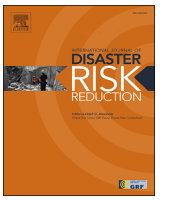
International Journal of Disaster Risk Reduction 82 (2022) 103388

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr



Actionable social science can guide community level wildfire solutions. An illustration from North Central Washington, US☆

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ARTICLE INFO

Keywords:
Wildfire
Risk mitigation
Preparation
Actionable
Co-production

ABSTRACT

In this study we illustrate the value of social data compiled at the community scale to guide a local wildfire mitigation and education effort. The four contiguous fire-prone study communities in North Central Washington, US, fall within the same jurisdictional fire service boundary and within one US census block group. Across the four communities, similar attitudes toward wildfire were observed. However, significant differences were found on the measures critical to tailoring wildfire preparation and mitigation programs to the local context such as risk mitigation behaviors, reported barriers to mitigation, and communication preferences across the four communities.

1. Introduction

Extreme wildfires threaten the economic and social resilience of communities located in the wildland-urban interface (WUI) - where wildland fuels meet residential development. An extreme wildfire can destroy a high proportion of homes, associated community infrastructure, and the social fabric of a community. While extreme wildfires can have many other negative outcomes, including civilian and firefighter fatalities [1], increasing suppression costs (https://www.nifc.gov/fire-information/statistics/suppression-costs), and ecological damage [2], a core element of a WUI disaster is the destruction of homes. As such, one critical aspect of WUI disasters is that they are a home ignition problem [3]. The fire science related to home ignition, while ever evolving, has established clear guidelines about what residents can do to reduce the ignitability of their homes [4,5]. However, implementation of such guidelines is problematic across the WUI. In places such as Canada, the US, and Australia where mitigation of wildfire risk on private property is largely voluntary, community-based wildfire programs often play a key role in educating and motivating residents to mitigate risk [6]. Such programs are often the vehicle for incentivizing private property owners to mitigate wildfire risk.

In addition to encouraging wildfire risk mitigation, community-based wildfire programs support residents' efforts to prepare for a wildfire event. The US embraces a "ready, set, go" approach where residents are expected to prepare for evacuation prior to a wildfire event and evacuate when given notice. This is not the only possible approach. For example, Australia takes a leave early or stay and

☆ The findings and conclusions in this paper are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy. This research was supported in part by the U.S. Department of Agriculture, Forest Service. Chelan County Fire District 1 funded the data collection.

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https://doi.org/10.1016/j.ijdrr.2022.103388
Received 3 December 2021; Received in revised form 13 October 2022; Accepted 16 October 2022
Available online 20 October 2022

defend approach which likely expands not only possible risks but also interventions to reduce that risk beyond those in the American context [1,7,8]). Divergent social and cross-cultural aspects of wildfire influence preparedness planning and communication, as well as evacuation options [9,10]. Across differing notions of wildfire preparation, local wildfire education programs tend to be the conduit to encouraging residents of diverse communities to prepare for a wildfire event.

In general, we know that the social dimensions of a community represent the capacity of a community to prepare and recover from a disaster [11]. And it is well recognized that WUI communities and their residents vary in their relationships to wildfire and their landscapes. Indeed, the National Cohesive Wildland Fire Management Strategy [12] explicitly recognizes a one-size-fits-all approach to creating fire adapted communities is not appropriate. However, there is a gap between this recognition and guidance on the specific social dimensions that are relevant to engagement on the wildfire issue within a given community. Likewise, there is a gap in the social science wildfire literature between characterizing social differences across communities and characterizing solutions built on such insights.

In this article, we use biophysical and social data collected at the property level to investigate whether practitioner defined "communities" within a contiguous geographic area are distinct in dimensions relevant to tailoring wildfire preparedness and mitigation education efforts. Specifically, we ask: *How can local, community-specific social data inform wildfire education efforts across diverse communities?* In pursuit of the answer to our question, the research attends to the notion that there is not a one-size-fits-all approach to fire adapted communities by investigating *what* (e.g., the messaging, the programs, the communication mode), if anything, about wildfire education efforts should be tailored to the local context? This contributes to the literature by going beyond using social dimensions to characterize types of communities [13] and describing intra-community variation [14] to examining the details of how a wildfire education program can leverage community-specific social dimensions to engage residents to mitigate and prepare for a wildfire. We examined four contiguous fire-prone communities in North Central Washington that are located within one jurisdictional fire service boundary and one census block group. Prior to the study, the local wildfire practitioner recognized distinctness across the four communities with respect to geography, parcel size, and the level of resident wildfire mitigation and preparation engagement. Study results confirmed the practitioner's initial notions and provided actionable information for tailoring wildfire education efforts to community differences. Surprisingly, similar attitudes toward wildfire were observed across the four communities. However, significant differences were found on measures critical to tailoring wildfire preparation and mitigation programs to the local context such as risk mitigation behaviors, reported barriers to mitigation, and communication preferences across the four communities. These results, while specific to the case study, suggest more broadly the importance of using locally scaled data to develop richer, more actionable insights for wildfire education programs than might be garnered from readily available secondary data, such as Census demographic or county-level statistics.

2. Literature

This study is motivated by two related bodies of literature: research that examines heterogeneity across WUI communities and research that examines how residents of WUI communities engage with wildfire risk. The body of literature related to heterogeneity across WUI communities relies on data that range from downscaled national social data to qualitative data from case studies. Some of this research characterizes WUI communities by providing insights into housing density and the expansion of the wildland-urban interface in shaping exposure to wildfire hazards [15,16]. Other work, leveraging housing density data along with biophysical wildfire data, provides metrics to assess wildfire risk to communities and to identify areas with a high likelihood of wildfire burning from public to private lands [17]. Informed by efforts to create indicators of disaster resilience and social vulnerability [18–20] examined place vulnerability to wildfire by adding in biophysical vulnerability to wildfire to a census-block level analysis and found limited coincidence of high social vulnerability and high wildfire exposure, with regional variation. In the US, the census block group represents the finest grained social data that is consistently available across all locations [21]. used census block groups to assess whether areas with low adaptive capacity may be particularly subject to wildfire transmission from public to private lands, finding limited areas of high social vulnerability within high fire exposure areas. Importantly [21], found that high social vulnerability census block groups had high population and structure density. Census block groups generally contain 600 to 3000 people and can be geographically large in sparsely populated areas. This aspect of census data limits its use for characterizing the social dimension of smaller WUI communities. Further, census data do not include information specific to wildfire risk mitigation and preparedness. A problem related to housing density and wildland-urban interface designation was highlighted by Ref. [22] who found that many buildings destroyed by wildfires in sparsely populated areas fall outside the designated WUI in the US. This literature has played an important role in characterizing the scope of the wildland fire problem, but it was not designed to provide insights into community level wildfire mitigation and education efforts.

Case study approaches have also been used to investigate WUI community heterogeneity and include both qualitative and quantitative approaches that primarily focus on the community scale. Ref. [13] parses this literature into two approaches: social-psychological approaches reliant on survey data and analyses focused on identifying potential determinants of risk reduction behaviors and qualitative process-focused approaches that attend to how residents engage wildfire issues. While the social-psychological approach has yielded limited predictive capacities due to community heterogeneity, the process-focused approaches yield nuanced understandings that are limited in their generalizability. This article differs from both approaches in that it uses survey data not to characterize determinants of risk reduction but rather to characterize different pathways for a program to follow to increase wildfire risk mitigation and preparation that attend to local context.

Several studies have sought to create typologies of WUI communities including work based in qualitative case studies [13], landowner types [23], and profiles based in territorial, topographic, and socioeconomic profiles [24].

Findings from both quantitative and qualitative approaches point towards the critical role that context, typically considered at the community-scale, plays in social characteristics and processes that local wildfire mitigation and education programs might support or leverage for improving community wildfire resilience [25].

The research that seeks to measure how WUI residents engage with wildfire risk includes broad explorations of demographic characteristics, social profiles, and processes [26] including wildfire attitudes and perceptions [27–31,52], the role of social capital and adaptive capacity [32–36], and risk mitigation behaviors [37–41].

There is small body of quantitative research that compares the social dimensions of community residents across different communities. Some of this research examines wildfire but not as the core consideration [42,43]. Ref. [14] took a data driven approach to identify community heterogeneity in the context of wildfire and found that residents' relationships with wildfire varied both within and across communities, depending on the measure. Key measures found to vary across communities included residents' sources of wildfire risk information, expectations of results of a wildfire, and the extent to which they have mitigated or are prepared for a wildfire event. One notable aspect of this study was the use of a large dataset comprised of spatially distinct communities served by different wildfire organizations across six different counties.

Together, these studies lend support to the assertions that community context matters for the development of actionable insights that support efforts to improve community resilience and that studies that do not sufficiently attend to scale may inadvertently obscure critical heterogeneity relevant to tailoring local wildfire education efforts. Our work here takes the next logical step in demonstrating how appropriately scaled data collection can elucidate heterogeneity to provide actionable insights for local practitioners.

3. Methods

3.1. Background and study area

The study area (i.e., the Squilchuck Drainage) is located outside the city of Wenatchee in Chelan County, Washington (Fig. 1). At the time of the study (2018) Chelan County was facing rising population growth and associated changes in land use from low fire risk uses such as orchards and irrigated agriculture to high fire risk uses such as home development. Chelan County had experienced regular fires since the 1970s. However, in 2015 the Chelan Complex, First Creek Fire, and Sleepy Hallow Fire resulted in loss of 96 homes in Chelan County. These wildfires and understandings about how population growth was affecting wildfire risk were a wake-up call about the need to get in front of the wildfire issue. The key organizations working with communities and property owners in the study area were Chelan County Fire District 1 (CCFD1), Cascadia Conservation District, and the Washington State Department of Natural Resources. A 2015 amendment to the 2005 Squilchuck Valley Community Wildfire Protection Plan provided some general education and outreach guidelines for these organizations in the entire Squilchuck Valley which includes the Squilchuck Drainage (https://cascadiacd.org/squilchuck-valley-cwpp_296.html, p. 15):

- Hold workshops for residents on Firewise (sic) landscaping, insect control, fire resistant construction methods, and other pertinent subjects.
- Encourage the use of the Firewise Communities/US (sic) website.
- Employ local media such as newspapers and radio to let the community know about Firewise (sic) activities and information.

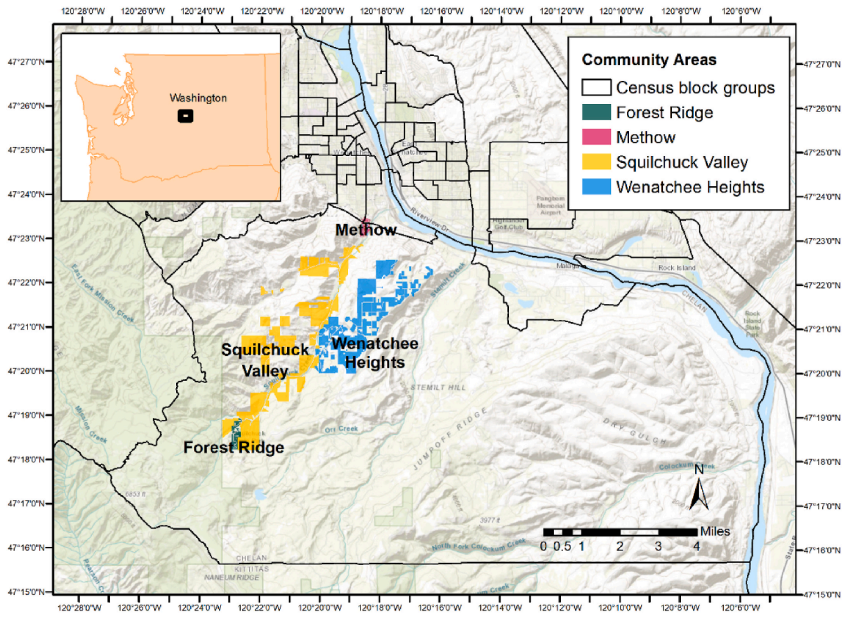

Fig. 1. Map of community areas studied in Squilchuck Drainage, Chelan County, Washington, USA.

As part of a larger research project on cross-boundary wildfire risk transmission (https://www.fs.usda.gov/rmrs/groups/comfrt), the researchers approached CCFD1 about engaging in a co-productive project. Coinciding with the initiation of this project, a voter approved property tax levy provided additional funding for CCFD1 to hire seasonal firefighters to perform home wildfire risk assessments, public outreach, and vegetative fuel reductions. The addition of a fulltime Community Wildfire Liaison position funded by the tax levy was key to CCFD1 expanding their wildfire risk education efforts and engaging in the research-practice project.

The first project decision was location of the study area. CCFD1 and the researchers identified communities along the Squilchuck Drainage, an area within the Squilchuck Valley, because CCFD1 considered the contiguous communities to be socially distinct and each community had similarities to other communities the fire district. Practically, research in this relatively small geographic area would allow CCFD1 to minimize travel time related to the rapid parcel-level wildfire risk assessments, one of the two types of data collections described below. The researchers were interested in examining community heterogeneity within an area subjected to similar wildfire education and outreach efforts. The land along the Squilchuck Drainage is mixed in terms of ownership (public and private) and private parcel size.

CCFD1 parses the Squilchuck Drainage into four communities, Methow, Wenatchee Heights, Squilchuck Valley,[1] and Forest Ridge, that run from the bottom of the drainage to the top, respectively. The elevation of the drainage runs from around 650 feet to over 3500 feet above sea level. Methow is a suburban community characterized by relatively new, densely situated housing. The homes in Wenatchee Heights vary greatly in age and are located on large lots with mixed residential and agricultural uses. Common areas are generally large and unmaintained. Hydrants are sparsely located throughout the area. Squilchuck Valley includes large residential parcels with both agriculture and forest landowners. All through the community, long driveways and limited turnarounds affect emergency response opportunities and some areas have older homes and steep roads with long driveways. The community of Forest Ridge is perched at the top of the drainage. This area is adjacent to and nearly surrounded by the Okanogan-Wenatchee National Forest with limited egress. The surrounding forest is dense. The community has an official homeowner's association, the Forest Ridge Wildfire Coalition, and became a Firewise USA® community (https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Firewise-USA/Become-a-Firewise-USA-site) in 2010.

The only easily accessible social data in the US are collected by the Bureau of Census. The entire study area falls within one US Census block group, the smallest geographic area for which such data are summarized (see Fig. 1), making it impossible to characterize basic demographic differences across communities. More importantly, CCFD1 wanted to understand if and how social aspects of the four communities suggest differing approaches to engagement on wildfire mitigation and preparation across the communities.

3.2. Co-production

In this study, a co-productive approach was implemented to provide social science that directs action (i.e., actionable science) related to engagement of residents in wildfire risk education efforts. There is an ever-growing literature on co-production in many contexts (e.g. Refs. [44–46], including participatory processes to inform wildfire response [47]. Co-production in this context refers to researchers and wildfire practitioners working together as equals to define the research question and approach and to interpret how the results can inform a local wildfire program and the broader wildfire social science literature. Actionable science is science that can be used to directly address real-world problems. As such, actionable science can serve as the basis for policy or programmatic decisions [51]. The participants in this co-productive project included social scientists and wildfire practitioners with a mutual interest in understanding how to encourage private landowners in fire prone communities to mitigate risk and prepare for a wildfire event.

As noted earlier, the team chose a study area comprised of four contiguous fire-prone communities in North Central Washington that fall within the same jurisdictional boundary and census block group. As part of the co-productive process, CCFD1 determined the boundaries of the study area. This is a distinct departure from traditional quantitative social science investigations in which scale is typically determined by researchers who tend to rely on jurisdictional boundaries or levels such as cities, counties, states, or nations when considering data collection. A priori, the local wildfire practitioner recognized that the study area was not one “community” but rather four distinct places which varied by geography, the engagement of residents on the issue of wildfire preparation and mitigation, the size of parcels and type of housing, and the history of the community with respect to residents' tenure. Based on this knowledge and related literature (e.g. Ref. [14]), the researchers expected to see some differences across communities. However, the communities were geographically proximate to each other, and similar wildfire education efforts and outreach had been available across the entire district. Thus, it was unknown if the practitioner's notions of community differences would be confirmed with data and, critically, how these differences might further translate into differences with actionable implications for the practitioner – aspects related to wildfire mitigation and preparedness.

3.3. Data collection

Two sources of data were collected by CCFD1 in the summer of 2018 (see Ref. [48] for a full description of the project and a full summary of the data collected). Chelan County assessor data were used to identify every residential parcel with a structure in the study area. These data were loaded into a geo-referenced data collection tool developed by the researchers. CCFD1 used the tool to conduct the parcel-level rapid wildfire risk assessments. The parcel-level rapid wildfire risk assessment included attributes related to building materials, vegetation near the home, background fuels, and topography, as well as fire department access to the parcel. The geocoded rapid risk assessments serve as an indicator of the relative risk of a private land parcel within a community rather than an absolute measure of risk. When CCFD1 was in the field conducting parcel-risk assessments, they corrected observed mistakes in the

[1] Squilchuck Valley is the name of a community and the name of the greater area described in the Squilchuck Valley Community Wildfire Protection Plan.

assessor data. For example, if the assessor data did not show a structure on a parcel but CCFD1 observed one, that parcel was assessed and added to the data.

The updated Chelan County assessor data served as the mailing list for the household survey, which included measures of homeowners' notions of wildfire risk, risk mitigation behaviors, barriers mitigation and preferred forms of wildfire risk communication. The survey was sent to the 652 parcels with a completed rapid risk assessment. In other words, the surveys were sent as a census of all households in the study area, rather than as a sample of households as is more common with social surveys. CCFD1 administered the household survey following a modified Dillman approach [49]; there were up to four mailings per household: the initial letter describing the study, the first survey packet, a postcard reminder, and a second survey packet. Each returned survey was paired with its parcel-level wildfire risk assessment. In total, 288 surveys were returned and completed household surveys, for a 44% response rate overall (Table 1). For the entire study area and within each of the four communities that comprised the study area, the distributions of the parcel-level overall risk ratings were similar for survey respondents and non-respondents. We speculate that the response rates, from a low in Methow of 31% to a high of 71% in Forest Ridge, are an indicator of the salience of the wildfire topic across the communities (Table 1).

3.4. Data analysis approach

We use the Kruskal-Wallis test to assess whether the survey question responses across the communities come from the same distribution. The Kruskal-Wallis test is a general nonparametric test, applicable to nominal, ordinal, interval, or ratio scale data, that assesses differences in the distribution of response. The advantage of the Kruskal-Wallis test in this study is that we use the same test across the variety of different types of response categories; we note that conclusions are nearly always the same as those derived by related parametric tests when appropriate. We use the test allowing for ties when assessing statistical significance. Because we conduct the Kruskal-Wallis test for many variables, we control for the false discovery rate (i.e., rejecting the null hypothesis when it is true) using the Benjamini-Hochberg procedure. We find all p-values less than 0.05 were significant after the Benjamini-Hochberg adjustment and report the original p-values. When distributional differences were found on a measure, we conduct pairwise comparisons using Dunn's test with a Benjamini-Hochberg adjustment for multiple comparisons as described in Ref. [50].

4. Results

The data analyses are guided by the research question: *How can community differentiation inform wildfire education?* We delve into this question by examining wildfire attitudes and perceptions, wildfire risk mitigation behaviors, and communication preferences. We examine how consideration of the Squilchuck Drainage as the unit of analysis compares to parsing the area into four distinct communities.

4.1. Parcel Size and demographics

The average parcel size for the entire study area is approximately six acres (Table 2). However, average parcel size varies across the communities from less than half acre lots in Methow to over ten acre lots in Squilchuck Valley. Likewise, the overall distributions of age, being retired, number of years in current home, and income mask some important differences across the communities. The pairwise comparisons, designated by superscript letters signifying the communities that differ significantly from the reference community, suggest these differences are not driven by one community being an outlier. Wenatchee Heights and Squilchuck Valley residents have longer tenures compared to Methow and Forest Ridge. Likewise, Squilchuck Valley has significantly more retired residents (51%) compared to Methow (26%). To illustrate the limitations of using census data to characterize the study area, we include comparisons to American Community Survey (ACS) data (https://www.census.gov/programs-surveys/acs/about.html) where possible. We would not expect the survey respondents to look like residents of the census block group as the census block covers a larger geographic area than the study area. Further, the ACS seeks to represent all individuals in the block group while this study seeks to represent households in the study area. The survey respondents are older on average than residents in the census block group, more educated, more likely to have lived in the house for over a year, own their home, and have higher average income. ACS data do not report percent retired or total number of years a resident has lived in their current home.

Table 1
Household survey response rate by community.

	Methow	Wenatchee Heights	Squilchuck Valley	Forest Ridge	Overall
Surveys mailed	165	197	222	68	652
Surveys completed and returned	51	76	113	48	288
Response rate***	31%^{SF}	38%^{SF}	51%^{MF}	71%^{MWS}	44%

***$p \leq 0.001$ for Kruskal-Wallis test of equality of response distributions across communities.
M: $p < 0.05$ for pairwise comparison with **M**ethow (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
W: $p < 0.05$ for pairwise comparison with **W**enatchee Heights (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
S: $p < 0.05$ for pairwise comparison with **S**quilchuck Valley (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
F: $p < 0.05$ for pairwise comparison with **F**orest Ridge (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).

Table 2
Parcel size and demographic variables by community.

	ACS data from Census Block Group	Methow	Wenatchee Heights	Squilchuck Valley	Forest Ridge	Overall
Mean parcel size [acres][a]		0.30	7.50	10.20	1.00	5.91
Median age [years]*	40.50	53.78	59.71	61.92	58.62	59.40
Percent college graduate or higher	26%	54%	58%	54%	66%	57%
Percent retired*		26%^{S}	41%	51%^{M}	44%	43%
Percent lived in same house 1 year or over	88%	99%	100%	100%	97%	99.5%
Average number of years lived in Squilchuck home***		10.28^{WS}	20.10^{MF}	19.83^{MF}	12.23^{SW}	16.94
Percent owner occupied housing	64%	94%	96%	92%	96%	94%
Mean earnings in past 12 months**	$73,347	$86,510	$103,461	$105,325	$148,750	$108,142

*p ≤ 0.05, **p < 0.01, ***p < 0.001 for Kruskal-Wallis test of equality of response distributions across communities.
M: p < 0.05 for pairwise comparison with **M**ethow (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
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S: p < 0.05 for pairwise comparison with **S**quilchuck Valley (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
F: p < 0.05 for pairwise comparison with **F**orest Ridge (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
[a] These data are secondary and we are not able to test the distribution across communities.

4.2. Wildfire attitudes and perceptions

The survey included numerous measures related to risk perceptions and attitudes [48]. Across the four communities, the distributions of responses to nine of the ten attitude statements were similar (see Appendix A). The exception was the statement "My property is at risk of wildfire" (Table 3). All the properties in the study were considered at risk of wildfire by CCFD1. Overall, 53% of the respondents in the study area thought their properties were at risk. Notably more residents in Forest Ridge (71%) agreed their properties were at risk of wildfire compared to Methow (30%). Looking more closely at wildfire risk perceptions, survey respondents were asked about the chances of a wildfire on their properties and the chances of their homes being destroyed or severely damaged conditional on a fire on their properties. Residents of the different communities generally think there is a low chance of a fire on their property this year (Table 3). However, that varies across the communities with Methow residents on average perceiving a lower chance of wildfire on their properties compared to Squilchuck Valley and Forest Ridge residents. Further, most survey respondents across all the communities thought there was less than a 50% chance that their home would be destroyed or damaged if there was a fire on their property. Consistent across all the communities, most residents think local firefighters have sufficient resources to keep the fire from spreading. A strong majority think local firefighters have enough resources to protect threatened home, a result that varies across the communities (Table 3).

4.3. Risk mitigation behaviors and barriers

Local education efforts seek to align resident expectations with the perspectives of wildfire professionals. Adopting the lens of CCFD1 when considering parcel-level wildfire risk, we see that looking at overall parcel-level wildfire risk ratings for the Squilchuck Drainage as a whole cover important differences across the communities (Table 4). Not only are the distributions of overall parcel-level wildfire risk ratings different across the four communities, pairwise-comparisons suggest the communities differ from each other. The most notable pairwise comparison is between Methow and Forest Ridge. Compared to Forest Ridge with 70% of the parcels rated high, very high, or extreme, 37% of the properties in Methow are rated high, very high, or extreme. This result is highly relevant to CCFD1 as the distribution of wildfire risk across communities is often used to prioritize how and/or where scarce wildfire program-

Table 3
Wildfire risk perceptions by community.

	Methow	Wenatchee Heights	Squilchuck Valley	Forest Ridge	Overall
Percent who agree or strongly agree that property is at risk of wildfire***	30% ^{SF}	46%	63% ^{M}	71% ^{M}	53%
Percent who think greater than 50% chance that a wildfire will be on property this year***	2%^{SFW}	8% ^{M}	8% ^{M}	9% ^{M}	7%
Percent who think greater than 50% chance home will be destroyed or severely damaged if there is a fire on the property this year***	35%	22%	20%	37%	26%
Percent who think local firefighters will have sufficient resources to keep the wildfire from spreading	71%	56%	51%	58%	57%
Percent who think local firefighters will have sufficient resources to protect threatened homes*	88%	66%	70%	70%	72%

*p ≤ 0.05, **p < 0.01, ***p < 0.001.for Kruskal-Wallis test of equality of response distributions across communities.
M: p < 0.05 for pairwise comparison with **M**ethow (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
W: p < 0.05 for pairwise comparison with **W**enatchee Heights (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
S: p < 0.05 for pairwise comparison with **S**quilchuck Valley (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
F: p < 0.05 for pairwise comparison with **F**orest Ridge (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).

Table 4
Distribution of overall parcel-level wildfire risk rating and select attributes by community.

	Methow (n = 165)	Wenatchee Heights (n = 197)	Squilchuck Valley (n = 222)	Forest Ridge (n = 68)	Overall (n = 652)
*Overall parcel-level wildfire risk rating:****[a]					
Low	10%	6%	1%	0%	4%
Moderate	53%	24%	14%	1%	26%
High	21%	27%	30%	24%	26%
Very High	16%	38%	46%	49%	36%
Extreme	0%	5%	9%	26%	8%
Defensible space attributes:					
Percent with vegetation near home that is heavy or severe (vs light or moderate)***	23%^{WSF}	52%^{M}	57%^{MF}	43%^{MS}	46%
Percent with combustibles within 30 feet of home	68%	80%	78%	81%	77%
Structure ignitibility attributes					
Percent with combustible siding***	97%^{WSF}	87%^{MF}	87%^{MF}	75%^{MWS}	88%
Percent with combustible roof***	0.61%^{WSF}	6%^{MF}	6%^{MF}	25%^{MWS}	70%

$p \leq 0.05$, **$p < 0.01$, ***$p < 0.001$.for Kruskal-Wallis test of equality of response distributions across communities.
M: $p < 0.05$ for pairwise comparison with **M**ethow (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
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F: $p < 0.05$ for pairwise comparison with **F**orest Ridge (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
[a] : $p < 0.05$ for all combinations of pairwise community comparisons (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).

matic efforts should focus. Examining key attributes that affect the overall parcel-level wildfire risk rating provides additional insights (Table 4). Compared to the other three communities, Methow has the fewest parcels with dense vegetation or other combustibles near the home. This translates to more defensible space in Methow, a critical component to reducing home ignition potential. In Forest Ridge, twenty-five percent of the homes have a combustible roof, the attribute that is most heavily weighted in the overall parcel-wildfire risk rating due to its strong contribution to home ignition potential.

The survey asked what residents were doing to prepare for a wildfire event and mitigate risk (Table 5). Preparation includes planning in advance for evacuation and signing up for reverse 911 that notifies residents of the status and proximity of a wildfire, as well as imminent and actual evacuations during a wildfire event. Overall, 76% of the residents in the study area said they have an evacuation plan and differences across communities appear to be minor. However, the overall sign-up rate for reverse 911 in only 7%. Even the high of a 19% signup rate in Forest Ridge is considered a low signup rate by CCFD1. Looking across the two preparation measures, residents of Methow are the least prepared and Forest Ridge Residents are the most prepared.

Community programs also encourage residents to reduce wildfire risk through mitigation actions on their parcel. The overall results for the study area obscure the fact that Forest Ridge residents report being more active mitigators than the other communities. For example, 98% of Forest Ridge residents reported reducing vegetation on their property and 70% reported that making their home more fire-resistant. One shortcoming of the mitigation measures in Table 5 is that we do not know about parcel or home conditions when the respondents moved into the home. Nor do we know how many community meetings were offered to the differing communities. As Forest Ridge has a HOA and is a designated Firewise USA® Community, residents might have had more wildfire activity opportunities compared to the other communities.

There are many barriers to mitigation and programs seek to reduce these barriers and incentivize residents to properly mitigate wildfire risk on their properties. Table 6 describes the percent of respondents indicating barriers to wildfire risk reduction on their properties. Looking at the overall results, physical difficulty doing the work is the top barrier for the study area, a result that holds for Wenatchee Heights and Squilchuck Valley. However, it varies across the communities. In Squilchuck Valley, 53% of the residents reported physical difficulty as a barrier. Among the barriers reported by Forest Ridge residents, financial expense and physical difficulty

Table 5
Preparation and mitigation by community.

	Methow	Wenatchee Heights	Squilchuck Valley	Forest Ridge	Overall
Preparation:					
Percent with an evacuation plan*	63%	73%	81%	88%	76%
Percent signed up for reverse 911**	2%	7%	4%	19%	7%
Mitigation:					
Percent reduced vegetation on property**	76%	93%	88%	98%	89%
Percent made home more fire resistant**	35%	63%	57%	70%	57%
Percent participated in a community wildfire activity***	16%	19%	28%	75%	32%

$p \leq 0.05$, **$p < 0.01$, ***$p < 0.001$.for Kruskal-Wallis test of equality of response distributions across communities.
M: $p < 0.05$ for pairwise comparison with **M**ethow (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
W: $p < 0.05$ for pairwise comparison with **W**enatchee Heights (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
S: $p < 0.05$ for pairwise comparison with **S**quilchuck Valley (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
F: $p < 0.05$ for pairwise comparison with **F**orest Ridge (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).

Table 6
Barriers and incentives by community.

	Methow	Wenatchee Heights	Squilchuck Valley	Forest Ridge	Overall
Percent reporting the following items prevent wildfire risk reduction on their property					
Physical difficulty doing the work*	31%	37%	53%	36%	42%
Financial Expense	27%	29%	43%	37%	35%
Time	29%	35%	42%	21%	35%
Lack of specific information on how to reduce wildfire risk**	39%	28%	24%	8%	25%
Lack of information about or options for removal of materials from thinning trees and other vegetation	22%	26%	28%	9%	23%
Do not want to change the way my property looks*	29%	18%	13%	6%	16%
Lack of effectiveness of risk reduction actions	13%	13%	13%	2%	11%
Percent reporting the following items would encourage wildfire risk reduction on their property.					
Specific information about what needs to be done on my property	73%	73%	72%	74%	72%
Help doing the work**	52%	57%	72%	78%	66%
Financial assistance*	49%	51%	64%	76%	60%
A list of recommended contractors	38%	38%	44%	44%	41%

*p ≤ 0.05, **p < 0.01, ***p < 0.001.for Kruskal-Wallis test of equality of response distributions across communities.

were the biggest barriers. Interestingly, less than 10% of the Forest Ridge residents reported that the other four barriers were keeping them from taking action to reduce wildfire risk on their properties. The physical difficulty of the work was the largest barrier for Squilchuck residents while lack of specific information was the largest barrier for Methow residents. Residents were also asked whether four programmatic tools would encourage them to reduce risk on their properties. Overall and for Methow, Wenatachee Heights, and Squilchuck Valley specific information about what needs to be done is the top item that would encourage residents to reduce wildfire risk. Over 70% of the Squilchuck Valley and Forest Ridge residents said that help doing the work would incentivize them to take action to reduce wildfire risk. Considering barriers and incentives together gives rise to some seemingly contradictory results such as only 8% of Forest Ridge residents reporting lack of specific information about how to reduce wildfire risk being a barrier and 74% saying specific information about what needs to be done on their properties would encourage them to reduce risk. Indeed, we see this pattern across all the communities.

4.4. Wildfire communication preferences

Residents receive wildfire information from many sources. Among the many active distributors of wildfire risk information in the area, the three top sources are CCFD1, media, and neighbors, friends, and family (Table 7). This result holds when considering the overall results or the communities of Methow, Wenatchee Heights, or Squilchuck Valley. In Forest Ridge, a designated Firewise USA® community, Firewise USA® is the third most reported wildfire information source. Cascadia Conservation District, Washington State Department of Natural Resources, and Firewise USA®, the sources mentioned in addition to CCFD1 in the Squilchuck Valley Commu-

Table 7
Communication variables by community.

	Methow	Wenatchee Heights	Squilchuck Valley	Forest Ridge	Overall
Percent received wildfire information from:					
Chelan County Fire District 1*	72%	74%	78%	96%	79%
Media (newspaper, TV, radio, internet)	83%	74%	79%	77%	78%
Neighbors, friends, or family***	53%	44%	58%	91%	59%
Cascadia Conservation District***	26%[F]	30%[F]	45%	69%	42%
Firewise USA***	20%[F]	17%[F]	28%[F]	85%	33%
Washington State Department of Natural Resources	13%	20%	25%	37%	24%
Percent who thought wildfire information from source is extremely or very useful (contingent on receiving information from the source):					
Chelan County Fire District 1*	53%	48%	67%	76%	62%
Firewise USA	33%	50%	62%	72%	62%
Cascadia Conservation District	33%	14%	42%	48%	38%
Neighbors, friends, or family***	24%	22%	33%	65%	38%
Media (newspaper, TV, radio, internet)	20%	30%[F]	28%	35%[W]	28%
Washington State Department of Natural Resources	17%	14%	26%	41%	26%
Percent who prefer Chelan County Fire District 1 communication mode:					
Newsletter (mailer)	65%	67%	69%	58%	66%
Email**	35%	28%	42%	62%	40%
Community meeting	27%	17%	23%	29%	23%
In-person interactions	16%	17%	28%	30%	23%
Social media (Facebook, Twitter)	20%	12%	13%	9%	13%

*p ≤ 0.05, **p < 0.01, ***p < 0.001.for Kruskal-Wallis test of equality of response distributions across communities.
F: p < 0.05 for pairwise comparison with **F**orest Ridge (Dunn's Pairwise with Benjamini-Hochberg correction).

nity Wildfire Protection Plan, were not used by very many residents in Methow, Wenatchee Valley, and Squilchuck Valley. Overall and across all the communities, CCFD1 and Firewise USA® were rated as providing the most useful wildfire information. The notable difference between these two information sources is that many of the community residents had received information from CCFD1 but very few from Firewise USA®. By contrast a consistent pattern is seen overall and across the communities of many residents receiving wildfire risk information from media and few considering that information to be very useful. Residents were also asked their preferred mode by which to receive wildfire risk information from CCFD1. Overall and across the study communities, newsletter and email were the top preferred communication modes. While 62% of the Forest Ridge residents preferred getting information via email, only 28% in Wenatchee Heights preferred email. Social media was the least preferred communication mode for all the communities.

5. Discussion

The results of this study suggest some differences and some commonalities across the social and biophysical characteristics of the study communities. In other words, there is nuanced complexity within the Squilchuck Drainage. While demographic differences across the communities were observed, it is not clear how wildfire programs can shape their efforts based on such data in isolation. In general, the results illustrated the value of pairing of social and biophysical data collected at the parcel level. If CCFD1 relied on survey data without the paired parcel risk data, they would not likely prioritize Forest Ridge as a community in need of programmatic support because the residents reported high levels of wildfire risk mitigation, participation in community wildfire activities, and evacuation planning. However, almost all the parcels in Forest Ridge were assessed by CCFD1 as having a high, very high, or extreme risk rating suggesting CCFD1 may want to prioritize engagement in Forest Ridge. We speculate that Forest Ridge residents may know the guidelines for parcel mitigation but need professional help figuring out how to properly implement those guidelines. CCFD1 may want to frame the topic as one of "proper" implementation of guidelines as almost all Forest Ridge residents reported reducing vegetation on their properties and making their homes more fire resistant. Although Forest Ridge residents had the highest income on average, financial assistance might be effective as financial expense was the most reported barrier to taking action to reduce wildfire risk on their properties.

The community scale social and biophysical data also demonstrated Methow as having distinct social biophysical and social characteristics. Methow was the community with the lowest overall parcel-level wildfire risk ratings and the least prepared for evacuation. Like the other communities, most Methow residents said specific information about what needs to be done on their properties would encourage them to reduce wildfire risk. Because providing mitigation information specific to a property is resource intensive as it involves an onsite visit and follow-up engagement, CCFD1 may consider focusing on onsite visits to the higher risk communities. However, they could start a newsletter to educate Methow residents about wildfire risk in general and the need to develop an evacuation plan that includes signing up for reverse 911 because fire department resources will quickly be constrained during a wildfire event.

The co-productive process of identifying communities lead to expectations of distinctness across all four communities. However, the communities of Wenatchee Heights and Squilchuck Valley were not found to be particularly distinct from each other. While the overall parcel-level wildfire risk rating differed across the two communities, the social measures were largely similar in Wenatchee Heights and Squilchuck Valley. This important result suggests that CCFD1 could consider these two communities as one with respect to developing approaches to wildfire education.

The results illustrated the general value of including survey measures that can guide solutions based on understandings of the problem. The battery of attitude questions (Appendix A), developed based on common anecdotes in the wildfire practitioner community, did not differ across the communities and were not particularly enlightening with respect to driving action. The data did not fully support the recommendation from the Squilchuck Valley Community Wildfire Protection Plan to focus on the messaging by Firewise USA® communities by holding workshops and relying on local media as a conduit of that information. Study results showed that across the study area, workshops may not be successful considering the small percent of respondents that indicated community meetings were a preferred mode of communication. In addition, media (newspaper, TV, radio, internet) were not considered a useful wildfire information source. The importance of community level differences comes to bear on the topic of wildfire information sources. Firewise USA® communities' wildfire information appears to be useful in the designated Firewise USA® community (i.e., Forest Ridge) but is not reaching or considered useful in the other communities. These data can also support programs making difficult decisions about how and where to allocate their scarce resources. Should communities with higher wildfire risk such as Forest Ridge be prioritized? Should communities with lower income such as Methow be prioritized? These decisions are complex and community level data can support better understandings about the nature of these tradeoffs.

6. Conclusion

Devastation of communities due to wildfires is an important issue. Wildfire practitioners often know, based on their personal experience and knowledge of an area, that education efforts should be differentiated across the communities they serve. However, those tasked with getting in front of the problem by promoting mitigation and preparation, rarely have the data they need to move beyond a one-size-fits-all approach. Social science research can play in important role in addressing urgent social problems, such as wildfire-related community destruction, if the results are actionable.

This research was framed by the recognition that wildfire caused home ignitions are a substantial problem in the US. The National Cohesive Wildland Fire Management Strategy [12] is explicit that a one-size-fits-all approach to creating fire adapted communities is not appropriate, however, guidance to local wildfire education programs is often directed at a large geographic area and of the general nature provided in the Squilchuck Valley Community Wildfire Protection Plan (i.e., hold workshops, encourage use of Firewise

USA® website, employ media). The co-productive process used in this study privileged the wildfire practitioner's notion of community distinctness. We illustrated how failure to recognize the Squilchuck Drainage as being comprised of distinct communities would have camouflaged a path to move away from a one-size-fits-all approach. However, there was nuance to that result as two of the communities were not found to be particularly different in actionable ways. We demonstrated how wildfire social science research can be actionable if the data include measures that characterize the problem and solutions and are analyzed at the same scale at which wildfire programs are administered. We do not know if the results from this study would extrapolate to other Chelan County WUI communities thought to be similar socially to Methow, Wenatchee Heights, Squilchuck Valley, and Forest Ridge. Such an investigation could be the next contribution to understandings about wildfire related social heterogeneity across communities. Further, while this study was US centric, the illustration of how wildfire social data – collected at appropriate scales – can support local wildfire education programs to tailor efforts likely transcends international differences in wildfire policy and culture. In addition, the co-productive approach and research methods can inform efforts to conduct actionable social science in other contexts.

Declaration of competing interest

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.

Data availability

The authors do not have permission to share data.

Appendix A. Wildfire attitudes

Mean Response to Wildfire Attitude Statements by Community. Response on a 5 point scale: 1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree.

	Methow	Wenatchee Heights	Squilchuck Valley	Forest Ridge	Overall
With proper technology, we can control most wildfires.	3.17	3.08	2.92	2.96	3.01
We should put out wildfires that threaten human life.	4.56	4.52	4.44	4.58	4.50
We should put out wildfires that threaten property.	4.12	4.13	3.95	4.13	4.052
During a wildfire, saving homes should be a priority over saving forests.	3.74	3.98	3.97	4.02	3.94
Wildfires are a natural part of the balance of a healthy forest/ecosystem.	4.22	4.00	4.13	4.24	4.13
I live here for the trees and will not remove any of them to reduce wildfire risk.	1.92	2.04	1.97	1.75	1.94
Managing the wildfire danger is a government responsibility, not mine.	2.04	2.08	1.86	1.87	1.95
Homeowners' actions to reduce wildfire are not effective.	1.78	1.94	1.82	1.82	1.85
My property is at risk of wildfire.***	2.92^{SF}	3.24	3.63^{M}	3.76^{M}	3.42
My effort to reduce wildfire risk on my property is ineffective because of the heavy vegetation on my neighbors' properties.	2.30	2.53	2.71	2.67	2.58

***$p \leq 0.001$ for Kruskal-Wallis test of equality of response distributions across communities.
M: $p < 0.05$ for pairwise comparison with **M**ethow (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
S: $p < 0.05$ for pairwise comparison with **S**quilchuck Valley (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).
F: $p < 0.05$ for pairwise comparison with **F**orest Ridge (Dunn's Pairwise Comparison with Benjamini-Hochberg correction).

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