Demographic Analysis of Transboundary Wildfire Exposure in the Western U.S.

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INTRODUCTION

Wildfire risk mitigation research has focused on either its biophysical or social components, with few studies attempting to integrate both. Studies that have coupled social and biophysical systems have not considered the source of fire risk (Cutter et al. 2003; Davies et al. 2018; Oliveira et al. 2017; Parisien et al. 2016; Rappold et al. 2017; Wigtil et al. 2016), or were applied at limited geographic scale (Fischer et al. 2014; Olsen et al. 2017) leaving a gap in our knowledge about how and where biophysical fire risk is transmitted and affects populations. Vulnerable populations, in terms of economic abilities, social structure and evacuation capabilities have lower capacity to protect their property, with limited access to public and private recovery assets (Peacock and Ragsdale 1997). Identification of these populations is critical for allocating official aid to minimize the loss of lives and property to wildfire.

In this study we examined social vulnerability to large wildfires using a transboundary exposure framework that accounts for the transmission of exposure from public to private lands and communities. Understanding the spatial linkage between an ignition and subsequent wildfire spread to communities allows social vulnerability to be related to the source of exposure, rather than the in-situ hazards. We examined two hypotheses:

H1: Populated places with high social vulnerability received disproportionately more fire and exposure from national forest.

H2: There are zones inside national forests that affected multiple high vulnerability populated places, creating disproportionate exposure compared to their size.

METHODS

This study was applied on three sites (Wenatchee, Washington; Central Sierra, California; Santa Fe, New Mexico) that included large areas of national forest land managed by the U.S. Forest Service (FS), with estimated high fire transmission and exposure to neighboring communities. Using social variables from the American Community Survey (ACS) at the scale of census block groups (hereafter referred to as "blocks"), a composite index of social vulnerability was estimated and related to biophysical fire transmission and exposure data. This coupling enabled us to understand which land tenures expose communities of high social vulnerability, and whether specific social indicators receive a disproportionate

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amount of exposure (hypothesis 1). For hypothesis 2, simulated ignitions were clustered to form high structure exposure zones inside national forests, where fuel treatments can be more effective in protecting multiple communities.

To estimate fire exposure, we used probabilistic wildfire risk components simulated with FSim (Short et al. 2016). Simulated perimeters were used to quantify the area burned on each land tenure and the structures affected within each community (Ager et al. 2014; 2018). Community polygons were intersected with the FSim fire perimeter layer. Intersections provided the parts of each perimeter that extend beyond the boundaries of each community or block, with the sum of those intersected parts characterized as either incoming (ignited on another land tenure) or non-transmitted (ignited and burned inside the same land tenure).

By using all simulated ignitions causing structure exposure, we applied a kernel density interpolation to get the ignition density and create community exposure clusters (hereafter referred to as "clusters"). These clusters produce at least 80 percent of all structure exposure generated from national forests within each study area. After identifying the exposed communities from national forest clusters, we identified all other ignitions that affected these communities but ignited on other land tenures. All blocks intersecting these ignitions were used to define each study area.

The ACS 5-year estimates for the period 2011-2015 were used to select variables that were linked with socially vulnerable populations (Cutter et al. 2003; Flanagan et al. 2011; Wigtil et al. 2016; Wright et al. 2012). We formed six broad groups that describe a similar social vulnerability aspect: households and population, socioeconomic status, household composition and disability, minority status and language, housing and transportation and occupation. For each block group, we estimated the percentages of each variable based on different population or household metrics.

The Social Vulnerability Index (Cutter et al. 2003) is an inductive approach to reduce a large set of social variables into a smaller set of uncorrelated latent factors using principal components analysis (PCA), aggregated to build the index (Tate 2012). All variables were estimated at the scale of blocks. The social vulnerability index (SOVI) was constructed with all variables for the entire dataset of each state. Each block's score was categorized into low (values < -0.5), moderate (-0.5 to 0.5) and high (>0.5) social vulnerability. Community social vulnerability was estimated by their areal percentage on each SOVI class: communities with >25 percent area in high SOVI class characterized as high; >40 percent area in moderate SOVI class and not high, as moderate; all the rest as low.

RESULTS

Most blocks in Wenatchee were of low SOVI, with only 3 percent in high and 25 percent in moderate SOVI classes (fig. 1). Central Sierra had less moderate (15%) but similar percentage of high SOVI blocks. About 76 percent of Santa Fe blocks had moderate SOVI values, followed by high (13%) and low SOVI values (11%). Regarding communities in Wenatchee, 33 were classified with low, 24 with moderate, and seven with high social vulnerability. Most communities in Santa Fe had moderate (n=53), followed by high (n=40) and low (n=15) social vulnerability. Lastly, in Central Sierra 79 communities had low, 26 moderate and 20 high social vulnerability.

Cluster Transmission and Exposure

The Central Sierra cluster covered 8.5 percent of the study area (fig. 1) and caused 13 percent of the total (all-lands) estimated structure exposure to blocks, affecting mostly low (72%) and moderate (28%) SOVI blocks. The Wenatchee cluster also covered 8.5 percent of the study area but caused 41 percent of all structure exposure to blocks, affecting low (49.3%) and moderate (50.7%) SOVI blocks. The Santa Fe cluster covered 10 percent of the study area and caused 22 percent of all structure exposure to blocks, affecting low (26%), moderate (58.5%) and high (15%) SOVI blocks.

Community Structure Exposure and Fire Received

In Wenatchee, 61 percent of the community area was exposed to fire. When we compared the percentage

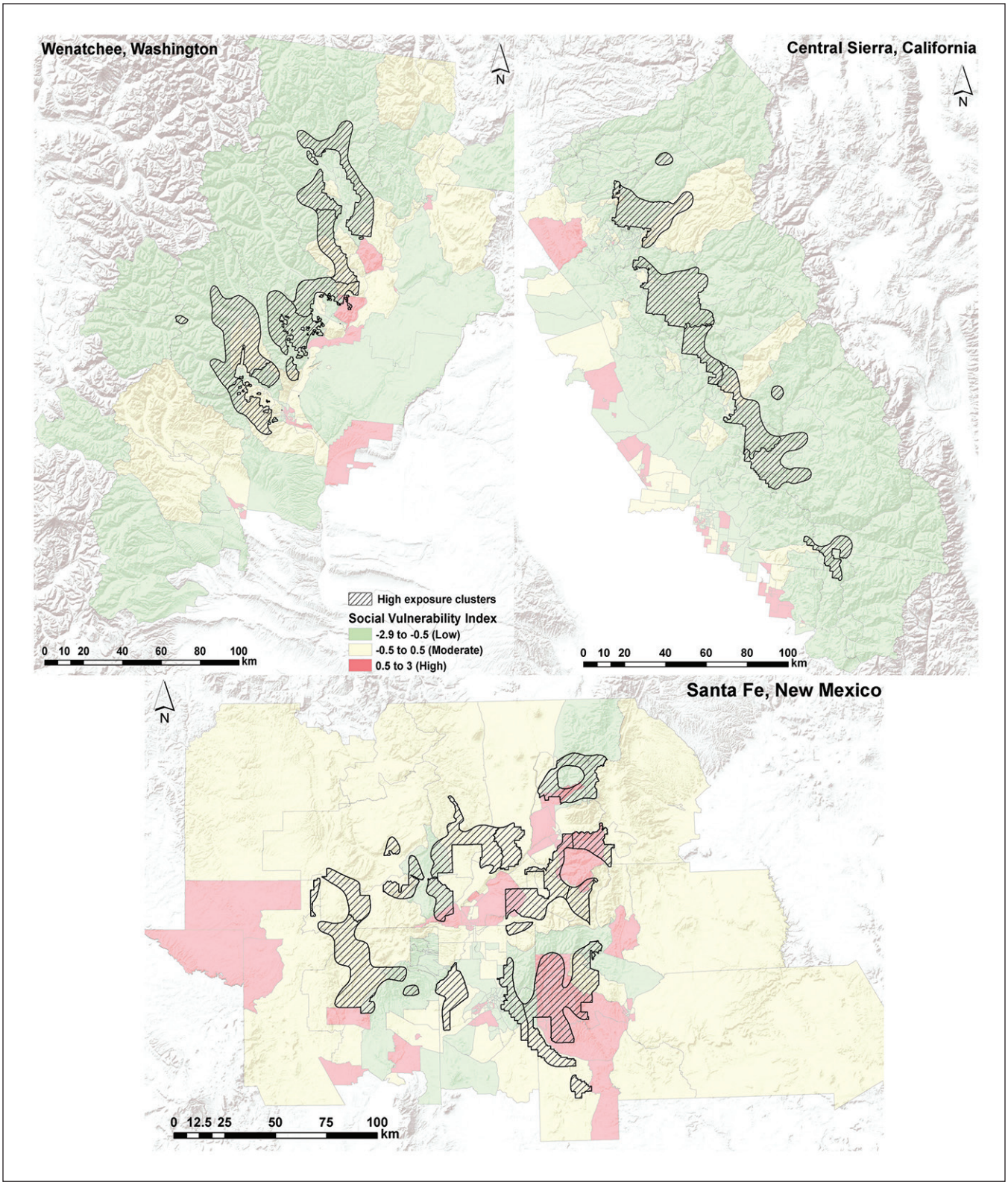

Figure 1—Classification of the social vulnerability index values for the Block Groups of the three study areas. Ignition clusters are shown as dashed polygons.

of exposure that each SOVI class received to its percentage area cover, high SOVI block exposure was disproportionately higher by 0.5 times (4.4% of total exposure vs. 2.9% cover); moderate SOVI block exposure was 1.1 times more (53.8% exposure vs. 24.9% cover); and low SOVI block exposure was 0.4 times less (41.8% exposure vs. 72.2% cover). There was a balance between structure exposure and the proportion of national forest area in Wenatchee (41.7% of all exposure vs. 47.5% cover), like private lands (19% exposure vs. 21.5% cover) and State lands (10% exposure vs. 13% cover). Communities comprise 8.7 percent of the Wenatchee study area but created 27 percent of exposure; on the contrary, tribal lands comprise 4.7 percent but created only 0.9 percent of exposure. The major structure exposure contributor in high SOVI communities were communities (46%) (non-transmitted fire), private lands (21%), and FS managed lands (17%) (fig. 2).

For Santa Fe, 74 percent of community area was exposed. High SOVI block exposure was disproportionately higher compared to its percentage area cover by 0.5 times (19.3% exposure vs. 13% cover), moderate SOVI block exposure was 0.3 times less (54.9% exposure vs. 75.8% cover), and low SOVI block exposure was 1.3 times more (25.8% exposure vs. 11% cover). Forest Service managed lands exposure was proportionate to their area (24.7% exposure vs. 23% cover in Santa Fe), similar to tribal lands (12.5% exposure vs. 12.7% cover). Disproportionately, private, Bureau of Land Management (BLM), and State lands cover 41.5 percent, 11.5 percent and 4.5 percent of the Santa Fe study area respectively, but caused only 15 percent, 6 percent and 2.5 percent of exposure respectively. Communities comprised only 6.4 percent of the Santa Fe study area but caused the 37.5 percent of all structure exposure. For high SOVI communities, exposure originated mostly from communities (35.9%), FS (18%) and private lands (15.5%) (fig. 2).

Lastly, 61.5 percent of the community area in Central Sierra was exposed. High SOVI block exposure was disproportionately higher compared to their percentage area cover by 0.25 times (4.7% exposure vs. 3.8% cover), moderate SOVI block exposure was 1.2 times higher (33% exposure vs. 15% cover), and low SOVI block exposure was 0.2 times less (62.4% exposure vs. 81.3% cover). Forest Service managed lands created

Figure 2—Fire received (left panels) and structure exposure (right panels) by land tenure for the high social vulnerability communities of the three study areas. FS: Forest Service (M: manageable; P: Protected); BLM: Bureau of Land Management.

disproportionately lower structure exposure compared to their area (13% exposure vs. 41% cover in Central Sierra), while private and BLM lands were more balanced (27% and 3.1% exposure vs. 25.6 percent and 3 percent of cover in Central Sierra respectively). National Park Service (NPS) lands (18% of Central Sierra) created less than 1 percent of exposure; on the contrary, communities (16.2% of Central Sierra) created 55 percent of exposure. The major structure exposure contributors in high SOVI communities were communities (53%) and private lands (45%) (fig. 2).

DISCUSSION

One of the main findings of this study was that exposure clusters on national forests, compared to their percentage area within each study site, affected disproportionally more communities and blocks, but only in Santa Fe did exposure affect some highly vulnerable communities. Forest Service managed lands had a strong fire and exposure contribution to the total problem but affected the highest vulnerability blocks proportionate to their area. The bulk of structure exposure originated from communities and private lands.

More than half of the total fire problem for all study areas originated from communities and private lands. Most community lands were private and created disproportionate exposure compared to their areal percentage. This finding can alter the perception of who is responsible for taking mitigation actions (e.g., the landowner vs. a local, State or Federal agency). It also suggests that homeowners and communities should initiate collaborations with adjacent land and homeowners and take actions towards reducing fire risk within their firesheds, an approach aligned with the recently announced shared stewardship initiatives of the U.S. Forest Service (USDA Forest Service 2018). Furthermore, our results showed that even though the FS is the major land owner in Central Sierra and Wenatchee, and the second largest in Santa Fe, it created proportionate exposure to its areal percentage. There was no evidence that the Forest Service contributes more exposure compared other land tenures to high vulnerability communities, while for Central Sierra it did not expose any high vulnerability communities. These findings reject hypothesis #1 and suggest that the problem was distributed among three key land tenures (Communities, Private, Federal/FS), supporting the need for further collaboration.

Ignitions on national forests, or on any other large landowner, can expose several communities to the same fire and there are large spatial clusters (sources) that can affect multiple communities (sinks). Most of the area within the Wenatchee clusters was close or inside moderate social vulnerability blocks, receiving half of cluster exposure. Since ignition clusters are managed by the Forest Service, implementation of additional fuel treatments (7% of cluster area was treated during 2009-2017) can reduce the amount of transmitted fire and exposure that moderate vulnerability blocks received. On the contrary, Central Sierra clusters were mostly close or inside low vulnerability blocks (receiving three quarters of cluster exposure), with high vulnerability blocks being far west of them (8.5% of these clusters has been treated during 2009-2017). Santa Fe clusters are mostly inside moderate vulnerability blocks, receiving half of the exposure that clusters caused. Since a forth of total exposure and transmission came from clusters, this suggests potential opportunities for greater federal investments there (2% already been treated during 2009-2017). Although clusters caused disproportionately more exposure compared to their size, we reject hypothesis #2 since they had a minor effect on high social vulnerability communities.

CONCLUSION

Without estimating and interpreting cross-boundary wildfire transmission it is difficult to implement "all lands" risk management policies (USDA Forest Service 2014) and the planning areas around communities will likely be substantial lower than it takes to reduce their exposure (Ager et al. 2015). This study provided new methods for prioritizing community wildfire protection investments with a coupled social-biophysical approach, targeting at reducing suppression costs, protect vulnerable populations, and leverage fuel management and firewise activities investments in underserved communities.

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