmental change are dynamic and localized

processes that natural resource managers must navigate with communities for responsive and context-appropriate policy and decision-making. Critically examining local context is a necessary precursor for appropriate and achievable management strategies across communities, as it takes into account important nuances regarding community residents' acceptance of forest or land management and additional factors that may influence their receptiveness to certain intervention and engagement approaches.

Better understanding of community heterogeneity can improve the efficacy of regional land management and planning. Incorporating variations in human and community perceptions of forest disturbance and land management should lead to a more salient appreciation of the role and implications of social and ecological heterogeneities in the changing landscape of north-central Colorado. In communities where trust and satisfaction in forest management are relatively high, planning and strategy implementation to manage forest disturbances can move forward quite smoothly. Where trust and satisfaction are low, however, work may be needed to find common ground and build stronger relationships before moving forward with management plans. Since community context and associated effects are not static, researchers and practitioners must recognize the ever-changing dynamics of communities across risk contexts – noting the contextualized biophysical and social processes that inform community perceptions of and responses to enduring environmental change.

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Tables

Table 1. Overview of Study Communities

County	Acres of MPB-Killed Forests (1996-2018 Cumulative)[a]	Community	Population (approx.)[b]	% of Forests Affected (Phases I~II)[c]	Social Vulnerability Index (Phases I~II)[d]
Eagle	194,000	Vail	4,835	21.2~61.7%	0.180~0.212
Grand	581,000	Granby	2,079	41.0~84.1%	0.224~0.239
		Kremmling	1,509	45.2~82.1%	0.234~0.283
Jackson	364,000	Walden	606	83.4~100.0%	0.310~0.354
Routt	345,000	Steamboat Springs	13,224	22.6~53.3%	0.196~0.215
Summit	143,000	Breckenridge	5,078	20.8~70.8%	0.202~0.218
		Dillon	1,064	25.2~73.4%	0.175~0.234
		Frisco	2,913	23.8~70.0%	0.171~0.255
		Silverthorne	4,402	25.4~70.9%	0.210~0.233

[a]Source: CSFS and USFS, 2019

[b]Source: U.S. Census Bureau, 2020

[c]This measure indicates the percentage of affected trees within a 15-mile radius around the census designated place boundary of each study community (REDACTED).

[d]The community social vulnerability index created based on sociodemographic, income, employment, and housing data from the 2009 and 2017 American Community Surveys (see REDACTED for further details). The ranges of this indicator for all census places in Colorado were 0.088–0.402 and 0.115–0.453 (minimum/maximum values = least/most vulnerable) in Phases I and II, respectively.

Table 2. Community Variations in Forest Risk Perceptions[a]

Variable	Time	Higher Amenity Communities						Lower Amenity Communities			All Communities[b]
		Breckenridge	Dillon	Frisco	Silverthorne	Vail	Steamboat Springs	Granby	Kremmling	Walden	
Forest risk perception	Phase I	**3.6**^{W}	**3.8**$^{S2(W)}$	**3.6**^{W}	**3.6**^{W}	**3.7**^{W}	**3.5**$^{D(K)W}$	**3.7**^{W}	**3.7**$^{(S2)W}$	**4.0**$^{B(D)FS1VS2GK}$	**3.7*****
	Phase II	**3.1**^{KW}	**3.3**^{W}	**3.1**^{KW}	**3.2**^{KW}	**3.2**^{W}	**3.2**^{KW}	**3.4**^{W}	**3.5**^{BFS1S2}	**3.8**^{BDFS1VS2G}	**3.3*****
Forest fire	Phase I	4.3	4.5	4.3^{GW}	4.4^{GW}	4.5^{S2}	4.2^{VGKW}	**4.6**^{FS1S2}	**4.5**^{S2}	4.6^{FS1S2}	4.5***
	Phase II	4.5	4.5	4.5	4.5	4.4	4.1^{W}	**4.4**	**4.3**	4.6^{S2}	4.4*
Falling trees	Phase I	**3.5**^{W}	3.7	3.6^{W}	**3.5**^{W}	3.6	**3.5**^{W}	**3.7**	**3.8**	**4.0**^{BFS1S2}	**3.7*****
	Phase II	**3.7**$^{(G)(K)W}$	3.8^{W}	3.7^{GKW}	**3.9**^{W}	3.6^{GKW}	**3.7**$^{(K)W}$	**4.1**$^{(B)FV}$	**4.1**$^{(B)F(S2)K}$	**4.4**^{BDFS1VS2}	**3.9*****
Decline in wildlife habitat	Phase I	3.6	**3.9**^{S1}	**3.7**	**3.5**^{DW}	**3.8**	**3.6**	3.8	3.7	3.9^{S1}	**3.7****
	Phase II	3.5	**3.3**	**3.4**	**3.2**^{W}	**3.4**	**3.2**^{W}	3.6	3.6	3.7^{S1S2}	**3.4****
Impact on livestock grazing	Phase I	**2.4**^{KW}	2.4^{KW}	**2.3**^{KW}	**2.4**^{KW}	**2.3**^{GKW}	**2.7**^{W}	2.8^{VW}	3.0^{BDFS1V}	3.5^{BDFS1VS2G}	**2.7*****
	Phase II	**1.9**^{GKW}	2.1^{KW}	**1.8**^{S2GKW}	**2.0**^{GKW}	**2.0**^{GKW}	**2.3**^{FKW}	2.6^{BFS1VW}	3.1^{BDFS1VS2}	3.4^{BDFS1VS2G}	**2.4*****
Increased erosion and runoff	Phase I	**3.6**^{W}	**4.0**	**3.8**	**3.7**	**3.9**	**3.8**	**3.8**	**3.8**	**4.0**^{B}	**3.8****
	Phase II	**3.3**	**3.4**	**3.2**^{W}	**3.3**$^{(W)}$	**3.3**$^{(W)}$	**3.3**$^{(W)}$	**3.4**	**3.4**	**3.7**$^{F(S1)(V)(S2)}$	**3.4***
Invasive plant species	Phase I	**3.6**	**3.9**	3.6	**3.8**	**3.7**	**3.7**	3.6$^{(W)}$	3.8	**3.9**$^{(G)}$	**3.7***
	Phase II	**3.4**	**3.6**	3.4	**3.4**	**3.4**	**3.4**	3.6	3.6	**3.6**	**3.5**
Loss of forests as an economic resource	Phase I	**3.3**^{KW}	**3.6**^{W}	**3.3**$^{(K)W}$	**3.4**^{W}	**3.3**$^{(K)W}$	**3.3**^{KW}	**3.7**^{W}	3.8$^{B(F)S1(V)W}$	**4.3**^{BDFS1VS2GK}	**3.6*****
	Phase II	**2.7**^{KW}	**3.0**^{KW}	**2.6**^{KW}	**2.7**^{KW}	**2.8**^{KW}	**2.9**^{KW}	**3.2**^{KW}	3.7^{BDFS1VS2G}	**4.0**^{BDFS1VS2G}	**3.1*****
Loss of scenic/aesthetic quality	Phase I	**4.2**	**4.4**	**4.3**	**4.3**	**4.2**	**4.1**	**4.1**	4.0	4.3	**4.2**(*)
	Phase II	**3.3**^{VS2KW}	**3.7**^{W}	**3.5**^{W}	**3.7**^{W}	**3.8**^{B}	**3.8**^{B}	**3.6**^{W}	3.9^{B}	4.1^{BDFS1G}	**3.7*****

Loss of tourism/recreation	Phase I	**3.6**^{S2}	**3.7**^{S2}	**3.6**^{S2}	**3.5**^{W}	**3.7**^{S2}	**3.1**^{BDFVW}	**3.5**^{W}	3.3^{W}	**3.9**^{S1S2GK}	**3.6*****
	Phase II	**2.3**^{GKW}	**2.8**^{W}	**2.5**^{W}	**2.7**^{W}	**2.8**^{W}	**2.7**^{W}	**2.9**^{BW}	3.0^{BW}	**3.6**^{BDFS1VS2GK}	**2.8*****
Loss of community identity	Phase I	**3.6**	**3.7**^{S2}	**3.5**	**3.6**	**3.7**^{S2}	**3.1**^{DVW}	**3.4**^{W}	**3.2**^{W}	**3.9**^{S2GK}	**3.5*****
	Phase II	**2.4**^{W}	**2.7**^{W}	**2.5**^{W}	**2.7**^{W}	**2.7**^{W}	**2.6**^{W}	**2.9**^{W}	**2.9**	**3.5**^{BDFS1VS2GK}	**2.8*****
Impact on property values	Phase I	**3.6**^{S2}	**3.9**^{S2}	**3.5**^{W}	**3.6**^{S2W}	**3.6**^{W}	**3.1**^{BDS1GKW}	**3.8**^{S2}	**3.7**^{S2}	**4.0**^{FS1VS2}	**3.7*****
	Phase II	**2.7**$^{(K)W}$	**2.8**^{W}	**2.6**^{KW}	**2.7**$^{(K)W}$	**2.5**^{KW}	**2.6**^{KW}	**3.0**^{W}	**3.2**$^{(B)F(S1)VS2}$	**3.6**^{BDFS1VS2G}	**2.9*****

[a]Given as means based on 5-point scale (1=Not Concerned to 5=Extremely Concerned). Pairs of bold numbers mean significant temporal changes (at the 0.05 or higher level) across the two study phases. Superscript codes indicate significant (or marginally significant if with brackets) differences with corresponding communities using post hoc Tukey's test. Codes for communities: B=Breckenridge, D=Dillon, F=Frisco, S1=Silverthorne, V=Vail, S2=Steamboat Springs, G=Granby, K=Kremmling, W=Walden.

[b]Asterisks indicate the statistical significance of differences among all communities. (*) $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 3. Community Variations in Perspectives on Forest Industry and Management[a]

Variable	Time	Higher Amenity Communities						Lower Amenity Communities			All Communities[b]
		Breckenridge	Dillon	Frisco	Silverthorne	Vail	Steamboat Springs	Granby	Kremmling	Walden	
Faith in Forest Industry	Phase I	2.5^{GKW}	2.5^{GKW}	2.5^{GKW}	2.6^{GKW}	2.5^{GKW}	2.5^{GKW}	2.9^{BDFS1VS2W}	3.1^{BDFS1VS2W}	**3.6**^{BDFS1VS2GK}	2.8***
	Phase II	2.5^{KW}	2.6^{KW}	2.5$^{(G)KW}$	2.6^{KW}	2.5^{KW}	2.5^{KW}	2.8$^{(F)KW}$	3.2^{BDFS1VS2G}	**3.3**^{BDFS1VS2G}	2.7***
Trust in Forest Management	Phase I	**2.7**^{KW}	**2.5**^{FVS2W}	**2.9**^{DGKW}	**2.7**^{KW}	**2.8**^{DGKW}	**3.0**^{DGKW}	**2.5**^{FVS2W}	**2.3**^{BFS1VS2}	2.0^{BDFS1VS2G}	**2.6***
	Phase II	**3.2**^{KW}	**3.2**^{KW}	**3.3**^{KW}	**3.1**^{KW}	**3.1**^{KW}	**3.2**^{KW}	**2.9**^{KW}	**2.5**^{BDFS1VS2G}	2.2^{BDFS1VS2G}	**3.0***
Biomass or Biofuels Power Generation	Phase I	**3.6**^{W}	3.6^{W}	3.7^{W}	3.5^{W}	3.5^{W}	3.5^{W}	3.8^{W}	3.6^{W}	**4.3**^{BDFS1VS2GK}	**3.7***
	Phase II	**3.2**^{KW}	3.5^{W}	3.4^{KW}	3.4^{KW}	3.5^{W}	3.4^{KW}	3.6^{W}	3.9^{BFS1S2}	**4.1**^{BDFS1VS2G}	**3.5***
Large scale timber processing	Phase I	2.3^{GKW}	2.4^{GKW}	2.2^{GKW}	2.4^{GKW}	**2.1**^{GKW}	**2.2**^{GKW}	**3.4**^{BDFS1VS2W}	3.3^{BDFS1VS2W}	4.0^{BDFS1VS2GK}	2.8***
	Phase II	2.3^{GKW}	2.6^{KW}	2.3^{GKW}	2.5^{GKW}	**2.4**^{GKW}	**2.5**^{GKW}	**3.1**^{BFS1VS2KW}	3.6^{BDFS1VS2G}	3.9^{BDFS1VS2G}	2.8***
Small scale timber processing	Phase I	3.4^{GKW}	3.4^{GKW}	3.3^{GKW}	3.4^{GKW}	3.1^{GKW}	3.3^{GKW}	4.0^{BDFS1VS2W}	4.2^{BDFS1VS2}	4.4^{BDFS1VS2G}	3.6***
	Phase II	3.2^{GKW}	3.5^{KW}	3.3^{GKW}	3.5^{KW}	3.2^{GKW}	3.4^{KW}	3.8^{BFVKW}	4.3^{BDFS1VS2G}	4.4^{BDFS1VS2G}	3.6***
Niche marketing	Phase I	3.7^{KW}	**3.7**^{KW}	**3.7**^{KW}	**3.7**^{KW}	**3.4**^{GKW}	**3.5**^{GKW}	4.0^{VS2W}	4.1^{BDFS1VS2}	4.3^{BDFS1VS2G}	**3.8***
	Phase II	3.8^{KW}	**4.0**	**4.0**	**3.9**^{KW}	**3.8**$^{(K)(W)}$	**3.8**^{KW}	3.9$^{(K)(W)}$	4.2$^{BS1(V)S2(G)}$	4.2$^{BS1(V)S2(G)}$	**4.0***

[a]Given as means based on 5-point scale (1=Strongly Disagree/Oppose to 5=Strongly Agree/Support). Pairs of bold numbers mean significant temporal changes (at the 0.05 or higher level) across the two study phases. Superscript codes indicate significant (or marginally significant if with brackets) differences with corresponding communities using post hoc Tukey's test. Codes for communities: B=Breckenridge, D=Dillon, F=Frisco, S1=Silverthorne, V=Vail, S2=Steamboat Springs, G=Granby, K=Kremmling, W=Walden.

[b]Asterisks indicate the statistical significance of differences among all communities. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 4. Community Variations in Satisfaction with Land Management Entities[a]

Variable	Time	Higher Amenity Communities						Lower Amenity Communities			All Communities[b]
		Breckenridge	Dillon	Frisco	Silverthorne	Vail	Steamboat Springs	Granby	Kremmling	Walden	
Local Entities	Phase I	**2.8**^{W}	**2.8**^{W}	**3.0**^{VW}	**2.9**^{VW}	**2.6**^{FS1GKW}	2.8^{W}	**3.0**^{VW}	**2.9**^{VW}	3.3$^{d\ GK}$	**2.9*****
	Phase II	**3.2**$^{(S2)}$	**3.2**$^{(S2)}$	**3.2**^{S2}	**3.2**^{S2}	**3.1**	2.9$^{(B)(D)FS1GKW}$	**3.1**^{S2}	**3.2**^{S2}	3.3^{S2}	**3.1*****
Private landowners	Phase I	**2.7**^{W}	**2.8**^{W}	3.1^{V}	2.9^{W}	**2.6**$^{F(S2)(K)W}$	3.0$^{(V)W}$	**2.9**^{W}	**3.0**$^{(V)W}$	3.5^{BDS1VS2GK}	**3.0*****
	Phase II	**3.1**^{W}	**3.1**^{W}	3.3^{S2}	3.1^{W}	**3.0**^{W}	2.8^{FKW}	**3.1**^{W}	**3.3**^{S2}	3.5^{BDS1VS2G}	**3.1*****
Local fire departments	Phase I	**3.2**^{W}	**3.2**^{W}	**3.4**$^{(W)}$	**3.3**^{W}	**3.1**^{W}	**3.3**^{W}	**3.3**^{W}	**3.2**^{W}	3.7$^{BD(F)S1VS2GK}$	**3.3*****
	Phase II	**4.3**^{S2GKW}	**4.1**^{S2}	**4.2**^{S2GK}	**4.0**^{S2}	**4.1**^{S2}	**3.6**^{BDFS1V}	**3.7**^{BF}	**3.7**^{BF}	3.8^{B}	**3.9*****
Private logging companies	Phase I	2.7^{GKW}	**2.7**^{GKW}	2.7^{GKW}	2.8^{GKW}	**2.6**$^{\mathbf{GKW}}$	2.8^{GKW}	3.2^{BDFS1VS2W}	3.5^{BDFS1VS2}	3.8^{BDFS1VS2G}	**3.0*****
	Phase II	2.8^{GKW}	**3.1**^{KW}	2.8^{GKW}	2.9^{GKW}	**2.9**$^{\mathbf{GKW}}$	2.9^{GKW}	3.3^{BFS1VS2W}	3.6^{BDFS1VS2}	3.7^{BDFS1VS2G}	**3.1*****
Developers	Phase I	2.2	**2.2**	2.3	2.4	2.2	2.2	2.5	2.3	2.6	2.4**
	Phase II	2.3	**2.5**	2.3	2.4	2.4	2.3	2.5	2.4	2.4	2.4
Homeowner associations	Phase I	3.0	2.9	3.2^{VS2K}	3.2^{VS2GK}	**2.6**^{FS1}	2.7^{FS1}	**2.8**^{S1}	2.7^{FS1}	2.9	**2.9*****
	Phase II	3.1^{S2}	3.1	3.3^{S2KW}	3.3^{S2KW}	**2.9**	2.7^{BFS}	**3.1**	2.8^{FS1}	2.8^{FS}	**3.0*****
Government Entities	Phase I	**2.7**^{KW}	**2.7**$^{(K)W}$	**3.0**$^{V(G)KW}$	**2.7**^{KW}	**2.6**^{F}	**2.9**^{KW}	**2.6**$^{(F)}$	**2.4**$^{B(D)FS1S2}$	**2.4**^{BDFS1S2}	**2.7*****
	Phase II	**3.6**^{S2GKW}	**3.4**^{GKW}	**3.5**^{GKW}	**3.5**$^{(S2)GKW}$	**3.4**^{KW}	**3.2**$^{(S)BKW}$	**3.0**^{BDFSW}	**2.7**^{BDFS1VS2}	**2.6**^{BDFS1VS2G}	**3.2*****
City government	Phase I	**3.0**^{GKVW}	**2.9**^{K}	3.2^{VS2GKW}	**3.0**^{VGKW}	**2.6**^{BFS1}	**2.7**^{F}	**2.6**^{BFS1}	**2.4**^{BDFS1}	2.6^{BFS1}	**2.8*****
	Phase II	**3.5**^{S2GKW}	**3.3**^{KW}	3.5^{S2GKW}	**3.3**^{S2GKW}	**3.5**^{S2GKW}	**3.0**^{BFS1V}	**3.0**^{BFS1V}	**2.7**^{BDFS1V}	2.6^{BDFS1V}	**3.1*****
County government	Phase I	**2.9**$^{V(K)}$	**2.8**	**3.0**^{VGK}	**2.9**^{VK}	**2.4**^{BFS1}	**2.8**	**2.6**^{F}	**2.5**$^{(B)FS1}$	2.7	**2.7*****
	Phase II	**3.6**^{S2GKW}	**3.5**^{S2GKW}	**3.6**^{S2GKW}	**3.6**^{S2GKW}	**3.3**	**3.0**^{BFDS1}	**3.0**^{BDFS}	**2.9**^{BDFS1}	2.8^{BDFS}	**3.3*****

State Forest Service	Phase I	**2.7**$^{(S2)}$	**2.8**	**3.0**^{K}	**2.7**^{S2}	**2.7**^{S2}	**3.1**$^{(B)S1VKW}$	**2.8**$^{(K)}$	**2.4**$^{FS2(G)}$	**2.6**^{S2}	**2.7*****
	Phase II	**3.7**^{GKW}	**3.5**^{KW}	**3.7**^{KW}	**3.6**^{KW}	**3.**5$^{K(W)}$	**3.5**^{K}	**3.3**^{B}	**2.8**^{BDFS1VS2}	**2.9**$^{BDFS1(V)}$	**3.4*****
Bureau of Land Management	Phase I	**2.6**$^{(S2)W}$	**2.5**^{S2}	**2.7**^{W}	**2.5**$^{S2(W)}$	**2.5**^{S2}	**2.9**$^{(B)DS1V(G)KW}$	**2.6**$^{(S2)W}$	2.4^{S2}	2.2$^{BF(S1)S2G}$	**2.5*****
	Phase II	**3.3**^{KW}	**3.3**^{KW}	**3.3**^{KW}	**3.3**^{KW}	**3.4**^{KW}	**3.2**^{KW}	**2.9**^{W}	2.6^{BDFS1VS2}	2.3^{BDFS1VS2G}	**3.0*****
US Forest Service	Phase I	**2.5**^{S2W}	**2.5**^{S2W}	**2.8**^{KW}	**2.5**^{S2W}	**2.6**$^{(S2)W}$	**3.**0$^{BDS1(V)GKW}$	**2.6**^{S2W}	**2.2**^{FS2W}	**1.8**$^{d\ GK}$	**2.5*****
	Phase II	**3.6**^{GKW}	**3.5**$^{(G)KW}$	**3.7**^{GKW}	**3.6**^{GKW}	**3.4**^{KW}	**3.4**^{KW}	**3.0**$^{B(D)FS1W}$	**2.6**^{BDFS1VS2}	**2.3**^{BDFS1VS2G}	**3.2*****

[a]Given as means based on 5-point scale (1=Very Dissatisfied to 5=Very Satisfied). Pairs of bold numbers mean significant temporal changes (at the 0.05 or higher level) across the two study phases. Superscript codes indicate significant (or marginally significant if with brackets) differences with corresponding communities using post hoc Tukey's test. Codes for communities: B=Breckenridge, D=Dillon, F=Frisco, S1=Silverthorne, V=Vail, S2=Steamboat Springs, G=Granby, K=Kremmling, W=Walden.

[b]Asterisks indicate the statistical significance of differences among all communities. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Figures

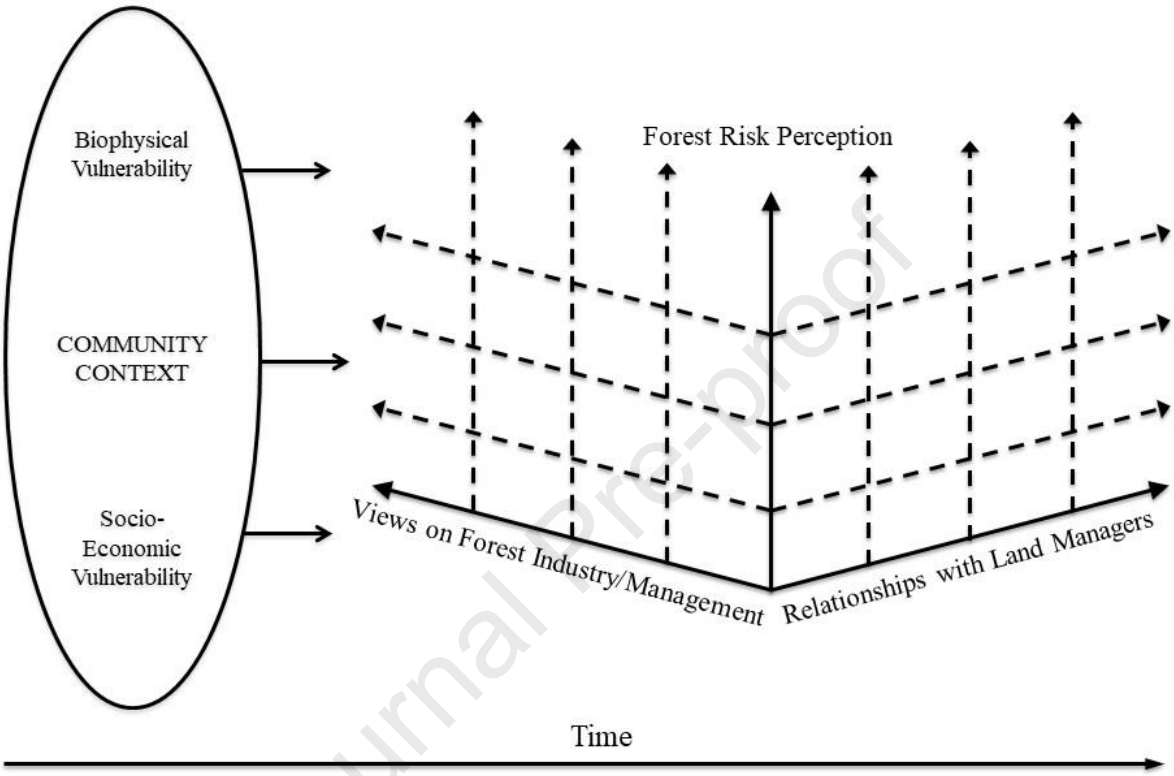


Fig. 1. An analytical framework of the dynamic community contextual effects on variations in local perceptions of forest disturbance and land management in Colorado. The matrix on the left side represents community variations in forest risk perception, views on forest industry and management, and relationships with land managers. While community response to the MPB outbreak includes several other components (e.g., beetle-related actions), the framework highlights these perceptual factors which are the focus of the present study. The time arrow indicates changing community context and variations. Source: adapted from conceptual models by Qin et al. (2021b, 2023) and Luloff et al. (2007).

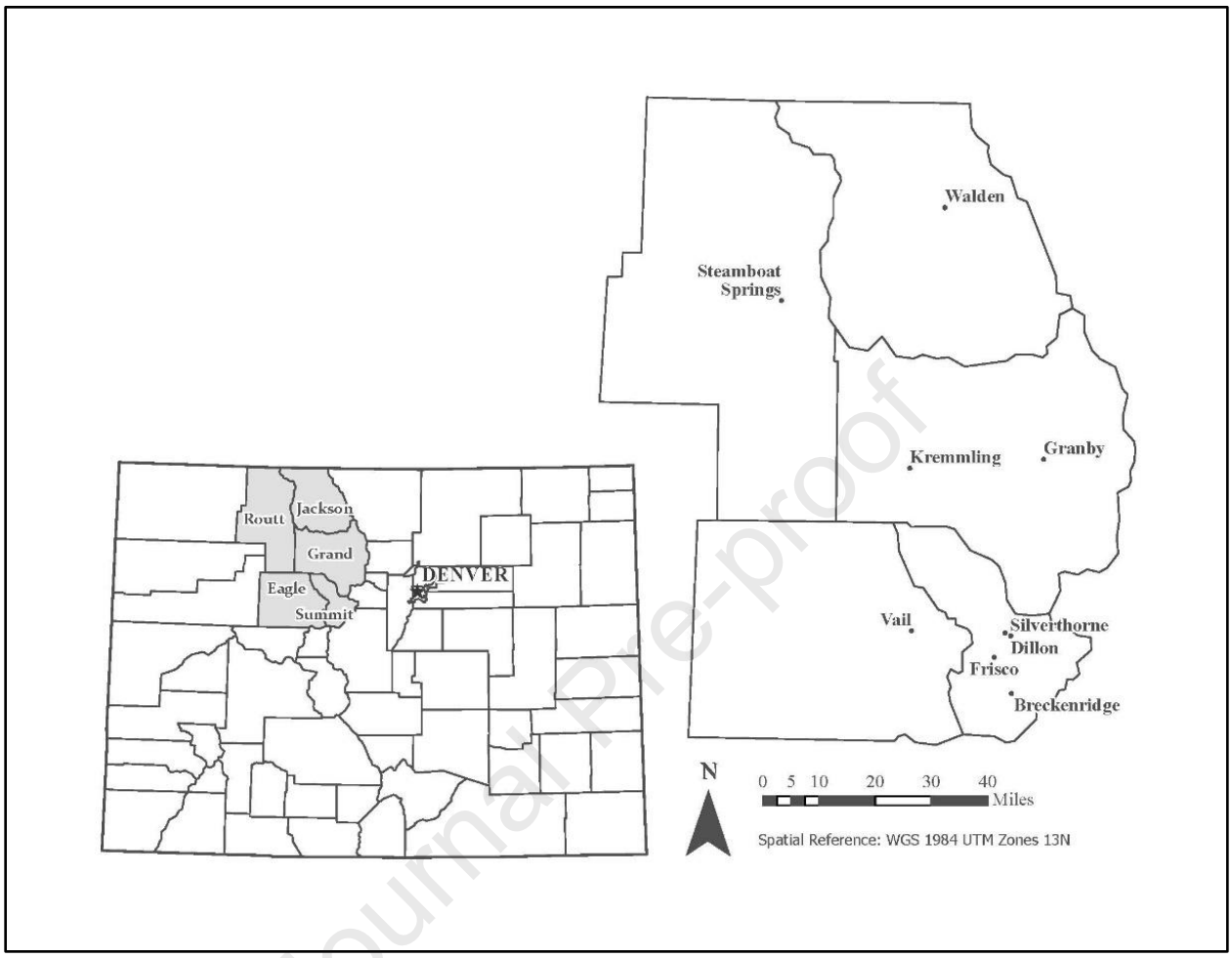
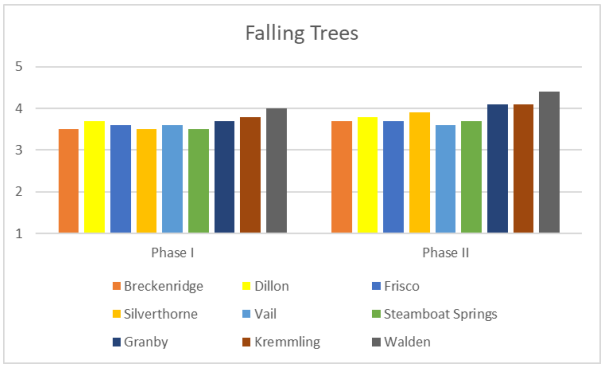
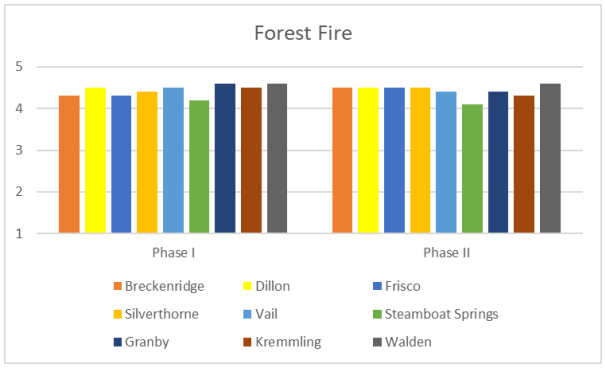


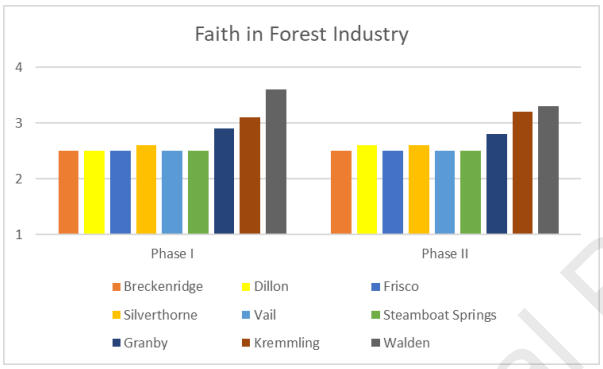
Fig. 2. Map of north-central Colorado and the study communities. Reprinted with kind permission from Removed for Blind Review (2021, Fig. 1). The four borders of the State of Colorado are at 37°N, 41°N, 102°03'W, and 109°03'W, respectively.



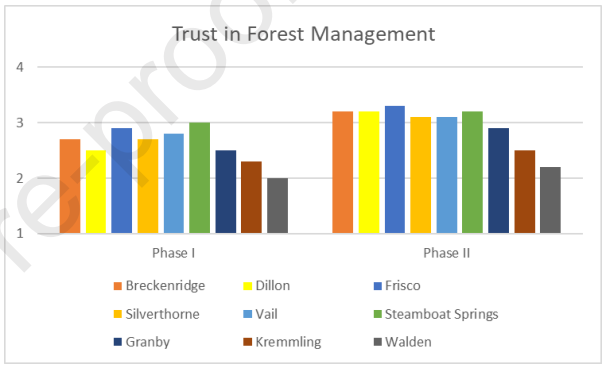
(a)



(b)



(c)



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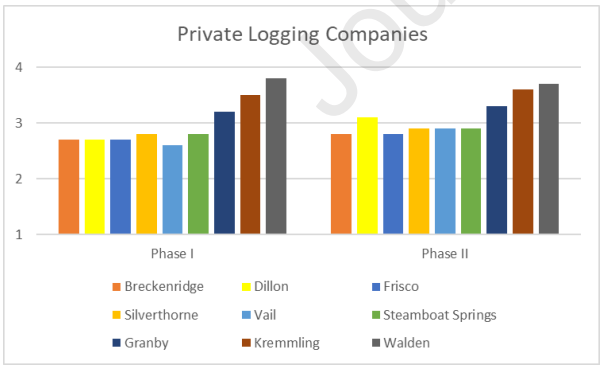
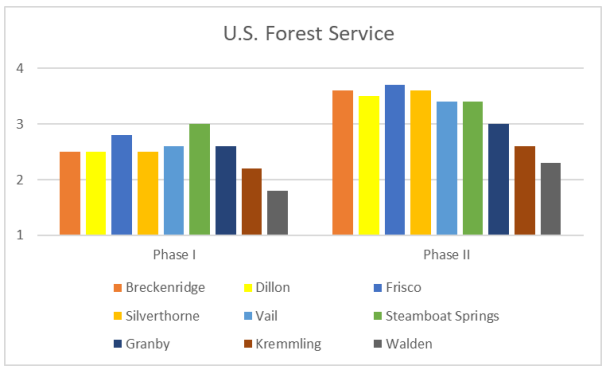


(e)



(f)

Fig. 3. Community variations in selected measures of forest risk perception, attitudes about forest industry and management, and satisfaction with land managers: (a) concern about falling trees; (b) concern about forest fire; (c) faith in forest industry; (d) trust in forest management; (e) satisfaction with private logging companies; and (f) satisfaction with U.S. Forest Service.

Exploring How Community Context Informs Variations in Local Perceptions of Forest Disturbance and Land Management in Colorado Over Time

Highlights

- Literature on community context and its effects on relevant phenomena is growing.
- The analysis combined longitudinal interview and survey data from Colorado.
- There were significant variations in community perceptions in both study phases.
- Community context informed evolving differences in local perceptional responses.
- Incorporating changing local contexts and variations can improve land management.

Exploring How Community Context Informs Variations in Local Perceptions of Forest Disturbance and Land Management in Colorado Over Time

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.