Global Environmental Change 41 (2016) 183–194

Contents lists available at ScienceDirect

Global Environmental Change

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

Formation and performance of collaborative disaster management networks: Evidence from a Swedish wildfire response

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ARTICLE INFO

Article history:
Received 3 May 2016
Received in revised form 12 October 2016
Accepted 20 October 2016
Available online 31 October 2016

Keywords:
Collaborative governance
Natural disasters
Networks
Complex societal challenges
ERGM

ABSTRACT

Natural disasters present a multitude of entangled societal challenges beyond the realms and capacities of single actors. Prior research confirms that effective collaboration is of critical significance to address such complex collective action problems. Yet, studies rarely investigate if patterns of collaboration are appropriately aligned ('fit') with how different challenges (tasks) are interdependent, or how levels of fit influence collective action performance. We develop a set of hypotheses specifying what constitutes a good fit between collaborative networks and task interdependency. Using unique empirical data from the response to a major wildfire in Sweden, we examine how individual actors select collaboration partners and tasks during the formation the collaborative crisis response network. Then we test if levels of fit in the established network influence performance. We show that patterns of actor and task interdependency influence the formation of collaborative networks and that a good fit seems to be associated with more effective collaboration. Our data even suggest that a good fit is more important for performance than actors' prior crisis management experience and level of professionalization. Further, we show that actors only partially engage in actor-task configurations conducive to high performance. Our study probes the limitations of simplified accounts of collaborative disaster management by enabling more precise and theoretically informed empirical inquiries regarding the mechanisms that shape the structure and performance of collaborative networks.

1. Introduction

Climate change is expected to bring an increase in the frequency and intensity of natural disasters (IPCC, 2014). An emerging consensus holds that societal responses to collective action problems such as natural disasters are most effective when orchestrated within collaborative governance networks supporting resource-sharing, development of joint solutions, and coordination to avoid duplication of work (Armitage et al., 2009; Folke et al., 2005; Gray, 1985; Waugh and Streib, 2006). Governance challenges related to large-scale natural disasters are however inherently complex to address due to the involvement of a large number of actors with different roles, beliefs, experiences, and capacities, and the interdependent societal and biophysical challenges generated by natural disasters (Ansell et al., 2010; Vespignani, 2010Reyers et al., 2015; Sidle et al., 2013; Waugh and Streib, 2006). These complexities often breed uncertainty about the nature of collective action problems, what actors should be engaged in the response, the preferences and choices of others, and operational goals (Koppenjan and Klijn, 2004). Understanding the mechanisms structuring governance networks, and how they operate and perform to support societies to bounce back from disasters hence presents a central research challenge with important practical implications (cf. Folke, 2006).

Yet, prior research does not adequately capture the interplay between patterns of collaboration and patterns of problem- and task interdependency encountered in disaster situations, or in other complex societal challenges such as sustainable development. Specifically, there is a lack of empirical research demonstrating how complex patterns of task interdependency may influence what tasks and collaboration partners actors engage with during disasters, and under what conditions collaboration is effective. Recent advances in multi-level network modeling (Bodin and Tengö, 2012; Brennecke and Rank, 2016; Guerrero et al., 2015;

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http://dx.doi.org/10.1016/j.gloenvcha.2016.10.004

Wang et al., 2013) provide opportunities to answer these questions in novel ways.

One step towards developing more elaborate theoretical accounts of effective collaborative arrangements for complex societal challenges is to examine what constitutes a good fit between collaborative network structure and task interdependency. In this argument, effective collaborative problem-solving is a function of interactions between the structure of the collaborative network and the structures of task interdependencies (cf. Galaz et al., 2008). Research on natural resource governance (Olsson et al., 2007) and common pool resource dilemmas (Feiock and Scholz, 2009) demonstrates that collaboration arrangements that fail to appropriately match structures and scales of the institutional and the biophysical environment often result in undesired outcomes. Yet, while studies acknowledge that task interdependency constitutes an important driver of collaboration they rarely empirically demonstrate the nature of task interdependency or how task interdependency influences collaboration and performance in different cases and settings (see however Guerrero et al., 2015).

To address this lack of research, we develop a formal model that enables us to document task interdependency and empirically investigate relationships between task interdependency and collaborative (social) network structures. A major wildfire erupting in Sweden in the summer of 2014 forms the empirical basis for our study. The wildfire, which was the largest and most devastating fire in Sweden's modern history, involved multiple municipalities, and a multitude of individuals and organizations were engaged in the crisis response network. In this study, we investigate the individuals (actors) that participated in the crisis response headquarters and in the local municipality-based crisis management organizations. We focus primarily on "mid-level managers" representing different organizations managing and coordinating diverse field activities, acquiring different types of physical and immaterial resources, and coping with the constant influx of new information related to the fire. Based on interview data, we divided and categorized the challenges, or problems, these actors were addressing into eleven separate tasks. Further, we also reconstructed patterns of task interdependencies based on two tasks relying on common resources and/or common activities. Next, using survey data, we empirically examine if and how patterns of collaboration during the disaster response depended on (or 'matched') these patterns of task interdependencies. We defined collaboration as exchange of information, coordination of activities, common planning, and discussion of common tasks. Hereby, we demonstrate if and how task interdependency is a factor that influences actors' selection of collaboration partners. We also examine if and how the specific combination of tasks that actors' choose to engage with relates to different structures of actor-to-actor collaborations and task interdependencies. Thus, for all these inquiries we use the model to unveil underlying social processes affecting how actors select collaboration partners and tasks when forming disaster response collaborative networks. In order words, the empirically observed network of actor- and task relationships constitutes the dependent variable that we seek to explain.

We also use the model to develop theoretical propositions specifying how certain patterns of actor- and task interdependencies constitute a good fit for more effective responses to collective action problems. Here, we turn the attention to plausible performance effects of certain patterns of actor- and task interdependencies. Hence, our model makes it possible to separate the *causes* for a given actor-task structure from the *effects* the very same structure might have on performance (i.e. in the latter case the actor-task network is treated as the explanatory variable, and performance constitutes the dependent variable). If all actors were to select collaboration partners and tasks for the sole purpose of maximizing collective performance, one would expect to see a prevalence of actors to engage in actor-task structures conducive to high performance. However, this expectation rests on a strong assumption of rationality, which holds that actors have access to full information and are motivated solely by a desire to enhance collective action. We will demonstrate that this is not necessarily the case.

2. Theory

2.1. Drivers of collaboration and its outcomes

Collaboration as a way to solve complex societal problems is gaining interest across many scientific fields and disciplines. In public management and administration, public actors working together to solve common and often complex problems through inter-organizational collaborations have received significant attention in research and practice (Raab et al., 2015; Turrini et al., 2010). Collaborative governance has a strong normative appeal, based on the assumption that inclusive and horizontally organized network approaches increase effectiveness in addressing complex and cross-sectoral problems (Ansell and Gash, 2007; Kickert et al., 1997; Koppenjan and Klijn, 2004). Most prior research on collaborative approaches focuses on two broad questions: (1) why actors choose to collaborate, and particularly why do they choose to collaborate with certain others, and (2) are collaborative approaches effective in solving the problems they are set out to address? Empirical research addressing the former question has revealed that there are many factors that shape actors' motivations to engage in collaboration and with whom they prefer to collaborate with (Berardo and Lubell, 2016; Henry et al., 2011; Ingold and Fischer, 2014; Nowell and Steelman, 2015; Scott and Thomas, 2016). Research in relation to the latter question has shown to be more problematic since what qualify as a desired outcome for a collaborative initiative often varies from case to case, and thus defining effectiveness is difficult, ambiguous, and context dependent (e.g. Turrini et al., 2010). Nonetheless, empirical evidence within the broad field of environmental management and governance is building up and demonstrates that collaborative approaches can be effective in solving complex problems, but it is also shown that there is no guarantee that this will happen automatically, and again, the effectiveness in problem solving depends on the specific tasks at hand (Barnes et al., 2016; Bodin et al., 2016b; Folke et al., 2005; Koontz and Thomas, 2006; Lubell et al., 2014; Scott, 2015; Ulibarri, 2015). These insights are corroborated by the growing literature on collaborative responses to crises and disasters, which sheds light on the challenges involved in managing collaboration within multi-organizational networks under conditions of threat, urgency, and uncertainty (McGuire and Silvia, 2010; Moynihan, 2009; Waugh and Streib, 2006). While this literature generally acknowledges the role of interdependency as a key driver for collaboration, less attention has been devoted to assessing the nature of task interdependency, how it affects collaboration, and conditions for collective disaster response performance.

Our study builds on these streams of research, and we seek to advance the understanding of both questions by empirically examining how the nature of the tasks at hand (i.e. the extent to which tasks are more or less interdependent) influence individual actors' choice of collaborating partners as well as effectiveness in performance. Answering these questions however requires development and application of new analytical methods. Hence our study is partly devoted to crafting an analytical approach (model) where patterns of actor collaborations, task interdependencies, and actor-task engagements are explicated. Below we introduce the basics of our modeling approach in conjunction with our propositions relating task performance to specific patterns of actor-task interdependencies.

2.2. A model for actor-task interdependencies

We base our analytical model on three theoretical and methodological approaches. Building from multilevel network models, which recognizes the potential connections that exist between networks at different levels within a complex system (Bodin et al., 2016a; Bodin and Tengö, 2012; Wang et al., 2013), we identify linkages within and between the 'task interdependency network' and the collaborative disaster responder network (Fig. 1). Next, we utilize a minimal building block approach, often applied in social network research (Berardo, 2014; McAllister et al., 2014), to specify theoretically grounded assumptions about relationships between configurations of nodes (i.e. building blocks of actors and tasks and their connections) and performance in terms of the ability to solve these tasks effectively. In the final step, we use multi-level exponential random graph models (ERGMs) (Wang et al., 2013) to infer whether actors select certain configurations over others. The point of a multilevel ERGM analysis is that, similar to multiple predictors in a regression, multiple configurations can be considered together to examine what are most important configurations explaining the structure of the entire network. However, ERGM is specifically constructed to deal with the inherent interdependencies that characterize network data. This feature differentiates ERGM from standard statistical methods such as linear and logistic regression since network data typically violates the assumption of data independency and therefore makes them inappropriate for this type of analyses.

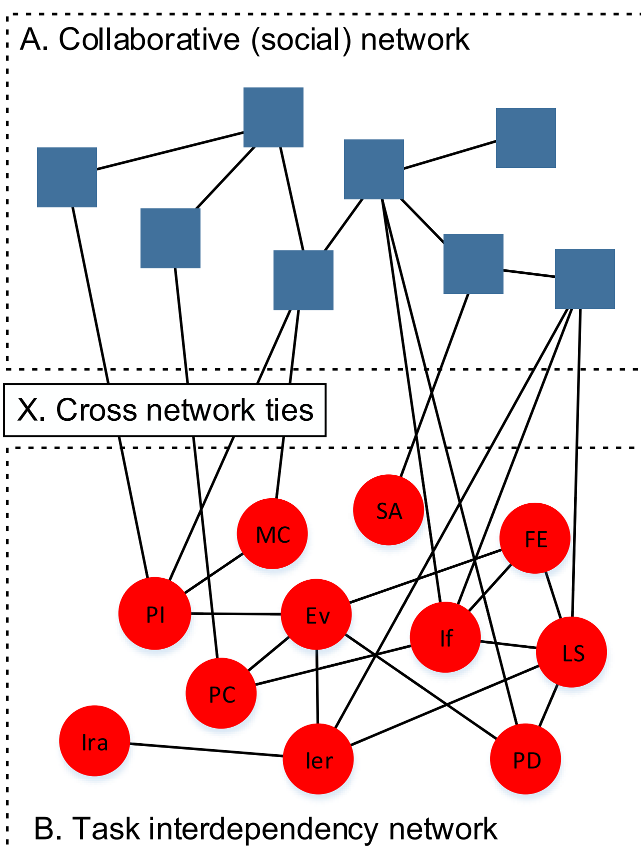


Fig. 1. Multilevel actor-task network. Basic configuration of multilevel network, displaying ties within and between actors within a social network (A) and a task interdependency network (B). Actors are connected to each other through collaborative social ties, and to tasks via ties based on engagement with certain tasks (X), and ties between tasks represent task interdependencies (B). The nodes in network B correspond to the tasks explained in Table 2: PI = Public Information, MC = Mass-media Contacts, PC = Psychosocial Care, Ira = Intra-Organizational Relations, Ier = Inter-Organizational Relations, Ev = Evacuation, SA = Situation Awareness, If = Infrastructure, FE = Fire Extinction, LS = Logistics and Supply, PD = Public Donations.

2.3. Actor-task configurations supporting collective action performance

Different tasks can be interdependent in many ways, but given the nature of the overall collective challenge in our case (responding to a rapidly evolving wildfire given limited time and organizational and material resources), we define task interdependency as a scenario where two tasks require exploitation of some common resource and/or activity. We further assume a positive relationship between efficient use of common resources and activities, and performance in terms of the ability to solve or address tasks effectively.

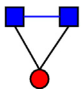
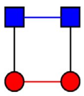
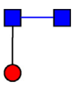
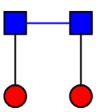
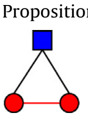
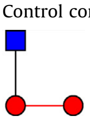
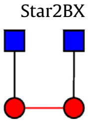
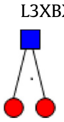
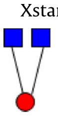
We define three propositions that specify different actor-to-task configurations and their presumed positive effect on collaborative performance using the minimal building block approach (Table 1). All propositions are founded on the assumption that interdependent tasks should be addressed in a coordinated fashion and not separately, and, in turn, that patterns of collaboration ideally should be appropriately aligned ('fit') with patterns of task interdependencies. Propositions 1–2 specify preferred patterns of collaborative partner selection, and proposition 3 specifies preferred patterns of task engagement. Again, it is important to distinguish between propositions regarding the effectiveness of certain configurations in collective problem-solving, and the configurations themselves as explanatory factors for observed actor-task structures (networks). Hence, in order to meet our research objective to better understand the formation of crisis response networks (i.e. actors' choices of collaborating partners and tasks to engage with), we do not limit our analysis to configurations proposed to be conducive to performance. In Table 1 we present some other actor-task configurations. However, at this point we refrain from proposing them being effective or not, instead we treat them as the controls (referred to as 'control configurations').

3. Material and methods

3.1. Empirical setting

Approximately 66% of Sweden's land area is covered by forests and Sweden has the second biggest afforested area (approximately 27 million hectares) in Europe. Some 4500 minor (0.5 ha on average) wildfires erupt in Sweden every year. Major wildfires are relatively rare compared to e.g. Russia, the US, Australia, or the Mediterreanean and occur once or twice every decade. In the summer of 2014, the wildfire that erupted in the *Västmanland* County developed into the biggest wildfire in Sweden's modern history spanning the boundaries of four municipalities (Fig. A1, Appendix A of Supplementary data). Due to a combination of high temperatures and heavy wind, the fire spread rapidly over an area larger than 15.000 ha, increasing the need for inter-organizational coordination. The need for coordination resulted in the creation of an operational headquarters (physically located in the community of 'Ramnäs'), which emerged gradually during the acute phase of the wildfire. The headquarters became an ad-hoc platform for collaboration and coordination in responding to the wildfire, and was populated by hundreds of individuals representing a range of private and public organizations at local, regional, and national levels. The four municipalities that were directly affected by the wildfire ('Sala', 'Surahammar', 'Norberg', and 'Fagersta') mobilized

Table 1
Propositions describing actor-task configurations and their potential implications for problem-solving effectiveness.

Configuration[a]	Interpretation
Actor selection configurations	
Propositions	
 TriangleXAX	*Proposition 1: Problem-solving is more effective if actors working on the same task collaborate* This configuration captures the tendency of actors to collaborate with other actors linked to the same task. Collaboration is expected to facilitate coordination and division of labor, which in turn increases the chances of an effective response. Conversely, lack of collaboration would increase the risk for maladaptive responses due to miscommunication or duplication of work and effort (e.g. Gray, 1985). Furthermore, the accessible pool of knowledge and experiences, typically needed to solve complex tasks, increases if actors that link to the same task collaborate.
 C4AXB	*Proposition 2: Responses to interdependent tasks are more effective if actors who are addressing pairs of interdependent tasks collaborate* This configuration captures the tendency of actors to collaborate with other actors linked to tasks that in turn are linked with the tasks they are linked to themselves. Ideally, two interconnected tasks should be addressed together as a 'whole'. This rests on the assumption that simultaneous attention to interconnected tasks allows for more systemic and integrated solutions, more efficient allocation of resources, coordination, and opportunities to identify and prevent unintended side-effects (Bodin and Tengö, 2012).
Control configurations	
 Star2AX	This configuration captures the tendency of actors that are linked to (relatively) many tasks to link to (relatively) many other actors. The configurations StarAX1A, L3AXB, and ASAXASB capture different alternate versions based on Star2AX as the base configuration (see Appendix A of Supplementary data).
 L3XAX	This configuration captures the tendency of actors that are linked to (relatively) many tasks to link to other actors also linked to (relatively) many tasks.
Task engagement configurations	
Propositions	
 TriangleXBX	*Proposition 3: Interdependent tasks are better solved if addressed by common actors* This configuration captures the tendency of actors to engage with tasks that are interdependent. Following the same logic as in proposition 2, this configuration is likely to facilitate more systemic and integrated solutions.
Control configurations	
 Star2BX	This configuration captures the tendency of actors to engage with tasks that in turn tend to be interdependent with several other tasks. The configurations StarAB1X, StarAX1B, and StarAXAB are different versions based on Star2BX as the base configuration (see Appendix A of Supplementary data).
 L3XBX	The logic of L3XBX is similar to Star2BX above regarding the tendency for interdependent tasks to be address by actors, but L3XBX also implies that both interdependent tasks are popular among the actors to engage with
 Xstar2A	The configuration Xstar2A represents the entangled configuration of TriangleXBX, recognizing that some actors might tend to link to more tasks than other actors.
 XStar2B	The configuration XStar2B represent an entangled configuration of TriangleXAX, recognizing that some tasks tend to attract more actors than other tasks.

■ Actor ● Task

[a] Configuration labels from (Wang et al., 2013).

their own crisis management organizations and retained collaboration within and across municipality borders (Fig. B6, Appendix B of Supplementary data). The headquarters together with these four municipalities form our disaster responder networks that we investigated to disentangle the relationships between task interdependency, collaboration, and performance.

Given that the operational headquarters was a different organizational structure compared to the municipalities (the former being an emergent *ad hoc* organizational structure), we analyze them as two separate networks when explaining social processes of partner selection and collaboration. By contrast, when estimating task-solving performance, we did not distinguish between the two networks but treated them as one single network.

3.2. Data gathering

3.2.1. Interviews

The bulk of the data analyzed in this study comprises responses from a survey issued to 129 individuals (actors) engaged in the disaster response organization during the acute phase of the wildfire. In preparing the survey, we begun with a series of in-depth informant interviews with a selection of actors also involved in the response to the wildfire (19 interviews with 16 individuals). These respondents were drawn from the four municipalities that were most affected by the fire (n = 8), and actors with leading roles in the Ramnäs operational headquarters (n = 8). Interviewees from the municipalities included one representative from the municipality administration and one disaster preparedness coordinator (a formal position upheld by an individual on a permanent basis). Headquarters respondents were selected based on their formal position as coordinators of different key functions in the headquarters (including logistics, planning, information, operations, management support, and personnel). These interviews provided important information about the disaster management process during the acute phase of the wildfire, names of key individuals that were later invited to participate in the survey, and helped identifying several core tasks encountered during the disaster response.

3.2.2. Survey

Interviewees were consulted to identify the actors that were engaged in the crisis response organization. Given that the headquarters was a relatively fluid entity with many individuals coming and going, we asked the respondents from the headquarters to identify individuals within their function whom spend two days or more in the headquarters. Names were drawn from contact lists retrieved from the County Administrative Board of Västmanland. This resulted in a selection of 77 headquarter-based respondents (individual actors) representing 39 organizations in total (see also Appendix B of Supplementary data). A list of respondents from the local (municipality) crisis management organizations was compiled through the interviews with the respondents from the municipalities. In total, we identified 52 respondents from the four municipalities, most of them being managers in charge of different functions within the municipality administration. In all, we consider this set of actors to form the bulk of the crisis response organization (i.e. collaborative network) during the acute phase of the fire, although we acknowledge that many more individuals were engaged – either on a shorter time frame, or being directly engaged with field-based activities (and hence less engaged in planning and management). For example, we excluded firefighters and other first responders engaged in the extinction of the fire from our study population. Further, we excluded a limited number of actors in the headquarters that our interviewees considered to be working in close tandem with other actors already included in the study population. Hereby, no important information would be lost while we could still maintain a manageable sample size covering the actors essentially constituting the complete crisis response network. The online survey included our study population of 129 individuals and was carried out in April–May 2015. We initiated the survey with an introduction letter followed by two automated reminder emails and, in a few cases, reminder phone calls. In total, 122 responses were received (74 headquarter and 48 municipality actors, respectively), for a total response rate of 94.6%.

To identify what tasks actors were working on during the acute phase of the wildfire, prior to the survey we asked the interviewees to describe what were the main problems and challenges encountered during the response. Based on this information, we identified a total of eleven tasks: public information, mass-media contacts, psychosocial care, intra-organizational relations, inter-organizational relations, evacuation, situation awareness, infrastructure, fire extinction, logistics and supply, and public donations (Fig. 1). In the next step, the list of eleven tasks was presented to the survey respondents whom were asked to indicate how much time they spent ('no time', 'little time', 'much time') to address each task. We only included tasks receiving 'much' attention in our analyses of effectiveness. In addition, we asked the respondents about their perceptions on how effective they (i.e. themselves and their collaborators) were in addressing each of these predefined tasks ('not at all effective', 'little effective', 'somewhat effective', 'much effective'). We acknowledge that ideally it would have been preferable to complement this self-assessment of effectiveness with external effectiveness assessments on a task-by-task level. However, since we were primarily interested in *comparing* effectiveness for different tasks, and not primarily interested in arriving at some objective measure of effectiveness for each and every task, we argue that self-assessment is a reasonably robust approach (cf. Mandell and Keast, 2008). In this context it should be mentioned that constructing a more objective measure of effectiveness enabling comparisons across different tasks is an overly daunting task (McConnell, 2011). Also, since we asked the respondents to assess how well they and 'their immediate collaborators' succeeded in addressing each task, we argue the scores are more reliable than they would have been if we asked them to assess overall effectiveness for each task. This approach is based on the assumption that the actors are in a better position to assess their own (perceived) level of effectiveness than to adequately assess the performance of the whole crisis response operation. To measure performance, we used the mean from the respondents' assessments of any a given task to arrive at an aggregated measure of effectiveness for each task respectively.

We also asked about the respondents' personal experiences in managing larger crises prior to the wildfire ('no experience', 'little experience', 'much experience'), and to what extent crisis management related issues were part of their ordinary work duties ('0 h/week', '1–2 h per week', '2–8 h per week', '8–16 h per week', '>16 h per week'). The survey asked several other questions not addressed in this study.

To collect social network data, each respondent was asked to indicate the level of collaboration during the acute phase of the wildfire ('much', 'less', or 'no collaboration') with any of the other 128 individuals being included the survey. Hence, respondents reported on their collaborations, within and across the municipalities and the operational headquarters, with all other individuals in our study population. To specify collaboration, we used the following wording: "collaboration refers to regular professional contacts aiming at some result, for example: exchange of information, coordination of activities, common planning, and discussion of common tasks." Responses regarding collaboration partners were used to construct the actor network (upper network layer in Fig. 1). The ties in the networks were assessed based on two actors each nominating each other as partners with whom they collaborated with 'much'. Fulfilling that criteria, an unweighted (binary) bidirectional ties was assumed, otherwise not. Through this approach we limited our analyses to "strong" ties (we however lowered that threshold for analyses of performance).

3.3. Data analyses

3.3.1. Task independencies

Managing complex natural disasters like major wildfires involves solving a range of different interconnected problems (tasks) (e.g. Fleming et al., 2015; Nowell and Steelman, 2015). Similar to many other complex governance challenges, the ability to address one task is therefore not independent of how other tasks are dealt with (Comfort et al., 2004). Generally, however, some tasks will be more independent than others. Of particular relevance for this study, given its focus on collaboration, are two or more tasks that are interdependent in the sense that their resolution depends on some *common* resources and/or activities. One specific example of the former is a situation where two tasks both depend upon access to individual managers with specific expertise or skills, and/or some type of common material resource (such as a limited number of transportation vehicles). An example of interdependency that emerges from common activities involves two different tasks that both involve provision of information to third-parties, e.g. the general public. In such cases, coordination across tasks aiming to integrate the provision of information reduces the risk that communication is being perceived as contradictory or confusing (e.g. Seeger, 2006).

For this study, we relied on in-depth interviews and public documents to define the most important tasks and their interdependencies. Some of the tasks that we identified through the interviews were also manifested in the organizational design of the operational headquarters (after a few days, the headquarters was organized into several 'sub-units' with different areas of responsibility, for example evacuation, infrastructure, and communication). To define task interdependencies, we draw on insights from prior research on emergency response task networks, which "represent tasks involved in emergency response and their intricate interdependencies" (Wang et al., 2014).

Due to differences in structural and functional properties between systems, there is no universal approach to documenting interdependency among system components (Wang et al., 2012). The same constraint applies in the study of task interdependency in complex natural disasters, where each individual case by definition presents a unique combination of tasks (Abrahamsson et al., 2010). This poses a methodological challenge in terms of documenting task interdependency in a way so that the resulting task interdependency network (i.e. the unique combination of tasks and couplings) is not arbitrary. In this study, we adopt a procedure combining an actor-based representation of interdependencies and an examination of interdependencies identified in a public investigation of the wildfire. The actor-based representation is based on interdependencies that we identified through the interviews. Next, we relied on a public inquiry launched after the wildfire to corroborate these findings and to search for additional interdependencies (Swedish Government Offices, 2015). Our examination of the public inquiry suggested at least three ways to identify task interdependencies:

- Organizational design—organizational solutions (pre-existing or ad hoc structures and procedures) can be founded on the perception that some tasks are interdependent
- Rules—some rules (broadly defined as plans and statutes) prescribe certain behaviors or responsibilities based on a recognition that tasks are interdependent
- Managerial flaws—post hoc and other after action reports might relate managerial flaws to a failure to recognize interdependency between tasks

Stated differently, the public inquiry provides an external operationalization of task interdependencies while the actor-based representation derives interdependencies as subjectively perceived by actors involved in the crisis response.

Based on these definitions and data, we constructed a task interdependency network for the acute phase of the wildfire. The task interdependency network only includes strong interdependencies, which we define according to the relative degree of task coupling (Perrow, 1999). To some extent, all tasks are interdependent by loose couplings – that is, where the ability to address one task is only weakly related to the ability to address other tasks. But in any given task network there are also a number of tighter couplings where tasks are highly interdependent. In our case, this implies that the resources and/or activities they have in common are of key importance for effective problem-solving. This also implies that the potential gains of effective coordination and collaboration among actors charged to address tightly coupled tasks are high.

In the final step, we consulted an informed expert (an anonymous individual with significant practical experience and insight into the Swedish crisis management system and with detailed knowledge about the wildfire response) to corroborate our predefined task interdependency network. The objective with this informal 'reliability test' was to confirm whether we had adequately covered relevant tasks and interdependencies. The expert agreed that the task network was an accurate representation of the challenges encountered during the wildfire.

3.3.2. Collaborative network formation

ERGMs represent a recently developed class of network models that builds on the idea of analyzing larger networks by studying the presence of smaller configurations (often called motifs, see e.g. Milo et al., 2002). ERGMs has recently been extended to account for multi-level networks (Wang et al., 2013), further described in Appendix A of Supplementary data. As in regression analysis, ERGM gives each configuration a parameter estimate and a standard error. The sign of a specific parameter estimate (positive or negative) determines whether the associated configurations are either enhanced or suppressed. The standard error is used to assess statistical significance. Configurations that are not needed to explain the network structure, or whose parameters are not significantly different from zero, are interpreted as neither enhanced nor suppressed (which generally implies that these configurations are neither statistically over- nor underrepresented in relation to what would be expected by chance in the observed network).

Technically, ERGM uses maximum likelihood simulation techniques to fit a parameter vector Θ to a stochastic network model (Lusher et al., 2013):

$$P^{\theta}(X = x) \propto \exp\{\theta s(x)\}$$

where X is a random network (x is the empirical network), and s(x) is a known vector of graph statistics on x. Multilevel ERGM is based on the same modeling approach although it introduces a second network layer along with a cross-cutting network layer that links these other two layers together (Appendix A of Supplementary data). Each element of s(x) represents a specific configuration, and decisions on what configurations to include in the model are often based on assumptions regarding tie formation processes. For this work, we focus on configurations related to our propositions and the specified controls (Table 1, see Appendix A of Supplementary data for a more in-depth description of our modeling approach). Specifically, we tried to find the best fitting models in an explorative manner while also ensuring that all configurations that are associated with our propositions (Table 1) were tested. Hence, if any of these, or any other configurations, are not included in our presentation of the modeling results, our tests revealed that they did either not improve model fit, and/or were given parameter estimates that were not significantly different from zero.

Furthermore, since multilevel ERGM treat the network layers separately (A, B and X in Fig. 1), it is possible to define one or more of them as fixed (given). Hereby, we were able to differentiate between assumed causal directions. Hence, in explaining choice of collaborating partners, we kept both the task network (B) and the actor-task network (X) fixed. Similarly, in explaining what tasks actors engage with, we kept the actor network (A) and the task network (X) fixed. We acknowledge that this is likely a simplification since the actors in our case had significant freedom to select both partners and tasks. However, we argue that by explicating these two (not mutually exclusive) causal directions using separate models, we allow for more transparency in our results, which also facilitates a qualitative assessment in terms of how "strong" these different causal directions might be.

3.3.3. Explaining performance in problem-solving

The counts of actor-task configurations covered by proposition 1–3 (Table 1) for all identified tasks (or pair of interdependent tasks for propositions 2 and 3) were first normalized. We then conducted linear regression analysis to assess if perceived performance on a task-by-task basis (dependent variables) could be explained by the normalized counts of the configurations specified in our propositions 1–3 (independent variables). In the Appendix A of Supplementary data, we describe the normalizing procedure, as well as some important limitations of our data that calls for caution in interpretation estimated *p*-values.

Problem-solving performance, on a task-by-task basis, was based on the mean values of perceived effectiveness among all actors that worked with the task in question. Since these estimates were based on the complete disaster responder network (i.e. no distinction was made between the municipality and the headquarters networks), we applied a less restrictive threshold for the presence of an actor-to-actor tie compared to the analysis of network formation. We did so since many of the between-organizational ties were not as often, in comparison to within-organizational ties, reciprocated with the tie strength assessment 'much collaboration' (this was expected since ties across organizational boundaries are generally weaker compared to within-organizational ties). Since we did not want to discriminate against these less strongly reciprocated but still important ties, we lowered the threshold. For this analysis we thus assumed an unweighted bidirectional tie if at least one in a pair of actors nominated the other as a collaborating partner with whom he/she collaborated with (again focusing exclusively on responses indicating 'much collaboration').

4. Results

4.1. Task interdependency network

Based on several expert interviews and analysis of public documents, we identified eleven tasks encountered during the wildfire response. We then reconstructed a 'task interdependency network' (Fig. 1) based on tight couplings between tasks whose solutions depended on common resources and/or joint activities. In summary, we identified 13 task interdependencies. Table 2 summarizes interdependencies based on common resources and/or activities.

4.2. The actor and actor-task networks

Descriptive statistics about actors' previous crisis management experience and level of professionalization, in total and per task, are presented in Figs. B1–B5 (Appendix B of Supplementary data). Situation awareness and public information were the most common tasks, each engaging 63 respondents (51.6%). On average, each task was addressed by 27.5 (22.5%) actors (considering responses indicating 'much' time spent on any given task). On average, respondents answering the question about collaboration partners (n = 122) identified 19 individuals with whom they collaborated during the wildfire. Given the more strict criterion of 'strong' social ties (based on answers indicating 'much collaboration'), the number drops to 9.1. Fig. B6 (Appendix B of Supplementary data) presents an illustration of the social (actor-to-actor) network (based exclusively on strong reciprocal ties between actors, i.e. ties nominations in the survey that were reciprocated by the receiver).

Interviews with key informants revealed that the crisis management organization in the operational headquarters was populated by many actors that were brought in from other parts of Sweden. In several cases, these actors lacked relevant competences and knowledge of local context. In turn, the process by which actors were assigned to different task was not always carried out in a fully deliberative and informed way. Rather, it was relatively common that actors had to improvise to identify and select suitable tasks to work with. But despite these difficulties, the respondents generally testified to a fairly open and encouraging atmosphere of collaboration, and that it was relatively easy to engage in collaboration with others (91 respondents [76%] indicated that initiation of collaboration worked 'well' or 'very well', whereas only seven respondents [6%] indicated that initiation of collaboration did not work).

4.3. Collaboration partner selection

In investigating partner selection, the task network and the actor-tasks links are seen as given, and the analysis seeks to unveil what mechanisms influence the formation of collaborative ties among actors. Our results indicate a weak but significant tendency of actors with multiple links to tasks to be less involved in collaboration (negative parameter for the Star2AX configuration, see Tables 1 and 3). Here and elsewhere, we do not distinguish between actors that are sought after as collaboration partners by others, and/or actors being more prone to seek collaboration. This tendency only applies to the headquarters-network and not to the municipality-network. We also find, across both networks (Table 3), that pairs of actors with multiple task linkages tend to collaborate with each other (positive estimates for L3XAX, see Table 1). Hence, even though actors in the headquarters-network that engaged with many tasks seem less inclined to collaborate with many others, they (as well as the municipality-actors) tended to collaborate with other actors that are also engaged with many tasks. This tendency is even stronger if tasks are interdependent (positive estimate for C4XAB in proposition 2, Table 1). The latter implies that actors' tendency to collaborate with other actors who are linked to interdependent tasks goes over and above the more general tendency of pairs of actors linked to many problems to collaborate with each other.

4.4. Task engagement

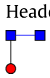
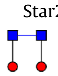
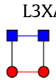
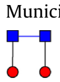
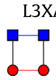
For this part of the analysis, the collaborative network as well as the task network is seen as given, and the analysis seeks to disentangle how patterns of collaborative ties and task interdependencies influence actors' choices of what task they engage with

Table 2
Substantive explanations of task interdependency links and sources.

Task A	Task B	Resources[a]	Activities[b]	Source[c]
Mass-media contacts (MC)	Public information (PI)	Information and public relations specialists	Press releases, interactions with media representatives, IT (web and social media)	I; PI – *organizational design*: joint function in headquarters (p. 63), joint planning resource (p. 60, 98), *rules*: integration of MC and PI part of contingency plan (p. 248, 257)
Public information	Evacuation (Ev)	–	Press releases, interactions with media representatives, IT (web and social media)	I
Evacuation	Psychosocial care (PC)	Psychosocial expertise to support affected populations	–	I; PI – *organizational design*: activating PC part of Ev (p. 59), joint function in headquarters (p. 63)
Intra-organizational relations (Ira)	Inter-organizational relations (Ier)	–	Organizational design, formation of task forces	I; PI – *managerial flaw*: unclear management model (p. 103)
Infrastructure (If)	Logistics and supply (LS)	Roads, railroads	Planning (where can we go – logistic), where should we focus resources (infra)	I
Logistics and supply (LS)	Public donations (PD)	Transportation vehicles, material to use/distribute/store	–	I
Public donations (PD)	Evacuation (Ev)	Personell at temporary housing	Accommodation, planning	I
Infrastructure (If)	Fire extinction (FE)	–	Planning to coordinate limited resources, based on need to uphold infrastructure vs. reducing property damage	I; PI: *organizational design* – joint planning/communication regarding e.g. road closures (p. 76)
Logistics and supply (LS)	Fire extinction (FE)	Transportation vehicles	–	I; PI – *managerial flaw*: difficulties to distribute food and material supply to first responders (p. 47)
Psychosocial care (PC)	Infrastructure (IS)	–	Joint planning	PI – *organizational design*: joint function in headquarters (p. 63)
Evacuation (Ev)	Fire extinction (FE)	First responders a limited resource required for both tasks	–	PI – *managerial flaw*: first responders needed to prioritize evacuation above fire extinction (p. 56, 84)
Inter-organizational relations (Ier)	Logistics and supply (LS)	Communication systems needed for coordination	Specification of responsibility needed to ensure swift mobilization of communication systems	PI – *managerial flaws*: unclear responsibility for communications system (p. 102), lack of technical support systems in headquarters (p. 102)
Evacuation (Ev)	Inter-organizational relations (Ier)		Clear division of responsibility needed to plan and execute evacuation	PI – unclear resposibility for evacuation planning (p. 74)

[a] Resources refer to one or several common human or physical resources required to solving two tasks.
[b] Activities refer to one or several common activities required to solving two tasks.
[c] Sources: I = interviews; PI = public inquiry (Swedish Government Offices, 2015).

Table 3
Partner selection. Results from multilevel ERGM seeking to explain actors' collaborations (assuming that the task network B and the assignment of tasks X are given, see Fig. 1). All parameter estimates are statistically significant.

Configuration	Parameter	Stderr
Headquarter		
	−0,2171	0,051
Star2AX		
	1,1838	0,164
L3XAX		
	0,3382	0,08
C4AXB		
Municipalities		
	0,9437	0,244
L3XAX		
	0,375	0,148
C4AXB		

(i.e. A and B in Fig. 1 are held constant). Patterns of task engagement are presented in Table 4. As predicted by the model, findings regarding actors' (headquarters-actors) linkages to tasks partially resemble patterns of collaboration partner selection (Table 3), although the presumed causal direction is different. Actors with many partners tend to engage with fewer tasks (negative estimate for Star2AX), but there is also a significant tendency for pairs of collaborating actors to each engage with many tasks, and/or engage with tasks that are interdependent (positive estimates for L3XAX and C4XAB). We also see a tendency of some headquarters-network actors to engage with many tasks (positive estimate for XStar2A, Tables 1 and 4).

The municipality-network presents a different pattern of task engagement compared to the headquarters-network. None of the tendencies observed for the headquarters actors are visible in the municipalities (model fit did not improve when including XStar2A, L3XAX, C4XAB in the ERGM, and the t-ratio for these configuration were well below 2, see Table 4 and Appendix A of Supplementary data). Instead, a significant but relatively weak tendency of the actors to engage with certain (i.e. popular) tasks was observed (positive estimate for XStar2B, Table 4). Also, in contrast to the headquarters-network, there is a significant tendency of municipality actors with many collaboration partners to engage with many tasks (positive estimate for Star2AX, Table 4). Finally, both the municipality and the headquarters actors tend to avoid tasks there are interdependent with many other tasks (negative estimates for StarAX1B and StarAB1X, Table 4 and Appendix A of Supplementary data).

Table 4
Task engagement. Results from multilevel ERGM seeking to explain actors' task engagement (assuming that the collaborative networks A and the task network B are given, see Fig. 1). All parameter estimates are statistically significant.

Configurations	Parameter	Stderr
Headquarter		
	0,2506	0,066
XStar2A	−0,1236	0,018
Star2AX	0,726	0,113
L3XAX	−0,2132	0,04
StarAX1B[a]	0,123	0,022
C4AXB		
Municipalities		
	0,0967	0,008
XStar2B	0,226	0,046
Star2AX	−0,128	0,06
StarAB1X[a]		

[a] Alternating star configurations based on Star2BX (Table 1).

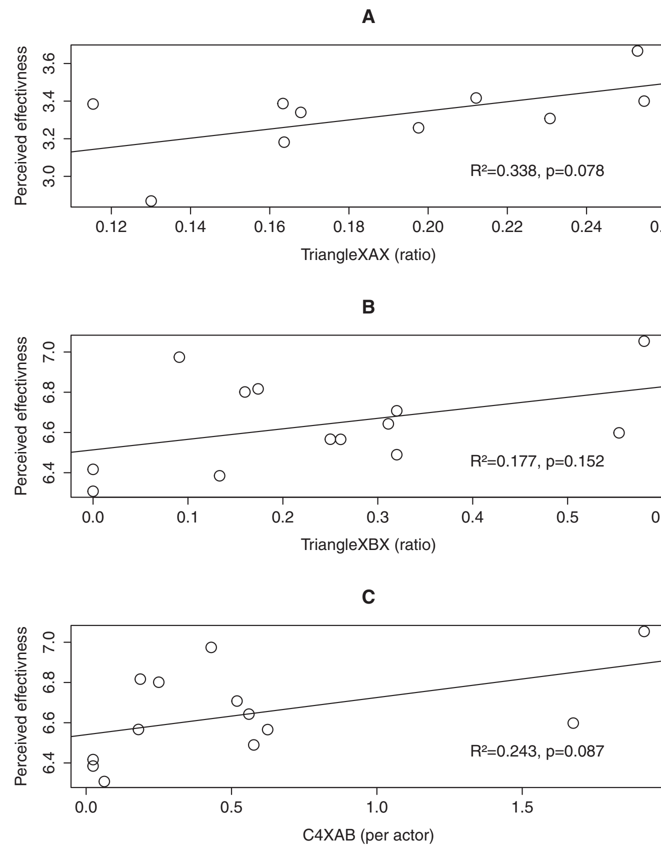


Fig. 2. Analyses of perceived performance. Scatter plots displaying the mean value of perceived performance versus (A) normalized degree of closed triangles of collaboration (two actors engaged with the same task collaborate, i.e. TriangleXAX in proposition 1), (B) normalized degree of closed triangles of task-interdependencies (an actor engage in two interdependent tasks, i.e. TriangleXBX in proposition 3), and (C) normalized degree of closed 2 actor- 2 task configurations (two actors engaged in two interdependent tasks collaborate, i.e. C4XAB in proposition 2). The lines represent the results from linear regression analyses, and R^2 and *p*-values are presented in the graphs. For (B) and (C), the values of performance represent the mean values of perceived performance for the two interdependent tasks being addressed. P-values should be considered with considerable caution (as discussed in Appendix A of Supplementary data).

4.5. Collective action performance

In addition to investigating partner selection and task engagement, we also conduct a tentative examination of collective action performance, which is measured using actors' subjective accounts of the response to each task respectively. Our unit of analysis in explaining problem-solving performance is the task, and our propositions offers a set of predictions about how patterns of actor and task relationships influence the actors' collective ability to address or solve tasks effectively (where effectiveness corresponds to high performance). The fact that our data is limited to eleven tasks (Fig. 1) imposes constraints on statistical inferences about relationships between actor-task structures and performance (these constraints are further discussed in Appendix A of Supplementary data, and includes not only the issue of limited data but also issues of data interdependencies). It should also be noted that we do not assume that our propositions by themselves fully explain performance. Nonetheless, we conducted a series of regression models to make an indicative assessment of whether our propositions are supported by the data (Fig. 2). The results reveal marginally statistically significant support for proposition 1 and 2, whereas proposition 3 receives less support.

To control for other explanatory factors, we conducted similar regression analyses for (1) the degree of interdependency of any given task, (2) the number of actors engaging with any given task, and (3) the mean levels of experiences and professionalization among the actors that engage with any given task (Appendix B of Supplementary data, Fig. B7). Hereby, we compare our primary results with the results from the same type of regression models using two basic structural characteristics of the actor-task network, and for varying levels of experiences and professionalization among actors as explanatory factors. None of these regressions obtained a R^2 higher than 0.124 or a *p*-value lower than 0.319 (Appendix B of Supplementary data), which should be compared to propositions 1 and 2 that received better fit and lower *p*-values. Hence, albeit considerable caution is warranted, our results suggest that propositions 1 and 2 are supported by the data, however we acknowledge the support for proposition 3 to be very weak.

5. Discussion

Our results confirm that the way actors select collaboration partners during a disruptive natural disaster is not random. Instead, the results show that the structure of task interdependencies significantly influences how actors select collaboration partners. This finding is consistent with a rational choice model of the individual, which predicts that actors – even in the midst of a disruptive disaster – engage in collaboration strategically, as a means to minimize loss and maximize resources to solve tasks effectively (Drabek and McEntire, 2002). At the same time, our findings also suggest that actors do not necessarily always engage in actor-task configurations conducive to *collective* problem-solving performance. Our findings also indicate a relationship between structures of actor- and task relationships and actors' choices regarding what tasks to engage with.

Our interview data confirm that actors had significant freedom to select collaboration partners, and also (albeit to a lesser extent) what tasks to engage with. Similar patterns between the municipalities and the headquarters in terms of partner selection (Table 3) support that finding (if partner selection was predetermined at an organizational level, we would have expected greater differences across the two networks). Giving actors significant freedom to seek effective ways for collaboration, and decide with whom to collaborate with, is often lauded as a viable strategy to establish effective collaborative arrangements. Previous work holds that such 'self-organizing' governance networks ensure access to diverse knowledge and experience, supporting joint understandings of complex problems and more effective responses to rapidly evolving governance problems such as a natural disasters (cf. Folke et al., 2005; Ostrom, 2010).

However, the finding that different task-selection dynamics were at play across the two networks (Table 4) suggest that individuals within the two networks faced different constraints and incentive structures, which influenced task engagement. We suggest that these differences can be explained by different temporal and organizational characteristics. The headquarters was an emergent *ad hoc* structure created for the sole purpose of coordinating the wildfire response, whereas the municipality-network largely resembled ordinary local government institutions. In theory, the latter generally implies less freedom in task-engagement since actors have predefined roles, expertise, and areas of responsibility. This conclusion receives further supported by the relatively simplicity of the results in Table 4 (fewer configurations are needed to predict the structural characteristics of the actor-task network). This observation, all else being equal, suggests that there are fewer social processes at play to influence task engagement. These insights expand prior work on how organizational incentive structures shape actors' willingness to participate in collaboration (Ansell and Gash, 2007). Our findings suggest that such incentives not only account for participation in collaboration, but can also shape more specific patterns of task engagement among actors.

Despite these organizational differences, our results demonstrate increased collaboration among actors facing interdependent tasks. This is both interesting and encouraging, since our findings show that this is a configuration conducive to effectiveness (Proposition 2, Table 1 and Fig. 2C). Here, it is also important to note what configurations were *not* supported by the data (i.e. not visible in Tables 3 and 4, which implies that they did not need to be included in the model to explain the observed network). We do not see any tendency among actors in any of the networks to engage with pairs of interdependent tasks captured in proposition 3 (model fit did not improve when including TriangleXBX in the ERGM, and the t-ratios for this configuration were well below 2). Yet, this is the one configuration that received weakest support in our analysis of performance (Proposition 3, Table 1 and Fig. 2B). Additionally, there is no statistically significant tendency of collaboration among actors who engage with the same task (model fit did not improve when including TriangleXAX in proposition 1, Table 1). This finding seems problematic and calls for further research to unveil the reasons why actors do not actively favor collaboration with actors that engage with the same task. Proposition 1 is founded on the rather straightforward assumption, as further explained in Table 1, that tasks would be solved more effectively if actors that are engaged in efforts to solve that specific task collaborate with each other (at least as long as collaboration is kept at a reasonable level, since overly connected actors might suppress performance (Uzzi and Spiro, 2005)). Furthermore, our results indicate that tasks that are being addressed by actors that collaborate with each other (TriangleXAX) are indeed associated with higher levels of performance (Fig. 2A).

In addition to the configurations captured by our propositions, we also find that actors in the headquarters-network that were engaged with a greater number of tasks were less inclined to collaborate with a greater number of other actors (Star2AX, Tables 3 and 4). Although we refrain from attempting to empirically assess how this pattern influenced performance, we speculate that this pattern is likely to have important implications for performance. Above all, actors working with a broader range of tasks become important bearers of information, which – if properly communicated to other actors – can have a positive effect on the collective ability to address tasks effectively. This is conceptually supported by research demonstrating the importance of network centrality for performance (Bodin et al., 2016b; Sparrowe et al., 2001). We also find that highly interdependent tasks (with tight couplings to many other tasks) tend to receive less attention compared to less interdependent tasks (StarAB1X and StarAX1B, which are alternating star configurations of Star2BX, both received significantly negative parameter estimates, see Table 4 and Appendix A of Supplementary data). This finding might be anticipated since the less dependent a task is on other tasks, the less complicated it will be to solve (all else being equal). Hence, actors might be more inclined to engage with these tasks since the likelihood for poor performance is lower, which reduces the risk for an actor to be blamed for managerial failures. The propensity to avoid highly interdependent tasks might also affect performance, although future research will have to explore if and how such effects come about.

In summary, our results demonstrate that actors' choices of collaborating partners, and their choices of what tasks to engage with, are influenced by structures of actor- and task interdependencies. Our findings also suggest that the two networks display a mixture of desired and less desired actor-task configurations. This observation corroborates post-hoc assessments of the wildfire response, which reflect a blend of positive and negative experiences (Swedish Government Offices, 2015), as well as prior work showing that disasters generally trigger a range of interdependent problems, which are dealt with by interconnected sub-networks that display varying levels of performance (Kapucu et al., 2010).

5.1. Concluding remarks

This study demonstrates how complex actor-and task selection processes can be empirically reconstructed using a minimal building block approach combined with stochastic multilevel network models. Specifically, our study confirms the importance of moving beyond simplified assertions of the utility of collaborative governance in addressing disasters by enabling more precise and theoretically informed empirical inquiries regarding the mechanisms that shape the structure and performance of collaborative networks. The merit of this approach largely rests on assumptions regarding how these processes influence performance in terms of the ability to cope with interdependent tasks. Documenting these causal links empirically is challenging and the findings presented here regarding task performance are tentative and need to be interpreted with caution. Our data sample is only large enough for an indicative statistical analysis of the relationship between structures and task performance, performance is assessed solely based on actors' own perceptions, and furthermore we acknowledge that defining ties and network boundaries in different ways could potentially alter modeling results. Nonetheless, from a managerial perspective, some actor-task configurations are likely more desirable regardless of such measurement problems. Configurations associated with adequate matching of collaboration and task interdependencies ('fit') could, based on partly normative assumptions about their importance in facilitating systemic and innovative solutions, be desired despite a lack of empirical evidence of performance.

The analytical approach introduced in this study has broad applicability beyond cases involving (semi-) autonomous actors with significant freedom to select what tasks to engage with and what actors to collaborate with. We therefore encourage future work to compare and contrast findings reported here with studies of mandated or centrally controlled collaboration networks (Gray, 1985; Provan and Kenis, 2007). We hope that this research will enable more comprehensive analyses of when, why, and ultimately how more effective collaborative approaches for disaster mitigation in particular and complex societal challenges in general can be accomplished.

Acknowledgments

We thank the respondents for participating in this study, and Johanna Yletyinen for support with some of the data analyses. This work was supported by Mistra through a core grant to Stockholm Resilience Centre at Stockholm University, the Swedish Civil Contingencies Agency, the Swedish Research Council Formas through a grant to D.N., and through a McCurdy research fellowship grant at Duke University to Ö.B.

Appendices A and B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.gloenvcha.2016.10.004.

References

Abrahamsson, M., Hassel, H., Tehler, H., 2010. Towards a system-oriented framework for analysing and evaluating emergency response. J. Contingencies Cris. Manage. 18, 14–25. doi:http://dx.doi.org/10.1111/j.1468-5973.2009.00601.x.
Ansell, C., Gash, A., 2007. Collaborative governance in theory and practice. J. Public Adm. Res. Theory 18, 543–571. doi:http://dx.doi.org/10.1093/jopart/mum032.
Ansell, C., Boin, A., Keller, A., 2010. Managing transboundary crises: identifying the building blocks of an effective response system. J. Contingencies Cris. Manage. 18, 195–207. doi:http://dx.doi.org/10.1111/j.1468-5973.2010.00620.x.
Armitage, D.R., Plummer, R., Berkes, F., Arthur, R.I., Charles, A.T., Davidson-Hunt, I.J., Diduck, A.P., Doubleday, N.C., Johnson, D.S., Marschke, M., McConney, P., Pinkerton, E.W., Wollenberg, E.K., 2009. Adaptive co-management for social–ecological complexity. Front. Ecol. Environ. 6, 95–102.
Barnes, M.L., Lynham, J., Kalberg, K., Leung, P., 2016. Social networks and environmental outcomes. Proc. Natl. Acad. Sci. U. S. A. doi:http://dx.doi.org/10.1073/pnas.1523245113.
Berardo, R., Lubell, M., 2016. Understanding what shapes a polycentric governance system. Public Adm. Rev doi:http://dx.doi.org/10.1111/puar.12532.
Berardo, R., 2014. Bridging and bonding capital in two-mode collaboration networks. Policy Stud. J. 42, 197–225. doi:http://dx.doi.org/10.1111/psj.12056.
Bodin, Ö., Tengö, M., 2012. Disentangling intangible social-ecological systems. Glob. Environ. Change 22, 430–439. doi:http://dx.doi.org/10.1016/j.gloenvcha.2012.01.005.
Bodin, Ö., Robins, G., Mcallister, R.R.J., Guerrero, A.M., Crona, B., Tengö, M., Lubell, M., 2016a. Theorizing benefits and constraints in collaborative environmental governance: a transdisciplinary social-ecological network approach for empirical investigations. Ecol. Soc. 21, 40. doi:http://dx.doi.org/10.5751/ES-08368-210140.
Bodin, Ö., Sandström, A., Crona, B., 2016b. Collaborative networks for effective ecosystem-based management: a set of working hypotheses. Policy Stud. J. doi:http://dx.doi.org/10.1111/psj.12146.
Brennecke, J., Rank, O.N., 2016. The interplay between formal project memberships and informal advice seeking in knowledge-intensive firms: a multilevel network approach. Soc. Networks 44, 307–318. doi:http://dx.doi.org/10.1016/j.socnet.2015.02.004.
Comfort, L.K., Ko, K., Zagorecki, A., 2004. Coordination in rapidly evolving disaster response systems: the role of information. Am. Behav. Sci. 48, 295–313. doi:http://dx.doi.org/10.1177/0002764204268987.
Drabek, T.E., McEntire, D.A., 2002. Emergent phenomena and multiorganizational coordination in disasters: lessons from the research literature. Int. J. Mass Emerg. Disasters 20, 197–224.
Feiock, R.C., Scholz, J.T., 2009. Self-Organizing Federalism: Collaborative Mechanisms to Mitigate Institutional Collective Action Dilemmas. Cambridge University Press, Cambridge.
Fleming, C.J., McCartha, E.B., Steelman, T.A., 2015. Conflict and collaboration in wildfire management: the role of mission alignment. Public Adm. Rev. 75, 445–454. doi:http://dx.doi.org/10.1111/puar.12353.
Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. Adaptive governance of social-ecological systems. Annu. Rev. Environ. Resour. 30, 441–473.
Folke, C., 2006. Resilience: the emergence of a perspective for social–ecological systems analyses. Glob. Environ. Change 16, 253–267.
Galaz, V., Hahn, T., Olsson, P., Folke, C., Svedin, U., 2008. The problem of fit among biophysical systems, environmental and resource regimes, and broader governance systems: insights and emerging challenges. In: Young, O.R., Schroeder, H., King, L.A. (Eds.), Institutions and Environmental Change: Principal Findings, Applications, and Research Frontiers. MIT Press, Cambridge, pp. 147–186.
Gray, B., 1985. Conditions facilitating interorganizational collaboration. Hum. Relations 38, 911–936. doi:http://dx.doi.org/10.1177/001872678503801001.
Guerrero, A.M., Bodin, Ö., McAllister, R.R.J., Wilson, K.A., 2015. Achieving social-ecological fit through bottom-up collaborative governance: an empirical investigation. Ecol. Soc. 20, 41. doi:http://dx.doi.org/10.5751/ES-08035-200441.
Henry, A.D., Lubell, M., McCoy, M., 2011. Belief systems and social capital as drivers of policy network structure: the case of California regional planning. J. Public Adm. Res. Theory 21, 419–444. doi:http://dx.doi.org/10.1093/jopart/muq042.
IPCC,, 2014. Climate change 2014: synthesis report. In: Pachauri, R.K., Meyer, L.A. (Eds.), Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, pp. 151.
Ingold, K., Fischer, M., 2014. Drivers of collaboration to mitigate climate change: an illustration of Swiss climate policy over 15 years. Glob. Environ. Change 24, 88–98. doi:http://dx.doi.org/10.1016/j.gloenvcha.2013.11.021.
Kapucu, N., Arslan, T., Collins, M.L., 2010. Examining intergovernmental and interorganizational response to catastrophic disasters: toward a network-centered approach. Adm. Soc. 42, 222–247. doi:http://dx.doi.org/10.1177/0095399710362517.
W.J.M. Kickert, E.-H. Klijn, J.F.M. Koppenjan, 1997. Managing Complex Networks: Strategies for the Public Sector, London.
Koontz, T.M., Thomas, C.W., 2006. What do we know and need to know about the environmental outcomes of collaborative management? Public Adm. Rev. 66, 111–121. doi:http://dx.doi.org/10.1111/j.1540-6210.2006.00671.x.
Koppenjan, J.F.M., Klijn, E.H., 2004. Managing uncertainties in networks. A Network Approach to Problem Solving and Decision-Making. Routledge, London, UK.
Lubell, M., Robins, G., Wang, P., 2014. Network structure and institutional complexity in an ecology of water management games. Ecol. Soc. 19, 23. doi:http://dx.doi.org/10.5751/ES-06880-190423.
Lusher, D., Koskinen, J., Robins, G., 2013. Exponential Random Graph Models for Social Networks: Theory, Methods, and Applications. Cambridge University Press, Cambridge.
Mandell, M.P., Keast, R., 2008. Evaluating the effectiveness of interorganizational relations through networks. Public Manage. Rev. 10, 715–731. doi:http://dx.doi.org/10.1080/14719030802423079.
McAllister, R.R.J., McCrea, R., Lubell, M.N., 2014. Policy networks, stakeholder interactions and climate adaptation in the region of South East Queensland, Australia. Reg. Environ. Chang. 14, 527–539. doi:http://dx.doi.org/10.1007/s10113-013-0489-4.
McConnell, A., 2011. Success? Failure? Something in-between? A framework for evaluating crisis management. Policy Soc. 30, 63–76. doi:http://dx.doi.org/10.1016/j.polsoc.2011.03.002.
McGuire, M., Silvia, C., 2010. The effect of problem severity, managerial and organizational capacity, and agency structure on intergovernmental collaboration: evidence from local emergency management. Public Adm. Rev. 70, 279–288. doi:http://dx.doi.org/10.1111/j.1540-6210.2010.02134.x.
Milo, R., Shen-Orr, S., Itzkovitz, S., Kashtan, N., Chklovskii, D., Alon, U., 2002. Network motifs: simple building blocks of complex networks. Science 80 (298), 824–827. doi:http://dx.doi.org/10.1126/science.298.5594.824.
Moynihan, D.P., 2009. The network governance of crisis response: case studies of incident command systems. J. Public Adm. Res. Theory 19, 895–915. doi:http://dx.doi.org/10.1093/jopart/mun033.
Nowell, B., Steelman, T., 2015. Communication under fire: the role of embeddedness in the emergence and efficacy of disaster response communication networks. J. Public Adm. Res. Theory 25, 929–952. doi:http://dx.doi.org/10.1093/jopart/muu021.

Olsson, P., Folke, C., Galaz, V., Hahn, T., Schultz, L., 2007. Enhancing the fit through adaptive co-management: creating and maintaining bridging functions for matching scales in the kristianstads vattenrike biosphere reserve, Sweden. Ecol. Soc. 12, 28.
Ostrom, E., 2010. A long polycentric journey. Annu. Rev. Polit. Sci. 13, 1–23. doi: http://dx.doi.org/10.1146/annurev.polisci.090808.123259.
Perrow, C., 1999. Normal Accidents: Living with High Risk Technologies. Princeton University Press, Princeton.
Provan, K.G., Kenis, P., 2007. Modes of network governance: structure management, and effectiveness. J. Public Adm. Res. Theory 18, 229–252. doi:http://dx.doi.org/10.1093/jopart/mum015.
Raab, J., Mannak, R.S., Cambre, B., 2015. Combining structure governance, and context: a configurational approach to network effectiveness. J. Public Adm. Res. Theory 25, 479–511. doi:http://dx.doi.org/10.1093/jopart/mut039.
Reyers, B., Nel, J.L., O'Farrell, P.J., Sitas, N., Nel, D.C., 2015. Navigating complexity through knowledge coproduction: mainstreaming ecosystem services into disaster risk reduction. Proc. Natl. Acad. Sci. U. S. A. 112, 7362–7368. doi:http://dx.doi.org/10.1073/pnas.1414374112.
Scott, T.A., Thomas, C.W., 2016. Unpacking the collaborative toolbox: why and when do public managers choose collaborative governance strategies? Policy Stud. J. 0, 1–24. doi:http://dx.doi.org/10.1111/psj.12162.
Scott, T., 2015. Does collaboration make any difference? Linking collaborative governance to environmental outcomes. J. Policy Anal. Manage. 34, 537–566. doi:http://dx.doi.org/10.1002/pam.21836.
Seeger, M.W., 2006. Best practices in crisis communication: an expert panel process. J. Appl. Commun. Res. 34, 232–244. doi:http://dx.doi.org/10.1080/00909880600769944.
Sidle, R.C., Benson, W.H., Carriger, J.F., Kamai, T., 2013. Broader perspective on ecosystem sustainability: consequences for decision making. Proc. Natl. Acad. Sci. U. S. A. 110, 9201–9208. doi:http://dx.doi.org/10.1073/pnas.1302328110.
Sparrowe, R.T., Liden, R.C., Wayne, S.J., Kraimer, M.L., 2001. Social networks and the performance of individuals and groups. Acad. Manage. J. 44, 316–325. doi: http://dx.doi.org/10.2307/3069458.
Swedish Government Offices, 2015. Rapport från Skogsbrandsutredningen.
Turrini, A., Cristofoli, D., Frosini, F., Nasi, G., 2010. Networking literature about determinants of network effectiveness. Public Adm. 88, 528–550. doi:http://dx.doi.org/10.1111/j.1467-9299.2009.01791.x.
Ulibarri, N., 2015. Tracing process to performance of collaborative governance: a comparative case study of federal hydropower licensing. Policy Stud. J. 43, 283–308. doi:http://dx.doi.org/10.1111/psj.12096.
Uzzi, B., Spiro, J., 2005. Collaboration and creativity: the small world problem. Am. J. Sociol. 111, 447–504. doi:http://dx.doi.org/10.1086/432782.
Vespignani, A., 2010. The fragility of interdependency. Nature 464, 984–985.
Wang, S., Hong, L., Chen, X., 2012. Vulnerability analysis of interdependent infrastructure systems: a methodological framework. Phys. A: Stat. Mech. Appl. 391, 3323–3335. doi:http://dx.doi.org/10.1016/j.physa.2011.12.043.
Wang, P., Robins, G., Pattison, P., Lazega, E., 2013. Exponential random graph models for multilevel networks. Soc. Networks 35, 96–115.
Wang, D., Qi, C., Wang, H., 2014. Improving emergency response collaboration and resource allocation by task network mapping and analysis. Saf. Sci. 70, 9–18. doi:http://dx.doi.org/10.1016/j.ssci.2014.05.005.
Waugh, W.L., Streib, G., 2006. Collaboration and leadership for effective emergency management. Public Adm. Rev. 66, 131–140. doi:http://dx.doi.org/10.1111/j.1540-6210.2006.00673.x.