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Evidence of effectiveness in the Cohesive Strategy: measuring and improving wildfire response

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Abstract. The United States' National Cohesive Wildfire Management Strategy aims to achieve greater social and ecological resilience to wildfire. It also raises the question: cohesive for whom and for what purpose? In this article, we address the wildfire response goal and what a cohesive response means. Namely, we define a cohesive response as the ability to co-manage across scales for a more effective wildfire response. Our approach is grounded in the reality of the growing complexity of wildfire – both biophysically and socio-politically. We suggest that suppression and fire operations are necessary, but insufficient in the face of this growing complexity as we seek safer and effective wildfire response. Using network-based concepts and drawing from the literature on socio-ecological resilience, we consider how scales can be matched, what can and should be communicated across scales, and what this means for creating more adaptable institutions for more effective wildfire response. Survey results from 21 fires during the 2013 wildfire season are presented to illustrate relative areas of strength and weakness related to wildfire response and how these measurements can feed into processes to facilitate social learning, adaptation and ultimately more resilient socio-ecological wildfire response institutions.

Additional keywords: co-management, disasters, networks, network governance, resilience, socio-ecological.

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Towards more effective wildfire response

The United States' National Cohesive Wildfire Management Strategy (hereafter Cohesive Strategy) focuses on the creation of fire-adapted communities, safe and effective wildfire response, and the restoration and maintenance of landscapes (US Department of Interior and US Department of Agriculture 2014). Broadly stated, the goal is to achieve greater social and ecological resilience to wildfire (Abrams *et al.* 2015; Steelman 2016). Although these lofty goals are admirable, they come to life only when operationalised in specific contexts that result in positive change.

Achieving socio-ecological resilience to wildfire is no easy feat, and practice, failure and experimentation have been part of the 'learning by doing' strategies broadly employed as the Cohesive Strategy has been implemented. The scholarly literature suggests that adaptation to evolving circumstances is an essential element for socio-ecological resilience (Holling 1978; Folke *et al.* 2005). Ideally, learning as part of the adaptation process occurs through monitoring and feedback that result in individual as well as collective change (Stringer *et al.* 2006; Reed *et al.* 2010). Abrams *et al.* (2015) suggest that the potential for learning and adaptation in socio-ecological systems is greatest when the following conditions are met: (1) scales are appropriately matched; (2) there is communication and relationship building across scales; and (3) institutions and organisations can be receptive to new information. A primary challenge for addressing the wildfire problem is how to build 'inclusive, scale-appropriate, adaptable institutions that incorporate local knowledge' (Abrams *et al.* 2015).

In wildfire response, we have scale mismatches between local preparedness and response and the federal resources that are typically deployed during a large, complex wildfire. Preparation and initial response occur at the local level, extended response occurs at the regional or national level, and mid- and long-term recovery transitions back to the local level. This raises important questions about how these different scales can be integrated effectively, how continuity across scales can be ensured and what kinds of information are needed to develop and appropriately allow adaptation of fire response institutions. What approaches do we have to help ensure we are working towards inclusive, scale-appropriate solutions for greater social and ecological resilience to wildfire?

In the present article, we demonstrate a methodology and apply it to answer this question. We focus on one domain within the Cohesive Strategy – wildfire response – and provide a working example of how goals can be conceptualised, specified and measured to inform better scale matches and facilitate communication to advance a safer and more effective wildfire

response. We define wildfire response as deliberate actions taken to address the socio-political and biophysical impacts of a wildfire when it is actively burning. The article begins with defining the problem and how different problem definitions shift the focus of how wildfire response alternatives can be framed. We approach wildfire response as the focus of an 'incident response network' and the functionality needed from that network to achieve success (Nowell and Steelman 2013). Using network concepts and risk co-management framing, we propose a method for measuring and evaluating wildfire response that helps bridge scales and facilitate communication. Results from 21 fires during the 2013 wildfire season are presented to illustrate relative areas of strength and weakness and how these measurements can feed into processes to facilitate the social learning, adaptation and ultimately more effective wildfire response. In doing so, we respond to a noted lack of research on wildfire response and the need for more research in this area (Dunn *et al.* 2017).

What do we mean by wildfire response? Operational vs systems-based problem definition

Historically, there have been two definitions driving research into wildfire response. These are: (1) wildfire operations and the strategic and tactical decisions related to operational wildland firefighting; and (2) a systems-based approach focused on operational plus additional functions, such as evacuation, road closures and sheltering among others, that occur as part of a more comprehensive wildfire response system and the network of actors that support these multiple functions (Nowell *et al.* 2018*a*).

Historically, the dominant narrative has defined the problem as presence of unintended fire, leading to suppression as the dominant alternative in wildfire management (Steelman and Burke 2007; Olson *et al.* 2015). The problem definition and alternatives are important because these then shape the social structures that implement solutions and the realm of subject matter expertise relevant to them. For instance, the Incident Command System (ICS) command organisational structure is the prevailing hierarchical bureaucratic design under the authority of an Incident Management Team (IMT) that is delegated authority for fire suppression (Nowell and Steelman in press). The command organisational structure comprises specialised roles related to planning, information, finance, safety, liaison, logistics and operations, and is overseen by an incident commander. A suppression problem definition suggests that operational activities under the command organisational structure of ICS are the dominant focus in wildfire response. Further, alternatives to address suppression as a problem have focused on modelling, monitoring, decision tools and influences associated with the operational aspects of fire management (Thompson 2014; Hand *et al.* 2015; O'Connor *et al.* 2016; Thompson *et al.* 2016*a*; Belval *et al.* 2017; Hand *et al.* 2107; Jolly and Freeborn 2017; Katuwal *et al.* 2017; Wei *et al.* 2017). Suppression has also been recognised as part of a broader operational toolbox, which includes managed wildland fire and prescribed fire. Each of these strategic approaches are recognised to have relative advantages and disadvantages in given settings (Steelman and McCaffrey 2011; Katuwal *et al.* 2016; Belval *et al.* 2017; Hand *et al.* 2017; Ingalsbee 2017; Katuwal *et al.* 2017; Stonesifer *et al.* 2017; Wei *et al.* 2017), including cost implications (Donovan and Brown 2005; Canton-Thompson *et al.* 2008). The point is that there is an organisational and expertise-based path dependence based on how the problem is defined.

The growing complexity of wildfire incidents may necessitate an alternative problem definition, which has implications for a different organisational framing, including who should be involved and what expertise is relevant. Large, complex wildfires activate a whole suite of response functions outside of, but interdependent with, the sphere of the IMT and fire operations. We have identified five key management domains as critical to a system-level conceptualisation of effective wildfire response. These are evacuations, sheltering and mass care, road closures, interagency coordination and response, and public information (Nowell *et al.* 2016). This complex mix of actors and their functional roles has been documented in what has been labelled a 'wildfire incident response network', as illustrated in Fig. 1 (Nowell and Steelman 2013; Nowell *et al.* 2018*a*). With this framing, fire management does not fall into the domain of just one agency or organisation and lies beyond the span of control of the command organisational structure of ICS (Nowell and Steelman in press). This systems-based definition refocuses attention on who should be considered as part of incident response and what functions are needed as part of an effective incident response. This characterisation of wildfire response as a network is part of a broader trend to see disasters as networked events (Kapucu 2005, 2006; Comfort and Kapucu 2006; Magsino 2009; Kapucu *et al.* 2010; McGuire and Schneck 2010; Faas *et al.* 2015). Effectiveness in response, given this more systems-based problem definition, focuses on how to improve coordination, communication and cooperation among a myriad of organisations and agencies that become active during wildfire response to achieve intended outcomes (Nowell *et al.* 2016).

Crossing scales, bridging, co-managing and incident response networks

The dynamics of large-scale wildfires typically include local response becoming overwhelmed at some point and requesting help from a regional or national resource – a Type 1 or 2 IMT. These are the most elite fire management teams in the United States. From a network standpoint, it is important that this external entity become well integrated into what was a previously functioning local network. In socio-ecological resilience terms, it means effectively integrating a cross-scale response. Conceptually, linkage across vertical and horizontal scales is important for increasing socio-ecological resilience (Berkes 2002), and bridging organisations (Cash *et al.* 2006; Crona and Parker 2012) have been identified as the entities that can facilitate these linkages. In the world of wildfire response, the linkage of the local response with the regional and/or federal response is often facilitated by the host agency that requests the additional resources. For example, in some cases, this can be the US Forest Service, National Park Service, Bureau of Land Management or Fish and Wildlife Service or a state agency.

The relative level of success of wildfire response often hinges on the pre-fire work done by the host unit to understand its own local response network as well as the ability of the incoming

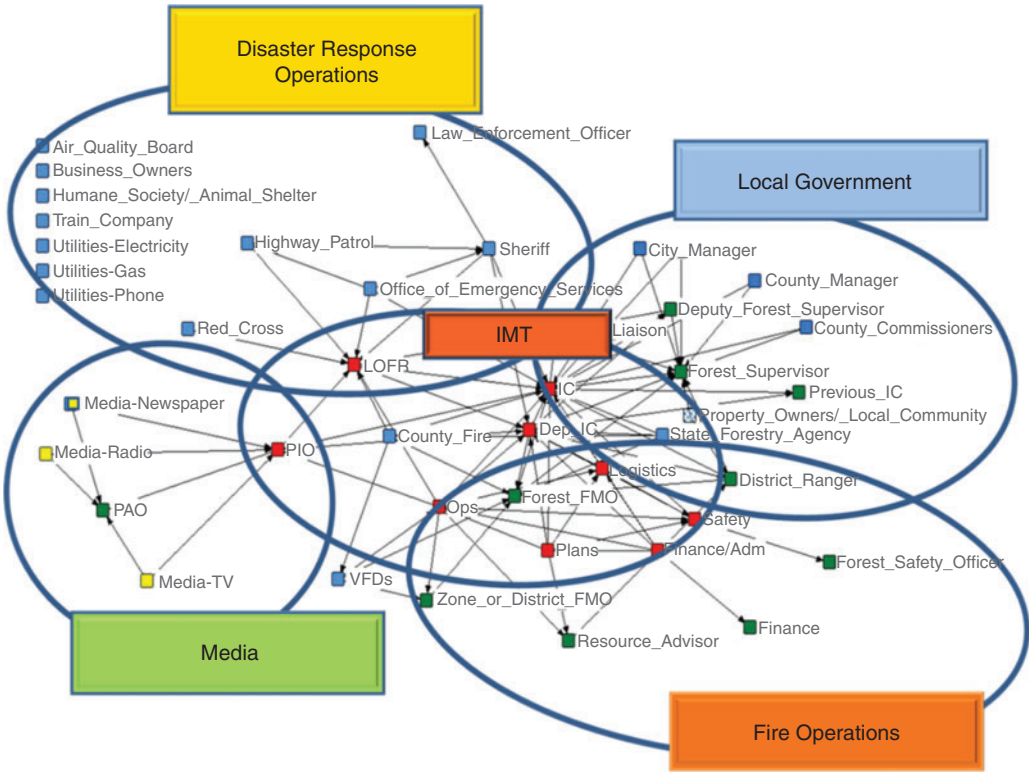

Fig. 1. Wildfire incident response network. FMO, fire management officer; IC, Incident Commander; IMT, Incident Management Team; LOFR, liaison officer; PAO, Public Affairs Officer; PIO, public information officer; VFD; volunteer fire department. Reprinted with permission from American Review of Public Administration.

IMT to understand and incorporate the local context where it will now be working. In short, it is the collective ability of the local unit and the extra-local response entity to cross scales and begin making joint decisions that leads to a more cohesive response. In some literature, this is addressed as the ability to co-manage (Berkes 2009). Large wildfire management is inherently an exercise in risk co-management (Calkin *et al.* 2015; Thompson *et al.* 2016*b*). Seldom is there a unified, monolithic 'community' prepared to make decisions. Rather, multiple individuals, representing varied values and interests, must come together under stressful, chaotic conditions to make life-and-death decisions. Lessons from the co-management literature indicate that it is a process dependent on two-way feedback and networking for its adaptive evolution (Pinkerton 1992; Armitage *et al.* 2008; Mahanty and Keen 2012). Co-management is then best envisioned as a process, rather than a static state (Berkes 2009).

If co-management is a process, then that still raises the question 'Co-manage with whom?' Boundary definitions – the decisions about who is included and excluded from consideration – are a critical element of co-management (Nowell *et al.* 2018*b*). The incident response network is one way to conceptualise the boundaries of co-management on a wildfire and what might constitute a basis for evaluating its efficacy. As both the local and extra-local become fused in the incident response network, the efficacy of the network and how the local and extra-local perform are the basis for assessing scale-based integration.

Based on these dynamics, we looked to three kinds of measurement to understand performance within an integrated incident response network. These included: (1) overall network performance; (2) IMT performance; and (3) host unit performance.

Methods: conceptualising and measuring performance in an incident response network

Developed based on key informant interviews with leaders in wildfire incident response, our network performance scale comprised 30 questions that covered five functional domains derived from previous research: evacuations, sheltering and mass care, road closures, interagency coordination and response, and public information (Nowell *et al.* 2016). Network performance measures can be found at https://research.cnr.ncsu.edu/blogs/firechasers/files/2014/05/Network-Performance-Measures-4.23.14.pdf [accessed 26 February 2019]. Additional factor analysis revealed a sixth subscale – cost share. Respondents were asked to self-report their level of agreement about the quality of network performance or the combined efforts of all responding agencies and units across the six functional areas on a 5-point Likert scale: 1, strongly disagree; 2, somewhat disagree; 3, neither agree nor disagree; 4, somewhat agree; 5, strongly agree; N/A, not applicable. All network respondents answered these questions.

The IMT performance scale covered 19 questions that focused on aspects of how well the IMT adapted to the local

context of the incident. IMT performance measures can be found at https://research.cnr.ncsu.edu/blogs/firechasers/files/2014/05/IMT-Performance-Measures-4.23.14.pdf [accessed 26 February 2019]. Host unit and local cooperating agency respondents were asked to indicate what room for improvement there might have been for IMT performance in 19 areas on a 5-point Likert scale (1, no room for improvement; 2, a little room for improvement; 3, some room for improvement; 4, quite a bit of room for improvement; 5, a lot of room for improvement; N/A, not applicable). Cooperating agencies, non-Forest Service (USFS) entities as well as the USFS rated the IMT's performance. Likewise, the host unit performance scale was composed of 14 items on a 5-point Likert scale (1, no room for improvement; 2, a little room for improvement; 3, some room for improvement; 4, quite a bit of room for improvement; 5, a lot of room for improvement; N/A, not applicable) that allowed the IMT to assess the local host's capacity for facilitating the integration of the IMT into its local operating environment. Host agency performance measures can be found at https://research.cnr.ncsu.edu/blogs/firechasers/files/2014/05/Host-Unit-Performance-Measures-4.23.14.pdf [accessed 26 February 2019].

In 2013, we used all three performance scales on 21 large wildfires in Idaho, Montana, Oregon and Washington. To meet our sample criteria, the wildfires needed to require a national or regional (Type 1 or 2) IMT and occur in the wildland–urban interface, where human populations, structures and other values at risk were threatened.

A total of 982 individuals were sent our survey and represented the USFS (Districts and Supervisor Office), IMTs, county emergency responders and other host land agencies such as the US Bureau of Land Management and state forestry or wildfire agencies, if appropriate. A total of 456 responded for an overall response rate of 46%, with IMT (95%, $n = 104$), USFS Districts (62%, $n = 76$) and USFS Supervisor Office (53%, $n = 81$) being over-represented in the sample and county organisations (37%, $n = 167$) and other host agencies (49%, $n = 26$) being under-represented in the sample.

Results

Our findings cover both how the entire network was evaluated by all respondents and how different stakeholder groups evaluated each other, e.g. IMTs evaluate host units and host units evaluate IMTs. The evaluation of the entire network provided a systems-level overview of effectiveness, whereas the different categories of respondents provided opportunity to understand and refine actions at a finer scale. Given that performance on wildfire response is inherently subjective and pluralistic in nature (Nowell *et al.* 2016), we argue that stakeholder assessments of performance are highly relevant to the domain.

Network performance

As illustrated in Fig. 2, we see stronger performance in the functional areas of public information and interagency coordination and response, with responses ranging from somewhat agree to strongly agree in self-reporting the quality of network performance in these dimensions. Higher numbers indicate greater agreement with this functional area by all network respondents. Areas of lower performance include cost share, sheltering and mass care and evacuation and re-entry. In general, we see stronger performance in areas of the network where the ICS command organisational structure is prevalent and the IMT has formal control.

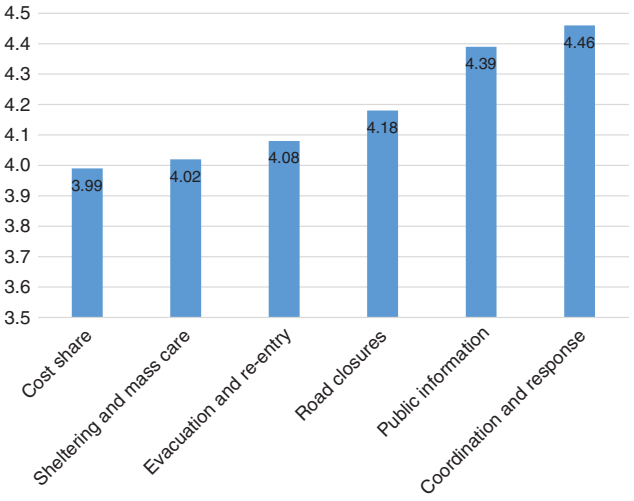

Fig. 2. Network performance by domain on 21 Type 1 and 2 wildfires in 2013.

IMT performance

On the average, IMT performance scores overall were good and ranged between 1, 'no room for improvement' to 2, 'a little room for improvement', as indicated in Fig. 3. Lower numbers are better and indicate less room for improvement. The areas where co-operators and host agencies viewed IMTs performing best included IMTs serving as a positive ambassador in their interactions with locals, staying in their lane and not overstepping their boundaries, being good team players by acknowledging cooperation, sharing credit with local agencies, being accessible and being helpful to local cooperating agencies.

Areas where local co-operators and host agencies saw the most room for improvement for IMT performance included engaging affected jurisdictions in planning and decision making from the outset of the incident. A set of responses pointed to IMTs needing to be more sensitive to local context overall. Responses included that there could be improvement in obtaining local biophysical contextual information, incorporating local values at risk and being sensitive to local community culture and political climate.

Host unit performance

Host units play a key role in helping IMTs, who may be unfamiliar with the area, get up to speed quickly on the people and things they need to know to be effective on the incident. On the whole, IMT responses were very positive for host units with scores ranging from 1, 'no room for improvement' to 2, 'a little room for improvement' (Fig. 4). Lower numbers are better and indicate less room for improvement.

IMT members saw the most room for improvement for host agency performance when it came to providing good maps of values at risk, providing timely contact information for local

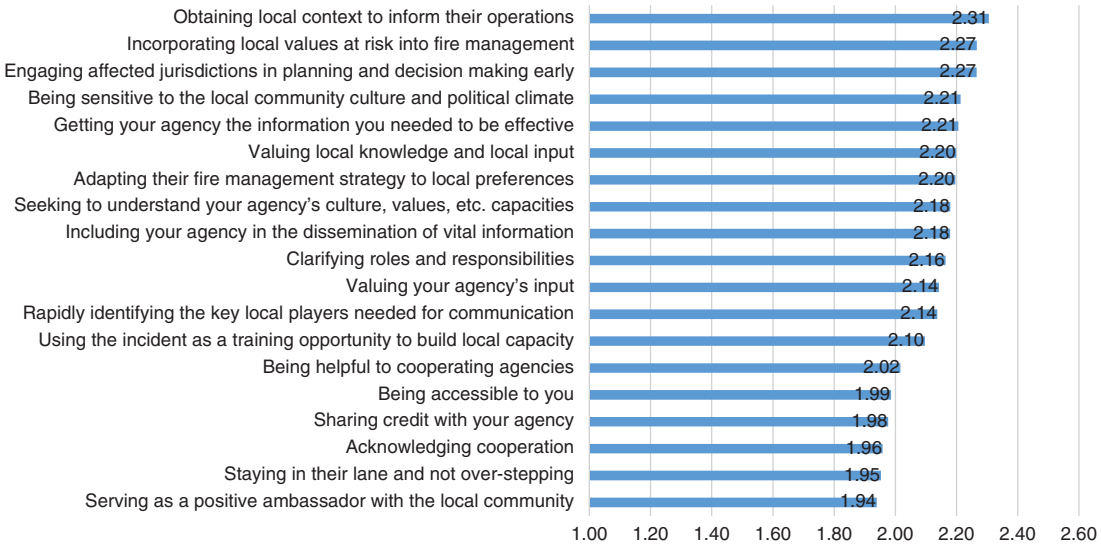

Fig. 3. Incident Management Team (IMT) areas for improvement in working with host units (1–5 room for improvement scale).

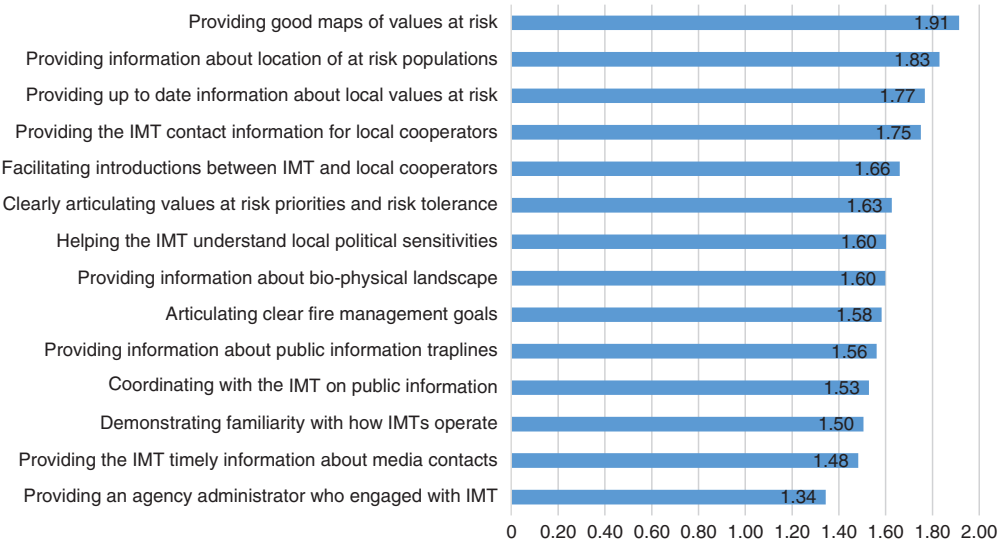

Fig. 4. Host unit areas for improvement in working with Incident Management Teams (IMTs) (1–5 room for improvement scale).

co-operators, providing up-to-date information about the location of residential populations and providing up-to-date information about local values at risk. Host agencies did a good job of providing an agency administrator who was effectively engaged in the incident, providing IMTs with pertinent media contacts, coordinating with IMTs on their public information messaging and demonstrating familiarity with how IMTs operate.

Discussion and conclusions

The Cohesive Strategy raises the question: cohesive for whom and for what purpose? In this article, we address the wildfire response goal and what it means to operationalise the ability to cross scales and potentially co-manage for a more cohesive response. Drawing from the literature on socio-ecological resilience (Holling 1978; Abrams *et al.* 2015; Folke *et al.* 2005), we provide insight into how scales can be matched, the basis for operationalising communication across scales and a path forward for creating more adaptable institutions for more effective wildfire response.

As a wildfire grows, the response must match the scale of its biophysical and jurisdictional complexity (Abrams *et al.* 2015; Steelman 2016). This means integrating a local-scale response with an extra-local response and ensuring there is effective communication and learning across these scales. Historically, wildfire response has been seen through the prism of operations and the need for suppression (Steelman and Burke 2007;

Olson *et al.* 2015; Dunn *et al.* 2017). Other functional aspects of wildfire response, such as evacuations, sheltering and mass care, road closures, interagency coordination and response, and cost share have received less attention. As fires grow in their complexity and scale, the necessity of including these additional functions also grows in importance. It is imperative that the biophysical and jurisdictional scale of the fire matches the socio-political scale. We suggest that a more systems-based definition for understanding wildfire response and the network of actors who are relevant to the functional domains involved will ultimately result in a more effective response. If this is the case, then we need measurement tools to help us understand what constitutes effective performance in these incident response networks. In the present article, we operationalise network-based concepts that provide a way to improve a systems-based response.

The importance of linkages across vertical and horizontal scales (Berkes 2002) and bridging organisations (Cash *et al.* 2006; Crona and Parker 2012) has been argued in the literature. We operationalise these concepts by suggesting that host units, principally the USFS, act as the primary bridging organisation between the local and extra-local scale in wildfire response. The conceptualisation of the host unit as a bridging organisation, the IMT as the extra-local entity for appropriate scale matching and the growing necessity of incident response networks suggest the need for evaluation tools for each. Our approach targets these three elements with context-appropriate questions that provide an avenue for feedback, communication and, ideally, the creation of more responsive wildfire institutions.

Based on the analysis of 21 wildfires in the 2013 wildfire season, network performance is varied based on function. Traditional areas where the command operating structure of the ICS direct attention, such as in interagency coordination and response and public information, received higher marks from all network participants surveyed. These are areas where the IMT has formal control and standard operating procedures are better understood. They are well practiced aspects of IMT standard operating procedure where individuals receive formal training through task books and mentorship. In contrast, areas outside the formal control of the IMT and the command operating structure of the ICS were rated less effective. These include cost share, evacuation and re-entry, and sheltering and mass care. These are areas where IMTs must share decision making with local responders. Our data particularly highlight the importance of improving communication and coordination between fire suppression operations and emergency response operations – evacuation, re-entry, sheltering and mass care. These areas will likely take greater attention and practice as they lie outside what has been the traditional scope of fire operations, but are nonetheless important when considered as part of a systems-wide response. Our tools sensitise all members of the incident response network to what is important and where improvements can be made.

Both the IMT and host unit performance were evaluated positively by their respective counterparts. Host units and co-operators who rated the IMT saw greater room for improvement than the IMT saw for the host unit. Arguably, the IMTs are doing a better job with what might be characterised as the superficial aspects of a co-managed fire response, such as being helpful to cooperating agencies, serving as an ambassador to the local community, being accessible to local agencies, acknowledging cooperation and sharing credit. These elements are critical, yet still comfortable within a hierarchical mode of governance. Areas where the IMTs are rated less well generally correspond to actions that require more power sharing. These include engaging affected jurisdictions in planning and decision making, and incorporating local values at risk into the management of the fire. The findings suggest that a deeper level of commitment to shared decision making may be needed and desirable. Our tools, as demonstrated through the findings presented here, create the opportunity for clearer communication as well as concrete actions and steps towards what it means to be more cohesive when we think about crossing scales and co-managing wildfire response. Co-management can be defined as the sharing of decision making between government and others (Berkes 2009). Our results suggest that moving beyond informing and acknowledging to more joint involvement and decision making is indicated.

The IMT responses showed that host units are doing a good job of providing media contacts, coordinating with the IMT on public information, and demonstrating familiarity with how IMTs operate. All of these harmonise with the standard operating procedures as part of the command operating structure of the ICS. ICS and the command operating structure seemingly provide an effective way to bridge the local with the extra-local, yet they also constrain the possibility of a more systems-based response. Building awareness of these constraints, while continuing to capitalise on the strengths of the ICS command operating structure will be important for any institutionalised progress. IMT responses indicated that host units could do a better job of providing maps of values at risk, providing timely contact information for all local co-operators, and providing up-to-date information about residential populations and local values at risk. These findings suggest specific action areas where host units could be better prepared to host an IMT. Having these items – maps, contact information, data about residential populations and local values at risk – could also prepare host units for greater involvement in decision making and potentially more equitable power sharing with the IMT during the incident. Better preparation at the host unit levels, coupled with greater integration of host unit and local involvement in decision making could help bridge scales more effectively.

At the outset of the present article, we articulated a difference between an operational *v.* systems-based definition related to wildfire response. We advocate for a systems-based approach owing to the growing socio-ecological complexity associated with wildfire response and the concomitant need for co-management in these complex environments. Our goals are to encourage effectiveness in response as they relate to how we can improve coordination, communication and cooperation among a myriad of organisations and agencies that become active during wildfire response to achieve intended outcomes (Nowell *et al.* 2016). However, it is equally important to note that we cannot ignore the importance of suppression, including the scarcity of resources at the national scale and how such resources can be allocated as part of an effective and efficient response, especially in light of taxpayer accountability and concerns for firefighter safety. Our perceptual measures document diverse perspectives and perceptions of efficacy related to the key functional domains

in wildfire response. These can be complemented by more objective measures detailed by Thompson *et al.* (2018), who seek to guide the allocation of national suppression resources so as not to perpetuate excessive suppression response. Neither approach fully captures the needs of what it means to have an efficient or effective response, but together they may come closer to addressing the resource allocation challenges along with the social and political dynamics associated with forging co-management as part of the Cohesive Strategy.

The Cohesive Strategy represents a new national approach for socio-ecological resilience to wildfire. New approaches and tools are needed to ensure we are working towards inclusive, scale-appropriate solutions to achieve this goal. We have laid out a rationale and methodological approach for measuring and evaluating what it means to be cohesive in wildfire response and how such responses might be improved. Our approach is grounded in the reality of the growing complexity of wildfire, both biophysically and socio-politically. Suppression and fire operations are necessary, but insufficient, in the face of this growing complexity as we seek safer and effective wildfire response.

Conflicts of interest

The authors declare no conflict of interest.

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References

Abrams JB, Knapp M, Paveglio TB, Ellison A, Moseley C, Nielsen-Pincus M, Carroll MC (2015) Re-envisioning community–wildfire relations in the US West as adaptive governance. *Ecology and Society* **20**, 34. doi:10.5751/ES-07848-200334

Armitage D, Marschke M, Plummer R (2008) Adaptive co-management and the paradox of learning. *Global Environmental Change* **18**, 86–98. doi:10.1016/J.GLOENVCHA.2007.07.002

Belval EJ, Wei Y, Calkin DE, Stonesifer CS, Thompson MP, Tipton JR (2017) Studying interregional wildland engine assignments for large fire suppression. *International Journal of Wildland Fire* **26**, 642–653. doi:10.1071/WF16162

Berkes F (2002) Cross-scale institutional linkages: perspectives from the bottom up. In 'The drama of the commons'. (Eds E Ostrom, T Dietz, N Dolsak, PC Stern, S Stonich and EU Weber) pp. 293–321 (National Academy Press: Washington, DC, USA).

Berkes F (2009) Evolution of co-management: role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management* **90**, 1692–1702. doi:10.1016/J.JENVMAN.2008.12.001

Calkin DE, Thompson ME, Finney MA (2015) Negative consequences of positive feedbacks in US wildfire management. *Forest Ecosystems* **2**, 9. doi:10.1186/S40663-015-0033-8

Canton-Thompson J, Gebert KM, Thompson B, Jones G, Calkin D, Donovan G (2008) External human factors in incident management team decision-making and their effect on large fire suppression expenditures. *Journal of Forestry* **106**, 416–424.

Cash DW, Adger WN, Berkes F, Garden P, Lebel L, Olsson P, Pritchard L, Young O (2006) Scale and cross-scale dynamics: governance and information in a multilevel world. *Ecology and Society* **11**, 8.

Comfort LK, Kapucu N (2006) Interorganizational coordination in extreme events: the World Trade Center attacks, September 11, 2001. *Natural Hazards* **39**, 309–327. doi:10.1007/S11069-006-0030-X

Crona BI, Parker JN (2012) Learning in support of governance: theories, methods, and a framework to assess how bridging organizations contribute to adaptive resource governance. *Ecology and Society* **17**, 32. doi:10.5751/ES-04534-170132

Donovan GH, Brown TC (2005) An alternative incentive structure for wildfire management on national forest land. *Forest Science* **51**, 387–395.

Dunn CJ, Calkin DE, Thompson MP (2017) Towards enhanced risk management: planning, decision making and monitoring of US wildfire response. *International Journal of Wildland Fire* **26**, 551–556. doi:10.1071/WF17089

Faas AJ, Jones EC, Tobin GA, Whiteford LM, Murphy AD (2015) Critical aspects of social networks in a resettlement setting. *Development in Practice* **25**, 221–233. doi:10.1080/09614524.2015.1000827

Folke C, Hahn T, Olsson P, Norberg J (2005) Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources* **30**, 441–473. doi:10.1146/ANNUREV.ENERGY.30.050504.144511

Hand M, Katuwal H, Calkin DE, Thompson MP (2017) The influence of management teams on the deployment of wildfire suppression resources. *International Journal of Wildland Fire* **26**, 615–629. doi:10.1071/WF16126

Hand MS, Wibbenmeyer MJ, Calkin DE, Thompson MP (2015) Risk preferences, probability weighting, and strategy trade-offs in wildfire management. *Risk Analysis* **35**, 1876–1891. doi:10.1111/RISA.12457

Holling CS (1978) 'Adaptive environmental assessment and management.' (John Wiley and Sons: London, UK)

Ingalsbee T (2017) Whither the paradigm shift? Large wildland fires and the wildfire paradox offer opportunities for a new paradigm of ecological fire management. *International Journal of Wildland Fire* **26**, 557–561. doi:10.1071/WF17062

Jolly WM, Freeborn PH (2017) Towards improving wildland firefighter situational awareness through daily fire behaviour risk assessments in the US Northern Rockies and Northern Great Basin. *International Journal of Wildland Fire* **26**, 574–586. doi:10.1071/WF16153

Kapucu N (2005) Interorganizational coordination in dynamic context: networks in emergency response management. *Connections* **26**, 33–48.

Kapucu N (2006) Interagency communication networks during emergencies boundary spanners in multiagency coordination. *American Review of Public Administration* **36**, 207–225. doi:10.1177/0275074005280605

Kapucu N, Arslan T, Collins ML (2010) Examining intergovernmental and interorganizational response to catastrophic disasters: toward a network-centered approach. *Administration & Society* **42**, 222–247. doi:10.1177/0095399710362517

Katuwal H, Calkin DE, Hand MS (2016) Production and efficiency of large wildland fire suppression effort: a stochastic frontier analysis. *Journal of Environmental Management* **166**, 227–236. doi:10.1016/J.JENVMAN.2015.10.030

Katuwal H, Dunn CJ, Calkin DE (2017) Characterising resource use and potential inefficiencies during large-fire suppression in the western US. *International Journal of Wildland Fire* **26**, 604–614. doi:10.1071/WF17054

Magsino SL (2009) 'Workshop summary: applications of social network analysis for building community disaster resilience.' (National Academies Press: Washington, DC, USA)

Mahanty S, Keen M (2012) Collaborative learning: bridging scales and interests. In 'Social learning in environmental management'. (Eds M Keen, VA Brown, and R Dyball) pp. 119–135. (Routledge: London, UK).

McGuire M, Schneck D (2010) What if Hurricane Katrina hit in 2020? The need for strategic management of disasters. *Public Administration Review* **70**, s201–s207. doi:10.1111/J.1540-6210.2010.02273.X

Nowell B, Steelman T (2013) The role of responder networks in promoting community resilience: toward a measurement framework of network capacity. In 'Disaster resiliency: interdisciplinary perspectives. (Eds N Kapcu, CV Hawkins and FI Rivera) pp. 232–257 (Routledge: New York, NY, USA)

Nowell B, Steelman T Beyond ICS: how should we govern complex disasters in the United States? *Journal of Homeland Security and Emergency Management* (in press)

Nowell B, Steelman T, Velez A-L, Goddette SK (2016) Perspective matters: the challenges of performance measurement in disaster networks. In 'Social network analysis of disaster response, recovery, and adaptation, 1st edn'. (Eds EC Jones and AJ Faas) pp. 59–73 (Elsevier: Oxford, UK).

Nowell B, Steelman T, Velez A-L, Yang Z (2018*a*) The structure of effective governance of disaster response networks: insights from the field. *American Review of Public Administration* **48**, 699–715. doi:10.1177/0275074017724225

Nowell B, Steelman T, Sudweeks J, Hano M, Velez A, Albrech K (2018*b*) Studying networks in complex problem domains: advancing methods in boundary specifications. *Perspectives on Public Management and Governance* **1**, 273–282.

O'Connor CD, Thompson MP, Rodriguez Y, Silva F (2016) Getting ahead of the wildfire problem: quantifying and mapping management challenges and opportunities. *Geosciences* **6**, 35. doi:10.3390/GEOSCIENCES6030035

Olson RL, Bengston DN, DeVaney LA, Thompson TAC (2015) Wildland fire management futures: insights from a foresight panel. USDA Forest Service, Northern Research Station, General Technical Report NRS-152. (Newtown Square, PA, USA)

Pinkerton EW (1992) Translating legal rights into management practice: overcoming barriers to the exercise of co-management. *Human Organization* **51**, 330–341. doi:10.17730/HUMO.51.4.V0127327J24U378R

Reed M, Evely A, Cundill G, Fazey I, Glass J, Laing A, Newig J (2010) What is social learning? *Ecology and Society* **15**, R1. doi:10.5751/ES-03564-1504R01

Steelman T (2016) US wildfire governance as a social-ecological problem. *Ecology and Society* **21**, 3. doi:10.5751/ES-08681-210403

Steelman TA, Burke C (2007) Is wildfire policy in the United States sustainable? *Journal of Forestry* **105**, 67–72.

Steelman TA, McCaffrey SM (2011) What is limiting more flexible fire management – public or agency pressure? *Journal of Forestry* **109**, 454–461.

Stonesifer CS, Calkin DE, Hand MS (2017) Federal fire managers' perceptions of the importance, scarcity and substitutability of suppression resources. *International Journal of Wildland Fire* **26**, 598–603. doi:10.1071/WF16124

Stringer LC, Dougill AJ, Fraser E, Hubacek K, Prel C, Reed MS (2006) Unpacking 'participation' in the adaptive management of social-ecological systems: a critical review. *Ecology and Society* **11**, 39. doi:10.5751/ES-01896-110239

Thompson MP (2014) Social, institutional, and psychological factors affecting wildfire incident decision making. *Society & Natural Resources* **27**, 636–644. doi:10.1080/08941920.2014.901460

Thompson MP, Bowden P, Brough A, Scott JH, Gilbertson-Day J, Taylor A, Anderson J, Haas JR (2016*a*) Application of wildfire risk assessment results to wildfire response planning in the southern Sierra Nevada, California, USA. *Forests* **7**, 64. doi:10.3390/F7030064

Thompson MP, MacGregor DG, Calkin DE (2016*b*) Risk management: core principles and practices, and their relevance to wildland fire. USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-350. (Fort Collins, CO, USA)

Thompson MP, Lauer C, Calkin D, Rieck J, Stonesifer C, Hand M (2018) Wildfire response performance measurement: current and future directions. *Fire* **1**, 21. doi:10.3390/FIRE1020021

US Department of Interior and US Department of Agriculture (2014) National Cohesive Wildland Fire Management Strategy. Available at https://www.forestsandrangelands.gov/strategy/ [Verified 10 April 2017]

Wei Y, Belval EJ, Thomspon MP, Calkin DE, Stonesifer CS (2017) A simulation and optimisation procedure to model daily suppression resource transfers during a fire season in Colorado. *International Journal of Wildland Fire* **26**, 630–641. doi:10.1071/WF16073