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Wildfire Risk Governance from the bottom up: linking local planning processes in fragmented landscapes

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Research

Wildfire risk governance from the bottom up: linking local planning processes in fragmented landscapes

Matthew Hamilton[1,2], *Max Nielsen-Pincus*[3] *and Cody R. Evers*[3]

ABSTRACT. The growing scale of natural hazards highlights the need for models of governance capable of addressing risk across administrative boundaries. However, risk governance systems are often fragmented, decentralized, and sustained by informal linkages among local-level risk mitigation planning processes. Improving resilience to the effects of environmental change requires a better understanding of factors that contribute to these linkages. Using data on the patterns of participation of 10,199 individual stakeholders in 837 community wildfire protection plans (CWPPs) within the western U.S., we document the emergence of a locally clustered but spatially extensive wildfire risk governance network. Our evaluation of factors that contribute to connectivity within this network indicates that risk interdependence (e.g., joint exposure to the same fires) between planning jurisdictions increases the prospects for linkages between planning processes, and that connectivity is also more likely among planning processes that are more proximate and similar to one another. We discuss how our results advance understanding of how changing hazard conditions prompt risk mitigation policy networks to reorganize, which in turn affects risk outcomes at multiple spatial scales.

Key Words: *community wildfire protection plans; polycentricity; risk governance networks; wildfire risk*

INTRODUCTION

The effects of environmental change bear out most directly at local levels, which stands in contrast to the large spatial scales of hazard conditions themselves. For example, while wildfire risk—the empirical focus of this paper—directly affects homeowners and communities, individual fires may burn tens of thousands of hectares and decisions about the allocation of resources to respond to a large-scale fire in one region have implications for fire management in other regions (Petrovic et al. 2012, Ager et al. 2016). The interplay between the multiple scales of risk and risk response presents a core challenge for environmental planners, especially in decentralized and fragmented risk mitigation planning governance systems. Such conditions both increase the need for connectivity among planning processes, e.g., to ensure complementary mitigation approaches across jurisdictions, but also limit the sorts of interactions among planning processes that enable such linkages (Wardropper et al. 2015, Gilissen et al. 2016).

In this paper we make distinct contributions to scholarship on multilevel governance and risk mitigation. First, we advance a perspective that even highly decentralized local-level risk governance processes can exhibit extensive connectivity, despite the absence of formal institutional structures that mandate or encourage interactions. Second, we evaluate the question of how geographically extensive risk mitigation networks can self-organize in fragmented institutional settings. We conceptualize self-organization as the accumulation of connectivity among semi-autonomous governance processes, and our analysis examines how attributes of actors and of planning processes affect the likelihood of connectivity across risk mitigation planning jurisdictions. Prior research in diverse environmental governance settings has demonstrated that patterns of interactions in collaborative processes reveal collective action, via information exchange, cooperation, and collaboration (Scott and Thomas 2015, Fischer and Sciarini 2016, Malkamäki et al. 2021).

In the context of environmental risk governance, a large body of research documents the importance of working across boundaries, which can provide a mechanism for addressing risk interdependence among neighboring jurisdictions (Ferranto et al. 2013, Fischer and Jasny 2017, Cyphers and Schultz 2019). Likewise, linkages among even distant (i.e., non-adjacent) jurisdictions exposed to common or similar risks offer opportunities to exchange hazard-specific information or disseminate resources more efficiently (Ansell et al. 2010, Steelman et al. 2014, Hamilton et al. 2019). We extend this field of research by exploring the degree to which stakeholder participation in local planning processes may gestate spatially extensive goal-directed networks. Such goal-directed networks are composed of autonomous actors who participate in joint efforts based on a common purpose (Provan and Kenis 2008), yet require some degree of governance to coordinate their joint efforts across the network as a whole (Carboni et al. 2019, Nowell and Milward 2022).

Our empirical context is wildfire risk governance in the western U.S. Like other dry, temperate regions globally, the western U.S. has experienced a pronounced increase in wildfire risk over the past several decades, owing to a persistent long-term fire deficit, longer and drier fire seasons, and rapid population growth and development in fire-prone landscapes (Abatzoglou and Kolden 2013, Parks et al. 2015, Radeloff et al. 2018). Because of increases in the size, frequency, and intensity of wildfires in recent years, annual wildfire suppression costs in the U.S. have exceeded $3 billion (NIFC 2022), much of which has been allocated to fire response in western states. Correspondingly, this region has transformed into a living laboratory of new models of risk governance that aim to address risk at multiple spatial scales (Abrams et al. 2015). At the same time, wildfire risk mitigation is conducted in an inherently fragmented and decentralized governance system, characterized by numerous and overlapping decision-making processes (Kelly et al. 2019).

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We examine cross-jurisdiction interaction using data on stakeholder participation in community wildfire protection plans (CWPPs). As we describe in more detail below, the CWPP model was introduced in the early 2000s with the goal of engaging community members and other local stakeholders in collaborative wildfire risk mitigation. Thousands of individuals have participated in the development of hundreds of plans within the western U.S. (Palsa et al. 2022). Nearly all planning documents include the names and affiliations of individuals who contributed to plan development, which enables detailed analysis of participation. Moreover, nearly all CWPPs have clearly delineated jurisdictional boundaries, which facilitates integration of environmental characteristics (e.g., exposure to wildfire) in analysis. We use these data to explore the following research questions:

1. Considering that the CWPP model did not explicitly encourage cross-jurisdiction participation, what is the scope of connectivity among planning processes?
2. How do characteristics of stakeholders affect the likelihood of their involvement across multiple planning jurisdictions?
3. How do characteristics of plans affect the likelihood that they attract "cross-jurisdiction" participants?
4. How do characteristics of dyads of plans affect the likelihood that individuals participate in both?

Our analysis necessarily emphasizes breadth over depth in the sense that we evaluate patterns of participation in planning processes that span 11 western states over two decades and lack rich accounts of decision making and social dynamics. Accordingly, our work complements case studies and other analyses that account for richer sets of details in more spatially and temporally constrained research settings than ours. After characterizing our study system, describing our methods, and presenting and discussing our results, we reflect on how future work, including qualitative studies, can test, contextualize, and otherwise build upon our findings. We conclude by highlighting how our findings advance understanding of how changing hazard conditions shape risk mitigation governance networks, with implications for risk outcomes at multiple spatial scales.

Community wildfire protection planning: a tool for local leadership in fragmented risk governance landscapes

Throughout the western U.S., CWPPs are one of the most extensively used tools for addressing wildfire risk at local levels. CWPPs were introduced in the 2003 Healthy Forests Restoration Act as a mechanism to engage residents and other local stakeholders in collaborative wildfire risk mitigation, for which emergency response organizations and public agencies had previously been primarily responsible (Williams et al. 2012, Abrams et al. 2016). There is considerable variation in the spatial scope of CWPP jurisdictions, which range from neighborhoods and communities to fire protection districts and counties. Guidance on developing CWPPs is vague (Jakes et al. 2011) and primarily stipulates that plans must be developed collaboratively and must propose actions to reduce flammable vegetation and the vulnerability of homes and other structures to fires (Society of American Foresters 2004).

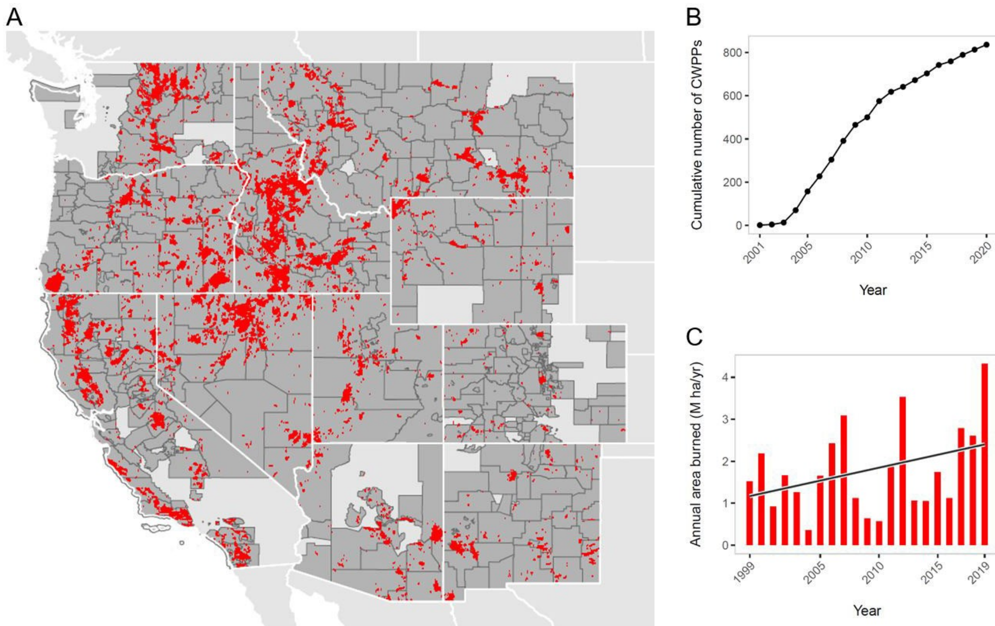
Although CWPPs have been used as a tool for local fire risk mitigation for nearly two decades, evidence of their effectiveness in reducing fire risk has been difficult to establish (Jakes and Sturtevant 2013). In part, the highly stochastic nature of fire itself —a highly improbable event in any locality during a particular year—complicates efforts to assess avoided losses resulting from a particular CWPP. Likewise, the lag between development of a CWPP and implementation of its risk mitigation measures increases the challenge of attributing outcomes to CWPP implementation (Nielsen-Pincus et al. 2019). Despite this uncertainty, scholars and practitioners have highlighted the collaborative nature of the CWPP process itself as a core benefit, in the sense that bringing together diverse stakeholder groups can facilitate learning and serve to build social capital that can in turn enable cooperation to implement challenging risk mitigation initiatives (Fleeger 2008, Lachapelle and McCool 2012).

CWPPs typify elements of institutional complexity that can defy centralized environmental governance. In particular, community-level CWPPs may be nested within larger county CWPPs, or may overlap one another in other ways, creating challenges for vertical integration across plans. Although each CWPP constitutes a relatively autonomous planning process within a defined jurisdiction, CWPPs may also be interdependent with one another, in large part because of actors' involvement in multiple planning processes. Such interdependence provides a mechanism for the exchange of information and resources among decision-making processes (Lubell 2013). Some actors, particularly those associated with organizations whose missions span broad geographies or jurisdictions (e.g., the U.S. Forest Service or a state-level Department of Natural Resources), may participate in multiple plans because the scale of an individual CWPPs overlaps broader jurisdictions or geographies of interest. Another form of interdependence concerns the potential for fire to spread between CWPP jurisdictions. Although each CWPP focuses on risk mitigation planning within a particular jurisdiction, it may be linked to a broader network of CWPPs in multiple ways. For example, fire risk within one planning jurisdiction may originate elsewhere, creating risk interdependence among multiple CWPPs. Depending on how fires spread within or across boundaries, actions undertaken in one jurisdiction can affect overlapping or nearby jurisdictions' exposure to risk (Ager et al. 2017).

When actors participate in such risk-interdependent CWPPs, they can contribute to the collective efficiency of risk mitigation planning at large spatial scales. Alternatively, actors who participate in one CWPP planning process gain exposure to the lessons and experiences of actors who participate in other CWPPs. In these respects, it is important to evaluate CWPPs collectively. This systems-level perspective conceptualizes the CWPP network as a polycentric risk governance system composed of semi-autonomous decision-making processes that are nevertheless interdependent because of overlapping risk and social/policy interaction.

It is important to note that CWPPs are one of many mechanisms for collaborative wildfire risk mitigation, several of which—Collaborative Forest Landscape Restoration Program, Stewardship End Result Contracting, and Good Neighbor Authority—support risk mitigation projects that span ownership boundaries.

Fig. 1. Panel A: Map of community wildfire protection plan (CWPP) jurisdictions (dark grey polygons) in 11 U.S. states, developed during the period 2001–2020. Red polygons indicate burnt area perimeters from wildland fires during 1999–2019 (using data from the Monitoring Trends in Burn Severity project; Eidenshink et al. 2007). Panel B: Cumulative growth of CWPPs in the same 11 U.S. states from 2001 to 2020. Panel C: Trend in area burned in the 11 states during the period 1999–2019.



Likewise, cross-boundary risk mitigation commonly occurs through less formalized collaborations among land management organizations (Hamilton et al. 2021) or among landowners (Fischer and Charnley 2012). In comparing these mechanisms with CWPPs, a crucial distinction is that CWPPs were not intended to facilitate collaboration beyond their own jurisdictional boundaries; the original policy guidance in the Healthy Forests Restoration Act emphasized engagement and collaboration within, but not between, CWPPs. For this reason, to the extent that cross-jurisdiction linkages are observed, such connectivity constitutes a by-product of the model of risk mitigation encouraged by the Healthy Forests Restoration Act.

METHODS

Data collection

Our analysis focuses on a dataset of actor participation in CWPPs in 11 U.S. states, including Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, and Wyoming (Fig. 1A). The study region encompasses rangelands, arid shrublands, desert, and wet and dry forest ecosystems. The geographic footprint of the dataset includes densely populated regions (e.g., coastal California and the Colorado Front Range) as well as extensive tracts of sparsely populated rural areas. Collectively, the 11 states also capture substantial variation in institutional settings in which CWPPs were developed. For example, nearly all CWPPs in Montana were developed at the county level, while in Washington, approximately twice as many CWPPs were developed at the community level relative to the county level.

In 2019–2021, we collected all publicly available CWPP documents for each of the 11 states, which range in date from 2001 to the time of data collection (Fig. 1B). Beginning in the mid-2000s, CWPP development increased sharply, and began to level off in the early 2010s, marking the beginning of saturation of coverage of risk-prone areas. Wildfire risk increased during the two decades that coincide with the development of CWPPs in our database (Fig. 1C).

We identified and extracted rosters of participants from all CWPPs. We defined participants as individuals who were involved in the development of the plan, and as such, did not include individuals who were only plan signatories. Of the 1056 publicly available CWPPs we collected, 219 did not include participants' names and organizational affiliations. These were excluded from analysis, resulting in a dataset of 837 CWPPs.

A total of 10,199 individuals participated in these CWPPs. We used participants' affiliations to classify them by organization type (Table 1). A large proportion of participants were local residents and did not contribute to planning processes as representatives of organizations. Nearly half of all participants represented local government agencies. Although CWPPs are inherently local planning processes, a substantial number of state and federal agency representatives contributed, comprising 8 and 13% of all participants, respectively. The remainder of participants represented non-governmental organizations (ranging from community groups to national conservation organizations), private businesses, and other types of organizations (e.g., tribal governments, universities). Among representatives of private businesses, we additionally identified those individuals who, as private consultants, helped prepare CWPPs, as prior research has highlighted the significant role that consultants play in plan development (Jakes et al. 2007, Abrams et al. 2016).

Table 1. Affiliations of actors (N = 10,199).

Actor affiliation	Number (%)
Individual (no affiliation)	1623 (16)
Local government	4331 (42)
State government	780 (8)
Federal government	1306 (13)
Non-governmental	1369 (13)
Private business	599 (6)
Private consultant (subset of private business category)	279 (3)
Other affiliations	191 (2)

Note: local government includes city, county, and other local governmental organizations, as well as local fire districts/departments; non-governmental includes Firewise organizations, home ownership associations, and non-profit organizations; other affiliations includes organizations such as universities and tribal governmental agencies.

We likewise characterized CWPPs based on geographic location, level, and participation of private consultants. Of the 11 states in our study area, the majority of CWPPs were developed in Colorado and California (Table 2). Most CWPPs address wildfire risk at the community (e.g., neighborhood, town) or county level, while a smaller proportion of plans were developed at the fire protection district level. At least one private consultant participated in approximately 40% of all CWPPs.

Table 2. Characteristics of community wildfire protection plans (CWPPs; N = 837).

CWPP attribute		Number (%)
State	Arizona	30 (4)
	California	171 (20)
	Colorado	207 (25)
	Idaho	99 (12)
	Montana	44 (5)
	New Mexico	55 (6)
	Nevada	37 (4)
	Oregon	66 (8)
	Utah	46 (5)
	Washington	59 (7)
	Wyoming	23 (3)
Level	Community	382 (46)
	County	384 (46)
	Fire protection district	71 (8)
Private consultant(s) involved	Yes	325 (39)
	No	512 (61)

We subsequently assembled a spatial dataset of the jurisdictions of all CWPPs. We obtained some jurisdictional boundaries via publicly available datasets, including the Oregon Spatial Data Library and the Colorado Forest Atlas. Other boundaries were georeferenced using maps from CWPP documents. In turn, CWPP jurisdictions enabled us to integrate data on planning processes with biophysical data. In particular, we measured wildfire hazard conditions within each CWPP jurisdiction using the Wildfire Hazard Potential (WHP) dataset (Dillon et al. 2015), which assigns all locations in the contiguous U.S. a ranking based on the potential for fires that would be difficult to suppress. We calculated CWPP hazard potential as the mean value of pixels within each jurisdiction.

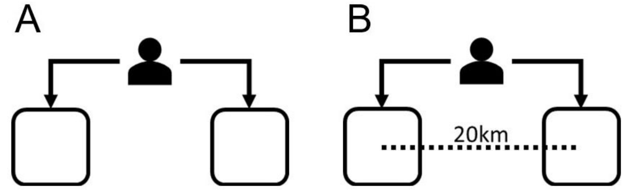
Finally, we constructed a network that measured patterns of participation of actors in CWPPs. Because we used the network to evaluate factors that affect participation across distinct planning processes, we excluded all actors who only participated in one CWPP and, subsequently, all CWPPs with no participants, which resulted in a network of 1846 individuals participating in 781 CWPPs.

Variables and analytical approach

Our analysis proceeded in two steps, the first of which evaluated actor- and CWPP-level attributes that affected the likelihood of cross-jurisdiction participation. Specifically, we estimated a logistic model that assessed whether actors participated in more than one CWPP as a function of their organizational affiliations. We subsequently estimated a generalized linear model that evaluated the proportion of CWPP participants that were involved in the development of at least one other CWPP as a function of CWPP attributes (including the size of the CWPP jurisdiction, the administrative level of the CWPP, and the state in which it was developed) and the proportion of its participants with different organizational affiliations.

The second step of our analysis involved the estimation of a network model that directly evaluated the likelihood of cross-jurisdiction participation as a function of characteristics of pairs of CWPPs. We focused on proximity, similarity or hazard levels, and risk interdependence as predictors of cross-jurisdiction participation. Each predictor was measured as a network motif, or substructure, involving three nodes - two CWPPs and one actor (Fig. 2). For example, "cross-jurisdiction activity: spatial distance" measures the tendency for actors to participate in pairs of CWPPs as function of the distance between the centroids of their jurisdictions. We measured "cross-jurisdiction activity: hazard difference" as the absolute value of the difference of mean hazard potential values between CWPPs in each dyad. We measured actors' tendency to participate in dyads of CWPPs as a function of the number of years that had elapsed between their development ("cross-jurisdiction activity: year difference").

Fig. 2. Network substructure for measuring for cross-jurisdiction participation, in which an actor participates in two community wildfire protection plans (CWPPs; A). The substructure can account for dyad-level characteristics of the CWPPs, such as the distance between the centroids of their jurisdictions (B).



The variable "cross-jurisdiction activity: exposure to prior fires" measured for each year (2000–2018) and for each dyad of CWPPs the expected number of housing units within areas of CWPPs burnt by wildfires prior to the development of the CWPPs. within the jurisdictions of both CWPPs, using records of historical wildfire perimeters We obtained wildfire perimeters from the Monitoring Trends in Burn Severity (MTBS) project (Eidenshink et al. 2007) and housing units from the SILVIS WUI dataset (Radeloff et al. 2005). We used the variable "cross-jurisdiction activity: exposure to prior simulated fires" to account for how stakeholders might perceive risk interdependence based on the probability of fire transmission between CWPP jurisdictions. Specifically, we utilized the 2019 wildfire simulation data from the national FSim library (Short et al. 2020), which includes plausible fires for the continental U.S. that were simulated under contemporary climate and fuel cover. Community exposure was calculated by intersecting these fire perimeters with wildland-urban interface (WUI) boundaries (Radeloff et al. 2005) to estimate the number of housing units within the resulting intersections, using the same approach as described above for calculating the "cross-jurisdiction activity: exposure to prior fires" variable. For details on estimating wildfire exposure see Ager et al. (2019). To measure inter-jurisdiction exposure to simulated fires, we isolated all locations of WUI exposure within a selected CWPP boundary, then identified the points of ignition for each exposure event. We then attributed those points with the exposure amount. We spatially joined these ignition points to all surrounding CWPP jurisdictions and then summed the total exposure for each. These dyads were calculated for all CWPP combinations, then made symmetrical by averaging reciprocal pairs (see Appendix 1 for additional details).

Finally, we constructed several variables to account for how characteristics of individual CWPPs and network substructures affected patterns of participation of actors in CWPPs. The "consultant" variable measures how participation in CWPPs varies as a function of whether private consultants helped facilitate preparation of the plans. The "level" variables measure how participation varies among CWPPs developed at the county and fire protection district levels, relative to the community level. The "jurisdiction size" variable evaluates how participation varies as a function of the area (log km^2) of the CWPP's jurisdiction. Finally, the "geometrically weighted degree (CWPPs)" variable captures the distribution of the number of participants in CWPPs, which indicates how the likelihood that an actor participates in a particular CWPP declines as a function of how many other actors also participate in that CWPP.

We analyzed the actor-CWPP network using an exponential random graph model (ERGM). ERGMs are statistical models that estimate the likelihood of a tie between a pair of nodes (e.g., the participation of an actor in a CWPP) as a function of how those nodes are embedded in the broader network (Snijders et al. 2006, Lusher et al. 2012). ERGMs have become an increasingly popular approach for modeling governance networks (Cranmer and Desmarais 2011, Lubell et al. 2012, Robins et al. 2012) and are appropriate for analysis of data such as ours, given their ability to account for interdependence by conditioning on the entire dataset (i.e., the network) when estimating coefficients. Specifically, ERGMs use Markov chain Monte Carlo simulation techniques to generate a large number of networks based on a set of initial parameter values (e.g., the number of ties, or the degree distribution), which are iteratively refined until the model converges on maximum likelihood parameter estimates. Because our network includes two types of nodes—actors and CWPPs—and linkages are not possible between actors or between CWPPs, we estimated a bipartite ERGM.

To evaluate the conditions under which actors participate in pairs of CWPPs, we used the "ergm.userterms" R package (Hunter et al. 2013) to develop a custom ERGM parameter that we used to evaluate each of the "cross-jurisdiction activity" measures. The parameter evaluates how the likelihood that an actor participates in two CWPPs varies as a function of a continuous variable measured at the level of the CWPP dyad itself. For example, the "cross-jurisdiction activity: spatial distance" variable examines how actors' tendencies to participate in pairs of CWPPs depended on the distance (in km) between the centroids of the CWPPs in each pair. Because these ERGM parameters may be broadly useful in a variety of empirical settings (i.e., not just in relation to cross-jurisdiction linkages in risk mitigation planning networks), code for their installation is available via links provided in the data availability statement.

To aid model convergence, we constrained the degree distribution of actors. This approach did not examine a subsample of the network; rather the model fixed the number of CWPPs that each actor participated in (i.e., the degree of each actor). As a result, we could not include parameters that evaluated how participation in CWPPs varied as a function of actor attributes (e.g., organizational affiliation). Although our decision to fix the number of CWPPs in which each actor participated limited the sample space of the model and our ability to include parameters that focused on actor attributes, the approach was in keeping with the scope of our research question about the conditions under which pairs of CWPPs are connected via participants. Effectively, our constraints on the model allowed us to ask the following: Given actors' varying capacities to participate in a certain number of CWPPs, what factors affect the likelihood that actors participate in particular pairs of CWPPs?

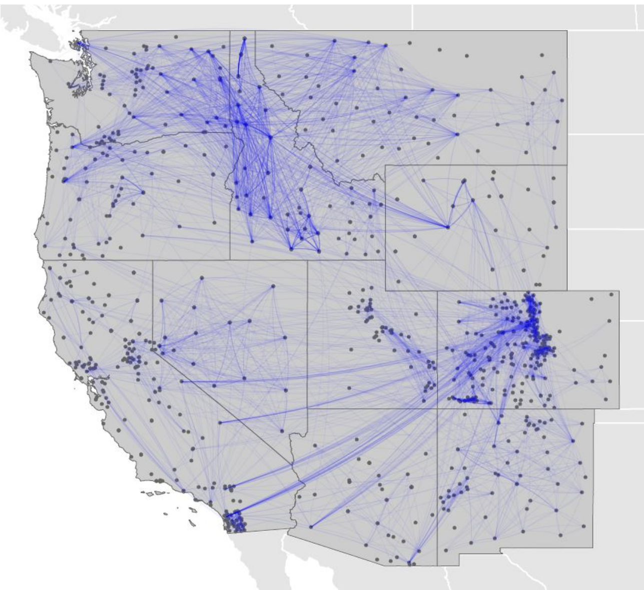
To measure the relationship between risk interdependence and cross-jurisdiction participation, we adopted the baseline modeling approach described by Jasny (2012), which allowed us to avoid model degeneracy. Specifically, we used the ERGM to simulate 1000 networks that shared the same structural features as the empirical network. For the empirical as well as all simulated networks, we calculated statistics for variants of the "cross-jurisdiction activity" parameter that focused on the effects of historical wildfires ("cross-jurisdiction activity: exposure to prior fires") and simulated fires ("cross-jurisdiction activity: exposure to simulated fires"). We measured the significance of these effects by calculating z-scores based on the comparison of statistics from the empirical network with the distribution of statistics from simulated networks. The model converged, and we provide evidence of goodness of fit in Appendix 2.

RESULTS

Scope of cross-jurisdiction participation

Patterns of individuals' participation in CWPPs comprise a cohesive network that spans the western U.S. The network is at once geographically extensive but also locally clustered. Figure 3 shows the ties between CWPPs, which are mapped to the centroid of their associated geographic jurisdiction. Blue lines depict cases

Fig. 3. Connectivity among community wildfire protection plans (CWPPs) in Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, and Wyoming. CWPPs are depicted as points (centroids of CWPP jurisdictions) and blue lines between pairs of CWPPs indicate that at least one individual participated in both planning processes.



where one or more people participated in the creation of both plans. The density of overlapping blue lines indicates areas where cross jurisdictional participation was more concentrated. Of particular note is the density of ties in Colorado, where a large number of plans were developed, but also within certain areas of Oregon, Washington, Utah, Idaho, and Southern California. These geographic connections indicate that actors tend to participate in more proximate CWPPs and CWPPs within the same state, but that there were numerous instances in which actors create linkages between distant CWPPs. Notably, many ties span state boundaries or even different regions within the western U. S. Cross-state ties were particularly dense between Oregon-Washington, Washington-Idaho, Montana-Idaho, and Colorado-California.

Characteristics of individuals who participate in multiple planning processes

Most CWPP participants participated in only a single plan (83%). Our logistic generalized linear model evaluated the likelihood that an individual was involved in multiple plans as a function of their affiliation type (Table 3). Individuals without organizational affiliations (e.g., private residents) were unlikely to participate in multiple plans. Representatives of state and federal government agencies were likely to participate in multiple plans, as were private consultants.

Table 3. Logistic generalized linear model estimates predicting the likelihood of an individual being involved in multiple community wildfire protection plans (affiliation categories are dummy coded so effects are relative to all other respondents).

Variable	Coefficient (std. error)
(Intercept)	-1.75 (0.10)*
Affiliation: individual (no affiliation)	-1.71 (0.18)*
Affiliation: local government	-0.04 (0.11)
Affiliation: state government	1.02 (0.13)*
Affiliation: federal government	0.96 (0.12)*
Affiliation: non-governmental	-0.27 (0.15)
Affiliation: private business	0.14 (0.16)
Affiliation: private consultant	1.29 (0.16)*
AIC	8480.89
BIC	8538.73
Log likelihood	-4232.44
Deviance	8464.89
Num. obs.	10199
Pseudo R^2	0.08 (McFadden); 0.07 (Cox and Snell); 0.12 (Nagelkerke)

* $p < 0.05$.

Characteristics of plans that attract cross-jurisdiction participants

Although most individuals did not participate in multiple CWPPs, most CWPPs had at least one participant who was involved in other CWPPs (92%). At the level of each CWPP, the mean proportion of participants involved in at least one other CWPP was 48% (IQR: 22%–75%). In general, the percent of CWPP participants involved in multiple plans was lower in plans that had a greater number of participants. Our linear regression model (Table 4) indicates that plans developed at the county level and fire protection district level tended to have respectively fewer and more cross-jurisdiction participants than those developed at the community level (the reference category).. CWPPs developed in Arizona, Colorado, Idaho, New Mexico, Nevada, and Washington tended to have fewer cross-jurisdiction participants than CWPPs developed in California (the reference category). Cross-jurisdiction participation was highest in plans in which a greater portion of participants were affiliated with state and federal agencies, and lower in plans where a greater portion of participants were unaffiliated, as well as were affiliated with local organizations, and non-governmental organizations. Cross-jurisdiction participation was also higher in plans in which private consultants were involved.

Characteristics of pairs of plans that attract the same participants

The ERGM (Table 5) indicates that cross-jurisdiction participation is more likely among more proximate and similar CWPPs. In particular, the likelihood that an actor participates in a given pair of CWPPs declines as the distance between their jurisdictions increases, holding all other variables constant. Likewise, the likelihood of an actor's participation in a pair of CWPPs is inversely related to the difference in levels of wildfire hazard potential of both CWPPs.

Table 4. Linear regression model estimates predicting the percentage of community wildfire protection plan participants involved in multiple plans.

Variable	Coefficient (std. error)
(Intercept)	0.46 (0.03)*
Participant count (x10)	-0.03 (0.01)*
Plan level: county †	-0.13 (0.03)*
Plan level: fire protection district †	0.02 (0.04)
State: Arizona ‡	0.16 (0.05)*
State: Colorado ‡	0.20 (0.03)*
State: Idaho ‡	0.41 (0.04)*
State: Montana ‡	0.05 (0.05)
State: New Mexico ‡	0.18 (0.04)*
State: Nevada ‡	0.15 (0.05)*
State: Oregon ‡	0.07 (0.04)
State: Utah ‡	0.09 (0.05)
State: Washington ‡	0.10 (0.04)*
State: Wyoming ‡	-0.01 (0.06)
Plan participants (%): individual (no affiliation)	-0.43 (0.07)*
Plan participants (%): local government	-0.19 (0.05)*
Plan participants (%): state government	0.25 (0.07)*
Plan participants (%): federal government	0.39 (0.07)*
Plan participants (%): non-governmental	-0.31 (0.07)*
Participation of private consultant	0.08 (0.02)*
R^2	0.33
Adj. R^2	0.32
Num. obs.	837

* $p < 0.05$.
† With reference to level: community.
‡ With reference to state: California.

Table 5. Results of an exponential random graph model that evaluates factors that contribute to the likelihood of an actor participating in a community wildfire protection plan (CWPP).

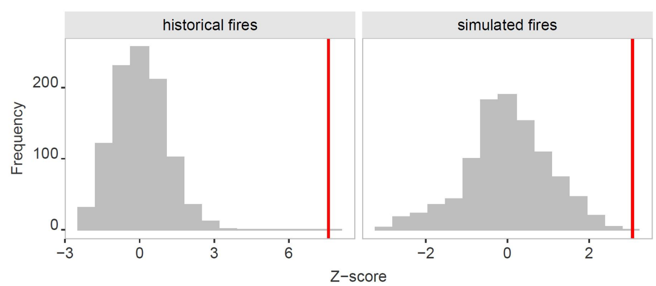
Parameter	Estimate (std. dev.)
Cross-jurisdiction activity: hazard difference	-0.14 (0.01)*
Cross-jurisdiction activity: spatial distance (100 km)	-0.18 (0.00)*
Cross-jurisdiction activity: year difference	-0.06 (0.00)*
Consultant involved	0.20 (0.03)*
Level: community †	0.43 (0.05)*
Level: fire protection district †	-0.26 (0.06)*
Jurisdiction size (log km^2)	0.21 (0.01)*
Geometrically weighted degree (CWPPs)	-0.08 (0.16)
AIC	- 13598.10
BIC	- 13500.65
Log likelihood	6807.05

* $p < 0.05$.
† With reference to level: county.

We also find that cross-jurisdiction participation is more likely among CWPPs jointly exposed to fire (Fig. 4). Specifically, actors are more likely to participate in dyads of CWPPs whose jurisdictions experienced the same fires prior to initiation of both planning processes. Likewise, cross-jurisdiction participation was more likely among CWPPs with greater levels of risk interdependence based on simulations of fires.

Estimates for other parameters included in the ERGM shed light on additional factors that shape the structure of the local wildfire risk governance network operating within and across the 11 states that comprise the study region. The "cross-jurisdiction activity: year difference" parameter indicates that actors were more likely to participate in pairs of CWPPs that were developed closer in time to one another. Whereas the "cross-jurisdiction activity" parameters evaluate factors associated with the likelihood that pairs of CWPPs are linked via actors, other parameters focus on the likelihood of participation of actors in CWPPs (i.e., actor-CWPP linkages). CWPPs in which private consultants were involved attracted more participants. Relative to county-level CWPPs, community-level CWPPs attracted more participants while fire protection district-level CWPPs attracted fewer participants. CWPPs with larger jurisdictions attracted more participants. The negative estimate for the "geometrically weighted (CWPPs)" parameter indicates a tendency for centralization of actors' participation in CWPPs (i.e., a small number CWPPs had a relatively large number of participants and a large number of CWPPs had a relatively small number of participants).

Fig. 4. Contribution of risk interdependence to cross-jurisdiction participation. Plots depict the degree to which empirical relationships (red vertical lines) between risk interdependence and cross-jurisdiction participation depart from expectations (grey histograms, which depict the distribution of each relationship from 1000 simulations of the community wildfire protection plan [CWPP] network, using the ERGM as a baseline). Plots demonstrate the higher likelihood of cross-jurisdiction participation between CWPP jurisdictions with greater exposure to historical wildfires that burned prior to development of the CWPPs as well as to simulated wildfires.



DISCUSSION

A common impediment to addressing risk mitigation at regional scales is the challenge of linking planning and management across jurisdictional boundaries (Burby 2006). This study examined how communities' efforts to plan for wildfire have spurred the development of a risk governance network that self-organized against the backdrop of fragmented and decentralized institutional settings. Our findings not only document the scale of connectivity among risk mitigation planning processes across the fire-prone western U.S. but also the factors that influence patterns of participation in these processes. These patterns of participation point to the goal-directed networking by which diverse actors grapple with intensifying wildfire risk at both local and regional scales. Active lines of research on goal-directed networks have developed in multiple fields of public policy, including healthcare systems and crime prevention (Raab et al. 2015, Nowell et al. 2019, Bright and Whelan 2020, Lemaire 2020), but have received less attention in the management of hazards and extreme events (but see Berthod et al. 2021). Recognizing this emergent structure is important as society adapts to increased wildfire, especially given the inherent uncertainty of wildfire hazard conditions at local scales.

Wildfire risk governance from the bottom up: the emergence of a large-scale network of planning processes

From their inception, CWPPs were intended to increase the number of stakeholders involved in community wildfire risk management. Increased local engagement in risk mitigation planning promised greater community buy-in, particularly with regards to government-led management actions often resisted by nearby residents (Grayzeck-Souter et al. 2009, Jakes et al. 2011). In many cases, much of the wildfire urban interface extends outside of municipal boundaries, where fire protection responsibility is often unclear, and where properties may be exposed to wildfire from diverse sources (Paveglio et al. 2013). In others, communities were tied together less by geography than by shared connections to agricultural-, natural resource-, and recreation-based economies that span larger regions. Many states, particularly those that are predominantly rural, have used counties as the basis for implementing plans. As a result, planning for community wildfire protections often extends into neighboring land and communities. The former is reflected in the greater awareness of cross-boundary fire management, recognizing the potential for fire to cross administrative boundaries. The latter, however, has received less attention, and the research presented in this article advances scientific understanding of the influences of cross-jurisdictional partnerships in community wildfire protection planning.

Our data reveal the emergence of a cohesive network of planning processes that spans the American West. This finding is somewhat surprising considering that CWPPs were developed in a highly decentralized governance model that emphasized local planning. The original policy guidance—as documented in the Health Forests Restoration Act of 2003—encouraged collaborative planning within the teams of stakeholders that convened to develop CWPPs but not between planning processes themselves. Nevertheless, a geographically extensive network self-organized, and includes thousands of local risk mitigation practitioners engaged in one or more planning processes. It is noteworthy that the emergence of this network coincided with a period of increasing fire activity and corresponding attention to the importance of boundary-spanning risk mitigation approaches. In particular, scholarship on wildfire risk mitigation increasingly emphasizes the need for cross-boundary coordination, given the potential for fires to spread from one jurisdiction to another and the need for multiple stakeholders to undertake collective action to implement large scale forest and fire management activities (Cyphers and Schultz 2019, Charnley et al. 2020). Fire risk governance plays out at multiple spatial scales, and coordination is just as important at the regional (e.g., inter-state) level as it is at the inter-community level (Steelman 2016). That such a bottom-up process as community wildfire protection planning spurred the development of a cohesive regional network highlights key opportunities for governance of wildfire risk. In particular, if national or regional programs were to be established with mandates to distribute substantial levels of funding to subsidize risk mitigation activities at local levels, the network could facilitate efficient dissemination of funds. Likewise, national and regional leaders could leverage the CWPP network to mobilize risk mitigation practitioners with diverse experiences and resources who are already interacting with one another.

Conditions that facilitate connectivity among risk mitigation planning processes

Our analyses shed light into the characteristics of individuals who participate in risk mitigation planning in multiple jurisdictions. Intuitively, individuals without organizational affiliations (e.g., local residents) tend to participate in only one CWPP; private consultants, not surprisingly, are more likely to participate in multiple CWPPs. We likewise find that representatives of state and federal governmental agencies tend to participate in multiple CWPPs, which suggests that these individuals play crucial roles in sharing information and other types of resources among planning jurisdictions. These findings suggest that local actors lack access to the cross-boundary learning mechanisms available to "policy elites" (e.g., private consultants, representatives of state and federal agencies), who are privileged by the structure inherent to the networks. This finding is likewise consistent with a broader shift in how government agencies (especially at the federal level) work to achieve policy goals (Milward and Provan 2000, Jessop 2013). In particular, many land management agencies, which comprise the bulk of government actors in our study population, are required to accommodate an increasingly broad set of objectives (e.g., for the U.S. Forest Service, recreation and habitat restoration in addition to timber production) despite declining budgets (Abrams 2019). Agencies have responded to these pressures by engaging with diverse stakeholder groups, which offers opportunities to align their operational objectives with the goals and values of these external groups. Our results suggest that agencies may view CWPPs as a venue for coordinating land management activities related to fire risk mitigation.

Our findings also reveal characteristics of planning processes that attract participants who in turn participate in other planning processes. Notably, we find an inverse relationship between the number of participants in a CWPP and the proportion of those individuals who participate in other CWPPs, possibly because in CWPPs with large numbers of participants, many participants are local residents who restrict their involvement to a single planning process. Likewise, our finding that county-level CWPPs attract fewer cross-jurisdiction participants is surprising given the tendency for community and fire protection district-level CWPPs to be nested within county-level CWPPs, which presents opportunities for individuals to facilitate linkages among planning processes whose jurisdictions overlap.

Our finding that linkages are more likely among jurisdictions that are more proximate and that share more similar hazard conditions supports theoretical expectations about how transaction costs shape actor involvement in collaborative governance networks. Generally speaking, proximity offers opportunities for actors to gain familiarity with one another (Wondolleck and Yaffee 2000), which can foster trust and consequently reduce the transaction costs of coordination. Likewise, coordination of risk mitigation among similar planning contexts offers greater opportunities to apply expertise from one jurisdiction to the other. We likewise demonstrate that linkages are more likely among jurisdictions jointly exposed to historical and simulated fires, which suggests that actors' perceptions of risk interdependence between planning jurisdictions encourages their participation in those planning processes. Prior research highlights how such fires can function as focusing events (Schumann et al. 2020), which garner attention and can mobilize efforts to reduce risk. Our findings are consistent with the idea that focusing events can prompt cross-jurisdiction coordination because they enable actors to better appreciate risks and the benefits of preventative action.

Scholars and practitioners alike have highlighted the need to increase the pace and scale of wildfire risk mitigation in the fire-prone American West (Topik and Lewis 2014, Schultz et al. 2019, Miller et al. 2020). From a governance perspective, actors' tendency to participate in CWPPs developed in nearby and similar jurisdictions can offer opportunities for policy learning and the application of lessons learned from one CWPP to other appropriate decision-making contexts. However, this tendency can also limit the potential for innovative risk mitigation approaches to gain broad exposure. In particular, our results highlight the potential for echo chambers to develop among clusters of similar and nearby CWPPs via overlapping patterns of actors' participation in those CWPPs. Such networks may resist new ideas (Newman and Dale 2005, Berardo 2014), which may be particularly consequential given the need for adaptation to changing environmental risk conditions, which magnify uncertainties associated with the efficacy of particular risk mitigation approaches (Thompson and Calkin 2011, Penman et al. 2020). Likewise, patterns of overlapping linkages between proximate and similar CWPPs may exacerbate mismatches between the scale of risk and scale of risk response by contributing to rich(poor)-get-richer(poorer) dynamics, which have been documented in hazard-prone landscapes throughout the American West (Lynn and Gerlitz 2006, Collins 2008, Nielsen-Pincus et al. 2018).

However, our finding that risk interdependence predicts connectivity across planning jurisdictions is encouraging in the sense that actors seem to respond to focusing events that highlight the value of larger scale risk mitigation responses. Notably, our probabilistic measure of risk interdependence (simulated fires) likewise predicted cross-jurisdiction participation, which suggests that actors may be equally attuned to the likelihood of exposure to future fires. Indeed, prior research has demonstrated good correspondence between burned areas based on simulated fires and area burned by recent fires (Ager et al. 2014). Although the highly stochastic nature of fire means that the benefits of connectivity among planning jurisdictions may never materialize (i.e., if jurisdictions do not experience fires), our findings suggest that actors nevertheless engage in cross-jurisdiction participation in anticipation of the possibility of boundary-spanning hazards as much as in response to "wake up calls" from prior fires (Árvai et al. 2006).

Certainly, participation in CWPPs represents only one factor of many that contribute to the community wildfire protection plans. For example, the U.S. Federal Emergency Management Agency has recently required county Hazard Mitigation Plans to address local wildfire risks. Likewise, wildfire exposure has become increasingly central to forest collaboratives and forest management plans. Indeed, a growing literature examines "networks of plans," where the effectiveness of a plans is often dependent on the degree to which they are integrated in other planning processes, including transportation, water delivery, and development code (Berke et al. 2015, 2019). This recognition has led to calls for integrated hazards planning (e.g., Malecha et al. 2019).

Future research can build upon our study in several ways. First, although CWPPs are among the most extensively used planning tools for local wildfire risk mitigation in the U.S., CWPPs do not operate in a vacuum, and individuals who participate in CWPPs commonly also participate in other planning processes. Future research should examine the broader ecosystem of collaborative risk mitigation decision-making processes, which would present opportunities to explore factors that mediate the exchange of resources among different types of processes, as well as other forms of coordination. Additionally, our data on patterns of participation can serve as a starting point for collection and analysis of more detailed data on the social and institutional dynamics that shape coordination of risk mitigation at large scales. For example, research on how planning networks shape competition for resources (e.g., grant funding for risk mitigation project) can shed light into how social processes can amplify or attenuate disparities in risk mitigation capacity over time, which is a significant issue in wildfire-prone regions (Davies et al. 2018).

CONCLUSION

Globally, environmental change highlights the need for new models of risk governance that address hazards that span administrative boundaries and play out at large spatial scales. At the same time, such governance systems will always be fragmented and polycentric, characterized by multiple and overlapping sources of authority, which contributes to the complexity of environmental problem solving (Ostrom 2010). Risk reduction presents a set of collective actions problems that all arise from the challenge of aligning the benefits of cross-boundary risk mitigation coordination with the benefits of large-scale risk reduction (Brummel et al. 2012). Localized planning processes and micro-level risk mitigation decisions matter (Bodin and Nohrstedt 2016). A crucial research goal is to improve understanding of the conditions that enable emergence of linkages among risk mitigation planning processes with distinct jurisdictions.

We focus on linkages between the jurisdictions of CWPPs, which were introduced to encourage collaboration among local stakeholders. Although CWPPs ostensibly focus on the "community," the capacity generated may transcend single scales. CWPPs were developed to improve preparedness by including a broad range of stakeholders in collaborative planning processes. Although plans ostensibly serve to guide efforts to reduce hazardous fuels and the vulnerability of homes and other structures to fires, many have argued that their actual utility is less tangible and more far-reaching (e.g., Jakes et al. 2011, Lachapelle and McCool 2012). Indeed, a core feature of the CWPP model is its flexibility, which in turn provides a context and forum for exchanging ideas, building a shared understanding of risk, and identifying and sharing values, assets, and resources.

To date, scholarship on CWPPs has primarily focused on case studies of particular planning processes (e.g., Brummel et al. 2010, Jakes et al. 2011, Lachapelle and McCool 2012, Jakes and

Sturtevant 2013) and large-n evaluations of the characteristics of plans (Palsa et al. 2022, Abrams et al. 2016). Limited research has focused on the linkages among CWPPs (but see Ager et al. 2015 for a discussion of the importance of coordination across CWPP boundaries). Such linkages deserve greater attention because they can shape risk mitigation capacity at scales beyond the jurisdictions of individual CWPPs. In particular, actors that participate in multiple planning processes can enable fire management at scales commensurate with fire risk; such actors can encourage the types of risk mitigation measures that reduce fire risk among jurisdictions that are interdependent based on the probability of fire transmission between them. In evaluating the conditions that facilitate such connectivity among plans, our study demonstrates that risk interdependence (e.g., joint exposure to the same fires) between planning jurisdictions increases the prospects for cross-plan participation, which is also more likely among planning processes that are more proximate and similar to one another. Taken together, these findings suggest that changing environmental hazard conditions may prompt linkages among planning processes, but such connectivity is limited in scale by factors that can increase transaction costs.

More broadly, one of the key insights from our study is that a locally clustered but spatially extensive network of planning processes emerged within the fire-prone western U.S., despite the absence of formal policy guidance. Such patterns of linkages can serve a crucial role in addressing wildfire risk governance challenges at multiple spatial scales, for example, by providing a latent source of social capital for diffusion of information or resources, or by enabling the coordination of risk mitigation strategies within regions.

Author Contributions:

Matthew Hamilton: Conceptualization; Data curation; Formal analysis; Funding acquisition; Project administration; Writing - original draft; Writing - review & editing. Cody Evers: Conceptualization; Data curation; Formal analysis; Funding acquisition; Project administration; Writing - original draft; Writing - review & editing. Max Nielsen-Pincus: Conceptualization; Data curation; Funding acquisition; Project administration; Writing - original draft; Writing - review & editing.

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Data Availability:

The data that support the findings of this study are openly available at https://doi.org/10.6084/m9.figshare.19193663 and code is available at https://doi.org/10.6084/m9.figshare.19193657.

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Appendix 1. Measurement of inter-jurisdiction exposure to simulated fires

To estimate wildfire exposure, we intersected 2019 fire simulation (FSim) wildfire perimeters against 2010 SILVIS wildland-urban interface (WUI) polygons, where each WUI polygon has a specific housing unit density based on 2010 census data. We assumed that wildfire exposure occurs whenever a wildfire polygon overlaps a WUI polygon. Using the intersected data, we estimated exposure for each resulting polygon fragment by calculating the product of the fragment area and the associated HU density. Next, we normalized the exposure value by the likelihood of the fire, which is simply 1 divided by the number of FSIM fire seasons simulated within a given region (typically 10,000 or 20,000 years). We subsequently recorded the XY location of centroid of the fragment and the XY location of ignition point for the original fire. This is called the exposure vector, which is composed of a 'source' coordinate (i.e., the ignition point) and a 'sink' coordinate (i.e., the WUI fragment centroid), and an exposure value.

We next joined the exposure vectors with CWPP jurisdictional boundaries using both source and sink coordinates. First, we extracted a subset of the exposure vector for all instances in which the sink coordinate (i.e., the WUI fragment centroid) was located within a given CWPP boundary, CWPP_i. The sum of exposure for these points represents the total annualized exposure for that CWPP. With this subset in hand, we then extracted the coordinates for the ignition points of these exposure vectors. Most ignitions points could have multiple instances given that a single fire could spread among multiple WUI polygons. Next, we joined these exposure vector ignition points with surrounding CWPP boundaries, joining duplicates of any exposure vector ignition points that fell within multiple jurisdictions. Next, we summed the exposure for each neighboring CWPP jurisdiction contributing exposure to CWPP_i. These exposure values represent the degree of exposure that CWPP_i receives from every surrounding CWPPs. We repeated this for all CWPPs, then combined these results into a matrix.

Within the matrix, rows represented the source CWPP and columns represented the sink CWPP. The combined exposure for each CWPP was recorded along the matrix diagonal (i.e., when i == j). In almost all cases, exposure transmission was asymmetrical. That is, the exposure from CWPP_i to CWPP_j was often different from CWPP_j to CWPP_i. Because our network was undirected, we averaged these reciprocal pairs such that i → j == j → i.

Appendix 2. Goodness of fit for exponential random graph models

The exponential random graph model (ERGM) was estimated with 15,000 iterations and a sample size of 15,000. We evaluated model fit of the ERGM by simulating networks based on model parameters and comparing statistics of our empirical networks to distributions of the same statistics from simulated networks. Boxplots in Figure A2.1 show statistics from 500 networks simulated using model parameters. Statistics from the observed networks (thick black lines) that cross near the center of boxplots indicate that the mean value of the corresponding statistics from simulations approximate the statistic from the empirical network.

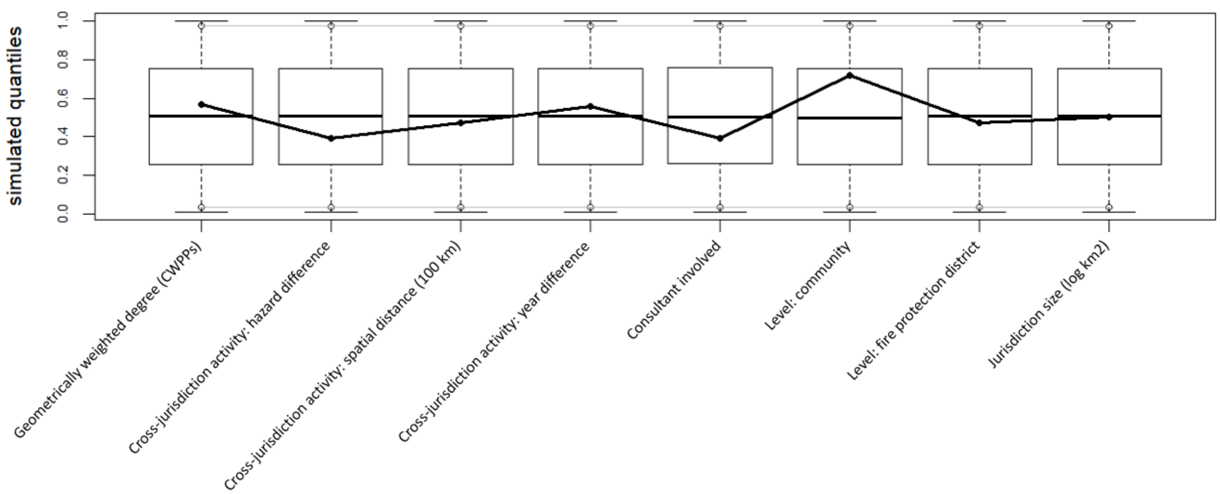

Figure A2.1: Goodness of fit of the exponential random graph model.