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Report

Mapping of social networks as a measure of social resilience of agents

Deliverable 4.2

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Short Description: The capacity of social network maps as a multi-purpose heuristic device is very useful – indeed necessary – if we want to explore ideas of community resilience and planning in the face of natural disasters. As White (1945) put it, if "floods are 'acts of God', flood losses are largely acts of man" and therefore being able to present a formalized, structured understanding of social aspects ("the social") is critical to understanding, communicating, and providing truly integrative research on what community resilience to multiple hazards actually means in practice. Resilience cannot be left to hydrologists and physical planners alone, it must include the social. Our social network maps provide such a model of the links between significant individuals involved in key stages of the disaster planning, response and recovery phases. Further, they do so in a structured manner which allows this necessary social data to be communicated across disciplinary divides and also to be located within the context of a wider conceptual framework that links (social) knowledge networks and (institutional) decision-making structures. As a result, better decisions may be made.

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About emBRACE

The primary aim of the emBRACE project is to build resilience to disasters amongst communities in Europe. To achieve this, it is vital to merge research knowledge, networking and practices as a prerequisite for more coherent scientific approaches. This we will do in the most collaborative way possible.

Specific Objectives

- ⇨ Identify the key dimensions of resilience across a range of disciplines and domains
- ⇨ Develop indicators and indicator systems to measure resilience concerning natural disaster events
- ⇨ Model societal resilience through simulation experiments
- ⇨ Provide a general conceptual framework of resilience, tested and grounded in cross-cultural contexts
- ⇨ Build networks and share knowledge across a range of stakeholders
- ⇨ Tailor communication products and project outputs and outcomes effectively to multiple collaborators, stakeholders and user groups

The emBRACE Methodology

The emBRACE project is methodologically rich and draws on partner expertise across the research methods spectrum. It will apply these methods across scales from the very local to the European.

emBRACE is structured around 9 Work Packages. WP1 will be a systematic evaluation of literature on resilience in the context of natural hazards and disasters. WP2 will develop a conceptual framework. WP3 comprises a disaster data review and needs assessment. WP4 will model societal resilience. WP5 will contextualise resilience using a series of Case studies (floods, heat waves, earthquakes and alpine hazards) across Europe (Czech Republic, Germany, Italy, Poland, Switzerland, Turkey and UK). WP6 will refine the framework: bridging theory, methods and practice. WP7 will exchange knowledge amongst a range of stakeholders. WP8 Policy and practice communication outputs to improve resilience-building in European societies.

Partners

- ⇨ Université catholique de Louvain (UCL) - **Belgium**
- ⇨ University of Northumbria at Newcastle (UoN) - **UK**
- ⇨ King's College London (KCL) - **UK**
- ⇨ United Nations University Institute for Environment and Human Security (UNU), **Bonn**
- ⇨ Accademia Europea per la Ricerca Applicata ed il Per-fezionamento Professionale Bolzano (EURAC) - **Italy**
- ⇨ Helmholtz-Zentrum Fuer Umweltforschung GMBH - UFZ (UFZ) - **Germany**
- ⇨ University of York (SEI-Y) - **UK**
- ⇨ Stockholm Environment Institute - Oxford Office Limited (SEI-O) - **UK**
- ⇨ Swiss Federal Institute for Forest, Snow and Landscape Research - WSL (WSL) - **Switzerland**
- ⇨ Middle East Technical University - Ankara (METU) – **Turkey**
- ⇨ University of Reading, **UK**

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1. Introduction

There is a growing literature that suggests that social networks play a critical role in resilience to disasters (Aldrich 2012, Beilin et al. 2013, Hawkins and Maurer 2010, López-Marrero and Tschakert 2011, Tobin et al. 2014). Social networks can help, particularly in assessing how the network topology (structure, i.e., defined as specific patterns of connections between network actors, called 'nodes' in network terminology) and dynamics (processes, i.e., interactions among the nodes over time and space) influence the nature and level of resilience in a community. Further they can help identify barriers or structural holes in effective communication among actors; highlight aspects of power imbalances; and, provide a multi-actor multi-scalar view of interrelationships within and among communities.

The qualities that make communities resilient can be seen as emanating from unique abilities – inherent or learned – that a community embodies (Barrios 2014). Social network mapping allows us to capture that embodiment. Resilience to natural disasters was at one stage largely left to be a domain of hydrologists, seismologists, geologists, volcanologists, engineers and physical planners. Recent scholarship has challenged this notion and asserts that practices and structures of political and economic relationships, as manifested through social networks, are critical to resilience study. Capturing the structure of social relationships, and mapping them in time and space, contributes to our understanding of how community resilience emerges (*cf*. Barrios 2014: 330).

Structured maps are necessary for understanding and comparing relationships across the levels of governance and across scales of community. Traditional social science methods have on occasions fallen into the practical fieldwork-generated trap of focussing on one scale of community alone. This is unhelpful for understanding what community resilience is, or how it can be facilitated, for the emergent property of community resilience is certainly the produce of cross-scale social relationships that allow communities at local levels to become resilient (or not). The creation of community resilience can be seen as a social capital embodied in the quality of the relationships between people: and this relationship between people can be measured by network mapping.

Further, while traditional social science data-gathering methodologies, such as surveys and interviews, can be used for understanding resilience, only a structured approach to collecting and *mapping* social network data allows us to model social relationships. This formulation allows us to both measure and depict, and lends itself to attaining a level of social network analysis that can be used to feedback into not only our understanding of social capital or resilience, but also into policy formulation. As a research tool, maps have proved very useful at structuring the knowledge of a range of significant actors and re-presenting that knowledge in a way that is quickly and relatively easily usable and understandable by other actors in other positions in space and time. Social network mapping (henceforth SNM) thus can help (a) stakeholders to locate their place within a wider network, and (b) this network can be communicated and explained to others.

Unlike many other more ‘inductive’ social science methods, SNM is relatively front-loaded in terms of the attention that must be given to research design. To attain the precision required for SNM, it is often suggested that the research problem must be clearly identified at the beginning, before any data collection is done and the SNM approach is applied (Beilin et al. 2013, Tobin et al. 2014). However, examples are beginning to surface where from a rich variety of qualitative data, such as narratives or archival data, social networks can emerge (Emmel and Clark 2009, Edwards, G. 2010). In emBRACE we have employed both the approaches, as can be seen from the two case studies that used SNM from each end, i.e. one gathering purposive quantitative data from surveys followed by participant interviews; and the other retrospectively culling network data from in-depth qualitative interview transcripts. We will discuss the pros and cons of both of these approaches (see section 2).

1.1 Objectives

The objective of this deliverable is mapping the networks of individuals and the institutions invested in disaster risk management through the use of social surveys and stakeholder workshops. “The mapping activities will provide quantitative data[1] (one-mode and two-mode network data) that will lead to the development of network measures of resilience (i.e. indicators).” (emBRACE Description of Work). Thus the main focus of this report is to describe the process and the application of the theory of social networks to disaster risk management. The DOW further unpacks the task as follows:

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[1] Here the word ‘quantitative’ is used to mean structured – with the possibility of a numerical value being associated: some of the data is, or course, still subjective.

> “Redundancy is a concept used in Social Network Analysis that can be appropriated to measure how resilient a network is to a perturbation. This task will assess different network measures relating to resilience, for example betweenness centrality (which is inversely correlated to resilience) and cliquishness (positively correlated to resilience). Based on investigation of social networks, the task will consider how network based resources, like support in times of need (or even its promise) and/or information and knowledge for risk management provided through the networks, can boost the sense of resilience.”

In order to deliver on this promise, we have briefly explored the appositeness of concepts about networks and how they work. The theoretical work is dealt with in section 1.2 below about the significance of social networks; and in section 1.3 on typology of social networks. This is followed in section 1.4 with a review of the application of social network visualization and mapping to understanding community resilience. This also includes a section on problems and prospects of social network mapping for disaster planning and response. Section 2 describes two emBRACE case studies where SNM inspired methods were applied. These are Alpine Hazards in South Tyrol, Italy (emBRACE 2015) and Floods in Northern England (emBRACE 2014b)[2]. This is followed by a discussion in section 3 that draws out case study findings on the application of social network mapping as a measure of social resilience among the communities. Section 4 presents the conclusions.

1.2 Social networks in promoting resilience to natural disasters

In recent years, the concept of resilience has been increasingly tied to the concept of social capital. Bourdieu (1986) had previously defined social capital as the sum of the resources, actual or virtual, that accrue to an individual or a group by virtue of possessing a durable network of more or less institutionalized relationships of mutual acquaintance and recognition, and this understanding has not changed. This definition addresses issues of unequal power and conflicting interest through a

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[2] Reports downloadable at: www.embrace-eu.org

critical study of the ways in which individuals and groups are able to effectively mobilize their social networks. Putnam (1996) has explained social capital as 'the features of social organization, such as networks, norms and social trust that enable participants to act together more effectively to pursue shared objectives (p.34). Lin (2008) has extended this idea further to specify social capital as the resources embedded in one's social networks, resources that can be accessed or mobilized through ties in the networks. Through social networks an actor may borrow or capture other actors' resources (e.g., their wealth, power or reputation) and these social resources can then generate a return for the actor.

Social capital is also distinguished as *structural* or *cognitive* (Uphoff and Wijayaratna 2000). S*tructural* forms of social capital are relatively external and objectified and are derived from various aspects of social relationships that can be explicitly described and modified. The category of structural social capital includes *roles, rules, procedures, and precedents* as well as social networks that establish on-going patterns of social interaction within and between communities. *Cognitive* forms of social capital, on the other hand, are more internal and subjective such as norms, values, attitudes and beliefs that predispose people to cooperate.

It is widely recognised that social capital is network-based (Bourdieu 1986, Coleman 1988, Putnam 2000, Burt 2000, Lin 2008). As such, social networks are often seen as a proxy to social capital (White 2002). Within social network theory, three types of connectedness, i.e., bonding, bridging, and linking have been identified as important for the networks within, between, and beyond communities. Bonding social capital refers to trusting and co-operative relations between members of a network who see themselves as being similar, in terms of their shared social identity. Bridging social capital comprises relations of respect and mutuality between people who may differ in their social identities, e.g., age, ethnicity or location, but otherwise more or less equal in terms of their status and power. Linking social capital, by contrast, may be defined as norms of respect and networks of trusting relationships between people who are interacting across explicit, formal or institutionalized power hierarchies, particularly as it pertains to accessing public and private services. While bonding and bridging capital are essentially 'horizontal', linking capital connects people across explicit 'vertical' power differentials. (Szreter and Woolcock 2004 pp. 654–655)

Recently, scholars have sought to link the speed and effectiveness of the process of disaster response and recovery to levels of trust and social capital. Aldrich(2010), while investigating the recovery process after the 1995 Kobe earthquake in Japan, finds that controlling for variables thought important in past research (e.g., damage, population density, economic conditions, and inequality among communities), social capital proves to be the strongest and most robust predictor of population recovery after catastrophe (p.595). López-Marrero and Tschakert (2011) in their study in the flood prone Puerto Rico municipalities show that vertical and horizontal social networks have provided resource flows and assistance in the aftermath of floods. These linkages were important in sharing of diverse knowledge and skills, and for thinking and acting together to develop potential flood management strategies. Increasing resilience to floods required the promotion of effective linkages and partnerships between community members and emergency managers to encourage collaborative flood management. Ainuddin and Routray (2012) investigated social networking and community trust in the aftermath of the earthquake in Baluchistan province of Pakistan. They used close interaction of the members of the community after the crisis and helping each other in the recovery and rebuilding process without any expectation for financial gain as proxies for community trust and social networking and found that these facilitated the coordination and cohesiveness within the community to recover quickly from the earthquake impacts (p.930).

What are the specific mechanisms that allow communities with denser networks to implement a faster recovery following a disaster? According to Aldrich (2010), they are the following. First, social ties can serve as ‘‘informal insurance”, allowing victims to draw upon ready-made support networks for financial, physical, and logistic guidance. Second, more politically active and better connected communities can better mobilize to present their demands to and extract resources from authorities. Third, embedded networks raise the cost of ‘‘exit’’ from a community and increase the probability that residents will use their ‘‘voice’’, following a disaster. In other words, better connected residents are more likely to articulate their demands to authorities and work together to overcome obstacles to recovery (*Ibid*.p.598-599).

Although the robustness and adaptation capacity of social networks are cited as one of the most promising developments for disaster risk reduction in recent years (Alexander 2013), researchers have pointed out how different types of networks and linkages result in different outcomes for the communities. Bourdieu’s comprehensive analysis of the symbolic capital, i.e., the underlying power relationships that shape individuals’ interactions in a social structure (what Uphoff and Wijayaratna 2000 – above – might refer to as a ‘cognitive form of social capital’), is pertinent here. The contingent characteristic of symbolic capital suggests that it is a principal mediator of social capital. As Ballet et al (2007) explains, symbolic capital defines what forms and uses of capital are acknowledged as legitimate bases of social positions—that is, the distribution of powers—in a given society, community, or social group. Community social capital refers here to a set of inter-individual social relationships that are governed by the distribution of this symbolic power among the members, but which are often not distributed equally among the members of the community (*Ibid* p.362). The implication for this is that social inequalities embedded in social networks may obstruct individuals and groups to effectively mobilise bonding capital. The impact of inter-group inequalities in social networks has been studied by researchers in disaster situations. Aldrich and Crook (2008) identifies the duality or 'double-edged sword' of social capital: interpersonal trust and social networks have a positive impact, yet close-knit community structures do not always produce positive outcomes, for example, it may result in the exclusion, rejection or denial of membership and benefits to others. The denial and rejection of the 'others' may have profound and damaging results for members within a social network and amongst competing social networks (White 2002, Cleaver 2005, Manyena 2014). Ganapati (2012) describes the 'downsides of social capital' further for women affected by earthquakes in Turkey, specifically, the perpetuation of gender-based assumptions in post-recovery efforts that placed women in conflict with the state authorities. She argues that attention must be paid to the intra-network power relationships, and particularly to the women's networks in social capital literature.

The potentially negative consequences of strong bonding capital in closed social networks have also no doubt contributed to the emphasis on bridging and linking social capital in the resilience literature following the seminal work of Granovetter (1973) on the strength of weak ties. The 'bridging' social capital contributes to cross-cultural and intergroup linkages, which has the potential to generate far more positive outcomes and inclusive benefits across and between different communities. By analogy, sparse or open networks facilitate access to better or more varied resources or information, control or influence (Lin 1999, Burt 2000, Coffé and Geys 2007, Tobin et al. 2014). Although research shows that the strength of linking capital, e.g., collaboration between community members and emergency managers, is unambiguous (López-Marrero and Tschakert 2011), this area of social capital is much less researched. However, it appears critical in disaster events which surpass a community's ability to cope on its own. Thus strong linking capital becomes essential for reducing vulnerability (Hawkins and Maurer 2010, Aldrich and Meyer 2015, Barker and Thomson 2015).

1.3 Typology of social networks

As described above, social networks are pervasive in all societies and have been widely investigated in recent years as a framework for understanding complex societies, particularly, in order to create robust and efficient networks in response to perturbations, or to improve management for business or social-ecological systems. Creating a robust network, however, depends on understanding the structure and dynamics inherent in the networks. Researchers have identified a number of network types. Below we briefly describe a few of them that have particular relevance in assessing the networks in emBRACE case study areas.

- **Complex dynamic social networks**

The recent literature on complex dynamic networks has largely focused on understanding what are the generic properties arising in networks under different mechanisms of link formation. Most of the mechanisms proposed traditionally have been static, as Vega-Rodondo (2006) argues. Building on research on the construction of small-world networks (Watts and Strogatz 1998), scale-free networks (Baraba´si and Albert 1999) and complex networks (Newman 2003), Vega-Rodondo proposes an approach to understanding complex social networks that is intrinsically dynamic, i.e. at the same time as processes of diffusion take place on the network, the network itself evolves - some links are destroyed while new links are created. As he formulates, the feedback loops between the evolution of the network and the dynamical system on the network are extremely important in understanding the complex dynamic nature of social networks. The theoretical framework proposed by Vega-Rodondo (ibid.) involves a given population of agents – individuals or organizations – who establish bilateral interactions (links) when profitable. The network evolves under changing conditions, e.g., the favourable circumstances lead to the formation of a particular link that may later on deteriorate causing that link to decay and vanish (depending on their volatility). At the same time, new opportunities recurrently arise that allow for the potential establishment of new links (depending on their similarity). Thus the dynamics of a network is conceived as a struggle between volatility (that underlies link decay) and similarity (that underlies new link formation). Further, he argues that the dynamics of inter-node similarity is governed by enhanced close interaction, reflected in most social networks. Thus, individuals who interact regularly tend to converge on their social norms and may build trust. The process of link formation generates three 'stylized facts' about social networks: the sharp transition due to small changes in parameters; the resilience of the network - even when the parameter returns to its original value, the change in the network remains permanent; and the multiplicity of equilibrium network structures. Bloch (2007), in his critique to Vega-Rodondo's theory, notes that although the feedback loop – implying that closer agents are more likely to form new links – is an important result, "one would like to understand better why other link formation processes proposed in the literature (pure random formation, preferential attachment, etc.) do not replicate the stylized facts. One also wonders whether the formation of new links is a mechanical process - as assumed in the paper - or arises from the optimizing behaviour of agents weighing the costs and benefits of the formation of new links." (p.17).

- **Adaptive co-evolutionary network**

The main proponents of adaptive co-evolutionary networks are Gross and Blasius (2008). In reviewing the previous scholarship in this field, they identify two lines of research. The first line is concerned with the *dynamics of networks*. Here, the topology of the network itself is regarded as a dynamical system. It changes in time according to specific, often local, rules. Investigations in this area have revealed that certain evolution rules give rise to peculiar network topologies with special properties. Notable examples include the formation of small world (Watts and Strogatz 1998) and scale-free networks (Baraba´si and Albert 1999). The second major line of network research focuses on the *dynamics on networks*. Here, each node of the network represents a dynamical system. The individual systems are coupled according to the network topology that remains static while the states of the nodes change dynamically. Important processes that are studied within this framework include processes such as opinion formation and epidemic spreading (Newman 2003). According to Gross and Blasius (2008), until recently, the two lines of network research were pursued almost independently in the physical science literature, although, examples of adaptive networks in the social sciences have been studied for decades. Processes like the spreading of rumours, opinions and ideas take place on social networks and are influenced by the topological, while, opinions or beliefs can in turn have an impact on the topology, when conflicting views can lead to the break-up of social contacts (p.261). Thus, in most real-world networks the evolution of the topology is invariably linked to the state of the network and vice versa. In this way a feedback loop between the topology and state of the network is formed. Networks which exhibit such a feedback loop are called co-evolutionary or adaptive networks. Study of the feedback loops can generate insights on how the complex dynamics of social networks give rise to robust topological self-organization of networks. The mechanism for self-organisation is considered an important principle of resilience of social-ecological systems (Ostrom 1990, Walker and Salt 2006, Norberg and Cumming 2008).

- **Coupled adaptive complex networks**

Recent scholarship has further noted that most networks of interest “do not live in isolation. Instead they form components of larger systems in which multiple networks with distinct topologies coexist and where elements distributed amongst different networks may interact directly.” (Leicht and D’Souza 2009 p. 1). This interaction has been termed as percolation i.e., the connectivity among networks. For example, as Leicht and D’Souza note, pathogens can affect human networks spread around the globe, as the recent case of Ebola outbreak showed, through regional and global transport network. Similarly, e-mail networks rely on the Internet which in turn relies on the electricity grid. Thus results obtained in the context of a single isolated network can change dramatically once interactions with other networks are incorporated. Building on the insights gained from percolation among networks as well as adaptivity of independent networks (Gross and Blasius 2008), Shai and Dobson (2013) observe that “real-world networks often interact with or depend on other networks, resulting in *coupled* adaptive networks in which there are links between otherwise independent networks.” Further extending this argument, they observe that one of the important characteristics of a coupled adaptive network is that, while the individual networks are independently adaptive, their dependencies—the links between them—are often permanent (non-adaptive). This limits an individual network’s ability to adapt in the face of challenges, since it can change its own topology but not its dependence on other networks. Whether it is passing on a disease or communicating information, or, whether it is an engineered road network or a biological network, they follow inter-network connections, which do not change with time, as the “dependencies between the coupled networks remain constant.”(p. 042812-1)

In the area of social-ecological systems, several authors have adapted the social network approach to study the structure of coupled social and ecological networks.

Bodin and Tengö (2012) identify meso-structures (motifs) of coupled networks to inform an analysis of a rural agricultural landscapes, using these measures to characterise the management regimes observed. Gonzalès and Parrott (2012) conceptualise different possible relationships among ecological and human sub-systems, such as those occurring in fisheries. They discuss the networks in terms of their robustness to a disturbance.

The above typologies of networks allow us a powerful insight into explaining how our case study networks function, and how complex, adaptive and stable such networks need to be to enhance community resilience. It is critical to know, for our designed approach, that one cannot understand the network-of-interest without understanding the broader context within which this network operates.

1.4. Assessing resilience using Social Network Maps (SNM)

The output of social networks is often presented quantitatively through measures of centrality and connectivity (Freeman 1978, Hanneman and Riddle 2005, Arceneaux 2012). Some studies adopt a range of such measures for assessing resilience and closely related aspects of a network, such as, self-organisation, diversity, redundancy, etc. (Folke 2006, Janssen et al. 2006, Walker and Salt 2006). Others have used the numbers generated though SNA as heuristic devices in discussions with stakeholders in how to interpret and use data, e.g., for natural resource management (Prell et al. 2009). Social network maps have also been used as visual displays to interrogate issues of interest. Network visualizations can reveal key features of a network, e.g., clusters of actors, structural holes, or bridges between clusters. They can also be used during the data collection process to interact with participants to check, confirm and interrogate data presented in the maps to help in the subsequent data collection process. As Conway (2014) observes maps can also be employed to co-create the network in 'real time', a process referred to as 'participatory mapping' (see also the following emBRACE case studies). Conway further discerns two prominent approaches to the production of network graphics. First, a 'graphical excellence' approach that seeks to communicate complex ideas with clarity, precision, and efficiency. Second, a 'visual argument' approach that can stimulate thoughts on the network features. "Whilst these two approaches are potentially complementary, for Tufte (1983 p. 51) 'graphical excellence' requires the researcher to 'tell the truth about the data' via the visual display; clearly this is at odds with a perspective that seeks to emphasize a particular version of the 'truth'." (Conway 2014, p.110). Pertinently, as Latour (2005 p. passim) points out (at the end of a long line of social thinkers) the data in this case isn't real: it is the social ties that are existentially real, not the maps we draw of them. Given this caveat, social network maps are useful and in their utility they adopt their own reality.

Practical applications of visually assessing the pattern of relationships in a network map are described by Cross et al. (2002). Cross's research in the contexts of business organisations, uses maps to reveal a number of interesting and actionable points, for example, identifying people that are highly central in networks can help a manager consider how to reallocate informational domains or decision-making rights so that the group as a whole is more effective; second, understanding who is peripheral in a network and crafting ways to effectively utilise the expertise resident in a given network; third, assessing junctures in networks that are fragmented across functional or hierarchical boundaries (or detecting sub-groups) can be particularly informative for social or technical interventions that help to integrate disparate groups (p.27).

Beilin et al (2013) undertook a case study of two peri-urban landscapes in Victoria, Australia to understand the invisible social drivers and social practices that contribute to local ecological knowledge for landscape management in the Australian Landcare (LC) project. As the LC was built on formal and informal networks, social network analysis was deemed a possible way of demonstrating the existence and importance of this hidden connectivity within and among the LC groups. The authors framed a theoretical question "can SNA demonstrate social resilience" and set out to define social resilience in this context and the qualities associated with that definition. Following the description of social and ecological resilience by Walker and Salt (2006), Beilin et al. identified the following four categories as characteristics of resilience:

(i) *Diversity:* In social terms, it included the plethora of skills and ideas that communities, networks, and groups contained and could draw on for innovation and adaptation.

(ii) *Modularity:* modules were defined as functional components within a sub-system or a larger system that could change and evolve to some extent in an autonomous manner. High modularity was described as a loose structure of linked modules in which change in one module was unlikely to have a severe impact on other modules. On the other hand, low modularity occurred if components were linked in such a way as to function with high dependency on each other, then any shocks or disturbance was likely to travel through the system very quickly, potentially causing a system collapse.

(iii) *Feedback:* this is referred to as how quickly and strongly the consequences of change in one part of the system will impact the other parts. Feedbacks occurred at multiple scales which allowed systems to self-organize to some degree. The authors suggested that Landcare Forums were an example of feedback loops that provided a venue for information and knowledge exchange both at state and national levels. While ideas about optimal ecological restoration practices were disseminated and transformed by local adaptation, these local responses also affected the techniques used to achieve broader restoration within and across production landscapes.

(iv) *Redundancy:* this referred to functioning of the system or subsystems. A system was considered to be more robust if high levels of redundancy existed, such that loss of one agent or group didn't jeopardize the whole system. The authors noted that redundancy was actively built into the LC project by way of a multifunctional network for landscape management that could keep operating even if one or more national or local projects ended.

The study used the visual display of the SNA maps to interrogate local understanding of group coherence and capacity. Social network maps were presented to the participants in a 'sense-making' process to assess its usefulness on-ground and with agency staff involved in the project. The social network maps or the sociograms, were found useful to the groups. As Beilin et al. noted, "We asked if a tool like SNA would be useful to LC groups in helping them to understand and evaluate how their networks functioned, and at a very simple level, given the simple displays that we provided, the answer was yes….. We asked if SNA made the social structures and community capacity underpinning social and ecological resilience within these LC landscapes visible, with the intention that policy makers could more readily support such CBNRM networks, if the connection between social networks and LEK was made more transparent. The agency personnel with whom we worked, and those attending the final presentation of the study to state government, were excited about the possibilities that this tool represents for both quantitative and qualitative interrogation because this has been a much neglected area." Overall, the study found that visual display of SNA tools that made indicators of resilience in social networks visible to policy makers was useful in that the connection between social networks and local ecological knowledge was made more transparent and that was deemed critical in bringing about transformative changes in ecosystem based management.

The other study of resilience-relevance to emBRACE was conducted by Tobin et al. (2014) based in Ecuador and Mexico around two active volcanoes and a landslide/flood area. The study set out to explore how exposure to chronic hazards has a cascading and cumulative effect on the recovery, coping ability, and sustainability of people who live in exposed, evacuated, and resettled communities. Further, it aimed to examine the extent to which social networks mitigate or exacerbate community resilience. Alongside a socio-demographic survey, the study attempted a network analysis: participants (ego) were asked to list 45 contacts (alters) from which 25 were randomly selected and classified according to their personal and social attributes, degree of emotional closeness to ego, the nature of support (social, personal, financial or material) provided by them to ego or vice versa, and the frequency of interaction with one another. The purpose was to assess how such traits affected resilience of the participants to hazard exposure, evacuation and resettlement outcomes. Four main network types were identified:

- *Tight/Closed Networks:* nearly everybody interacts with everybody else forming a tight, often dense group, likely with high cultural homogeneity;
- *Extended Networks:* relatively closed cores but with some ties or bridges to more loosely connected individuals;
- *Subgroup Networks:* at least two distinct groups or cores—these may or may not be well-bridged or connected; and
- *Sparse Networks:* relatively few ties among individuals and few bridges—low density.

The study found that disaster recovery in Ecuador and Mexico was significantly impacted by types of social networks and that the networks played different roles depending on the prevailing conditions in the community,

In Mexico the results suggested that medium density, sub-group networks with good bridging or connectivity to different sub-groups were better adapted to the demands of the disasters and evacuations than those with denser networks and limited bridging. On the other hand, participants with sparse or open/weak networks might not have sufficient social support to act in emergency situations and hence were often more vulnerable and showed lower levels of well-being. Networks with close ties provided greater support mechanisms fostering reciprocal relationships amongst their contacts, including more sharing of materials, labour, tools, and food, than other networks. Nevertheless, networks that incorporated subgroups that extended well beyond the local community often provided additional benefits such as diversity of resources or information, and exhibited stronger well-being even in cases of evacuations.

In Ecuador, similarly, dense personal networks with strong ties and close relationships were associated with greater levels of support and hence recovery, than those with looser networks. However, networks with only a few unique connections were especially important with individuals receiving higher levels of support (material, emotional and informational) than those with more complex networks.

Overall in both the areas social networks impacted disaster recovery and influenced well-being for communities prone to chronic disasters. The degree of variation, however, depended on disaster contexts, frequency of evacuation and patterns of resettlements. It appeared that social networks had been negatively impacted by the resettlement and it needed time before new relationships are constructed.

1.5 Prospects and problems of using social network tools

As noted above, social network analysis has emerged as an important tool in analysing a diverse set of social phenomenon. However, researchers have also noted a number of problems associated with the nature of network data and the methods applied in analysing this data. Butts (2009) notes that the representational framework of networks as the set of nodes together with a set of pairwise relationships among them can be quite restrictive. The correct result will depend on the assumptions the researcher makes about what is interacting, the nature of that interaction, and the time scale on which that interaction takes place. A framework with a well-defined set of discrete components whose interactions are strictly dyadic in nature and are dichotomous, (i.e., either present or absent) can be “so restrictive as to be useless”. (p.414). For example, many interactions can be episodic and can occur at variable intensity, which can substantially alter the properties of the resulting network. The other problem is that ‘non-reciprocal nomination’, where a link is reported by only one of the two individuals in a dyad, maybe ‘symmetrized’ i.e. any interaction was made reciprocal if one node indicated an interaction (Scott, 1991 quoted in Conway, 2014, p.104). Network analysis is also accused of over emphasizing the quantity rather than the quality of relationships. This however can be tackled to some extent by allowing the links to carry different weights or different attributes. Further, if the maps prove of utility in practice to the researchers and to those whose data has informed them (see Section 1.4 above) then we believe that this point can be largely overcome when it comes down to using both the maps (as heuristic devices) and any analysis derived from them.

Boundary setting is another problem in cases where the membership of the group is poorly defined as in the case with informal networks and communities. In such instances, often a snowball sampling is applied whereby a known member identifies further members to include in the group for investigation. In employing such a 'snowball' sampling approach, the network researcher must at some point decide where and when to stop collecting data (Conway 2014 p. 105). The basic problem here, as Butts (2009) notes, is the definition of the class of distinct nodes on which the relationship of interest is based – can such a class be defined and is it scientifically useful to do so? Butts concedes that the choice of individual humans as nodes in studies of friendship or kinship networks, or in the use of individual publications in citation studies, is well-justified. However, studies of interactions between aggregates such as groups, households, or organizations may encounter problems due to the fluidity of the interacting units and the fact that subunits of a larger unit may themselves interact with others both within and without the "parent." For example, his research on organizational responses to the World Trade Centre disaster in 2001, found pooling all the groups operating under the aegis of one national government, obscured the difference between small units such as urban search-and-rescue teams and large government ministries or departments, and this also incorrectly suggested that the resources or collaborators of one are necessarily available to the other. This is an important problem as the choice of a node set can substantially influence the size and density of the resulting network, and the subsequent analysis particularly in hierarchical contexts. Ideally the set of nodes should be defined so as to include all distinct entities that are capable of participating in the relationship under study across networks. Butts suggests that a possible way to tackle this might be simultaneous analysis of the same system at multiple levels of aggregation (*Ibid* pp.414-415).

Time scales may also impact on network processes. Conway (2014) identifies a number of problems related to data collected through questionnaire surveys, interviews, or archival documents that often relate to events taking place over a period of time, as such “effectively conflating time and disregarding the ordering of relational events” (p.105). Butts (2009) warns that failure to consider the time scales on which the processes of interests unfold can lead to ‘extremely misleading results’ (p.416) as a dynamic network analysis may differ from those of a static, time-aggregated network. The impact of the entry and exit of network members on edge dynamics can only be understood by taking into account the dynamic nature of the set of nodes, this is sometimes done by using time-series data, studying processes as time-intervals in long term relationships, or instantaneous events while using radio or internet communications.

Although the above shows that making assumptions and approximations on the nodes, links and time scale can be problematic, studies using participatory research methods, particularly, ‘boundary-spanning narratives’ that can pull together actors with experiential understanding with those having more technical understanding of the systems at work (Ingram et al. 2014). In our case studies, we have tried to address these problems using narratives and stories that underlie the maps (see section 2 below).

2. Case Studies

This deliverable (emBRACE Del.4.2) is part of a suite of reports emanating from Work Package 4, which describes the progress made towards the aim of mapping and modelling (i.e. describing and representing in a structured manner) societal resilience. It follows the emBRACE Framework (emBRACE 2014a), see Figure 1 below.

The framework depicts the dynamic interactions of community resilience across three component domains: resources and capacities, actions and learning. Further, community resilience is influenced by outside forces, comprising context, disturbance and change over time. With its disaster risk governance focus such external context is also acknowledged to encompass laws, policies and responsibilities, which enable and support civil protection practices. These factors influence the development of community resilience through all phases of the disaster risk management cycle of preparedness, response, recovery, mitigation

Fig. 1: The final iteration of the emBRACE framework

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This high-level model iteratively both informed and was informed by the case studies. Thus, the process of social network mapping is intrinsically linked to the framework, as well as to the cases, and the social network mapping process describes one of the critical resources leading towards community resilience as well as the process by which actions can take place and learning can be disseminated. The empirical realities of each case study's social and civil ***Actions***; experience and ***Learning***; and natural and social-political ***Resources & Capacities*** can be explored and more fully understood within the context of the social network map which provides a stylized representation of case study.

Two of emBRACE case studies, Alpine Hazards in South Tyrol, Italy (emBRACE 2015) and Floods in Northern England (emBRACE 2014b), applied social network tools to explore community resilience. These are presented below.

2.1 Alpine Hazards in South Tyrol, Italy

The context

In the Alps, natural hazards are part of everyday life and tied into local history and culture. They shape the livelihoods, identity and resilience of the community. Communities live with continuous risk and cope frequently with small, and sometimes major, impact events. Every year, different kinds of natural hazard events cause damages, losses and sometimes deaths. How to prepare for, cope with and recover from them are key questions for these societies.

This case study focuses on the situation within the municipality of Badia in the Eastern part of the Italian Autonomous Province of Bolzano. This Province, also known as South Tyrol, lies at the geographic and cultural crossroads of northern and southern Europe. It is Italy’s northernmost province and borders Switzerland and Austria (see Map1 below).

Map 1: The location of the municipality of Badia (red area) in South Tyrol
Source: EURAC based on data from the Autonomous Province of Bolzano/Bozen.

When compared to other European areas that are for example at risk of large river floods or earthquakes, alpine regions face a greater variety of natural hazards. In average, these hazards occur at a higher frequency, but are mostly combined with a smaller damage potential.

In December 2012 a landslide occurred in the area of the municipality of Badia triggered mainly by heavy precipitation and temperature variations in the weeks and months before the event. The landslide destroyed 4 residential buildings and 37 people of four Hamlets in immediate vicinity needed to be evacuated. In addition, the down-sliding material threatened to create a lake by damming the riverbed of the Gader stream (Mair and Larcher 2014). In this context, we carried out a study on the nature and dynamic of different actors' disaster 'response' networks so as to understand better how these contributed to their community resilience.

In our case study we refer to the following two types of communities:

Geographical communities are those with identifiable geographical or administrative boundaries or arising from other forms of physical proximity (for example, a street or an apartment block). The geographical community is the boundary of choice for many disaster management functions, although, while likely to be affected by the same type of natural hazard (such as flooding) the boundary can contain much variability (for example, in the context of flood risk, properties on raised ground within a flood envelope may be less vulnerable). In our case study, the geographical community is delimited by the administrative borders of the municipality of Badia and includes all people with a residence in the area of the municipality. In the following discussion we have described them as 'community network'.

Organisational communities comprise, in this context, communities of people drawn from organizations (both statutory and voluntary) providing disaster-related services and support. The members of this community may also share a geographical location and may be affected in the same way as the communities they support (emBRACE 2012). In the following analysis, we have described them as 'organisational network'.

The organisational network comprises two levels:

1) The provincial level, including officers and experts from different departments within the Province of Bolzano involved in risk management (e.g. the Provincial Civil Protection, the Geological office, the Professional Fire brigade); and

2) The local level, including the volunteer organizations, the officers and experts of the municipality, the local divisions of the Province of Bolzano and the local division of the Carabinieri (the national military police of Italy). As described in the definition of the organisation network, in Badia, members of this network are also members of the community network that they support.

Application of social network mapping

In the case study work, we wanted to understand the existing network structure within the communities, as well as the horizontal and vertical ties between members of social networks that help transmit information and provide access to resources at critical time (Aldrich 2012).

In mapping the social networks, we applied two different approaches. First, we carried out a questionnaire survey of 934 households. In this survey, we asked people, to which institutions or organisations they go for support; and who, from their personal network, they contact, in case of an event. Respondents could list up to six institutions ranking them according to their importance. The survey responses were handwritten in three different languages (Ladin, Italian and German) that had to be checked and translated into English so that the analysis could be performed by UK and Italy-based SNM experts. Taking the total number of answers, a frequency analysis was carried out and visualized in network diagram using the software R (R. Development Core Team 2014).The Gephi software (Bastian et al. 2009) was used to make a modularity analysis that helped detection of community structure, by making partitions of the network into sub-networks that are more densely interconnected.

Second, in addition to the population survey, we applied the Net-Map approach (Schiffer 2007) and we carried out individual semi-structured interviews with people working for the institutions that were identified in the survey as the most important for disaster resilience. This method allows to look at situations where different kinds of actors and institutions have to work together to reach a common goal. Some of the actors that participated in this exercise have a double role: they are members of the community, and at the same time, they are actively involved in risk management as part of volunteer organizations, such as, the fire brigade or the first aid service. Some work for local organizations, e.g. the municipality or the local civil protection unit. Others are part of different departments at provincial level but located in Bolzano (over an hour’s drive from the scene of the landslide in Badia), such as, the provincial civil protection, the professional fire brigade or the department for hydraulic engineering. During the interviews, we applied network mapping tools to map and visualize the participants' knowledge and experiences. The use of maps have proved very useful at structuring the knowledge of a range of significant actors and re-presenting that knowledge in a way that is quickly and relatively easily usable and understandable by other actors in other positions in space and time (Taylor et al. 2014). Finally this method allowed understanding of individual views of different kinds of stakeholders holding different responsibilities, power and weaknesses within the network, and their links with actors from different scales, backgrounds and sphere of influence and responsibilities. The interviews focused on their role in risk management and in particular on their experiences during and after the disaster event. The process of social network mapping aimed at assessing and visualizing patterns of responsibility, power, and relationships among different authorities and actors responsible for natural hazard management, communication and coordination. Further, it captured linkages between the organizational network and the community.

During the individual interviews stakeholders created qualitative network maps in 3 steps. First, they wrote names of the actors they engage with on post-it stickers; in the second step, they placed the stickers on a paper sheet according to the perceived closeness of collaboration; the third step, they drew links between them and the actors. The created "paper maps" were afterwards transcribed and imported into the Gephi software for further visualisation and analysis.

Map Analysis

Visualization of all responses for the question, "which institutional actors do you connect to in case of an event" resulted in the "blue graph" depicted below. This visualization forms a bipartite network showing all connections between respondents and institutional actors. A bipartite (or two-mode) network shows the structure of relations among two types of network nodes such as actors and events, where links connect actors and events only (i.e. there are no actor-actor or event-event links). This is a relatively large, sparse network consisting of 934 nodes and 2092 links.

The graphical output helped to visualize proximity – if two institutions were placed close together it meant that some individuals were linked to both of them. It also puts the most central agents more towards the centre. In this figure, the three most

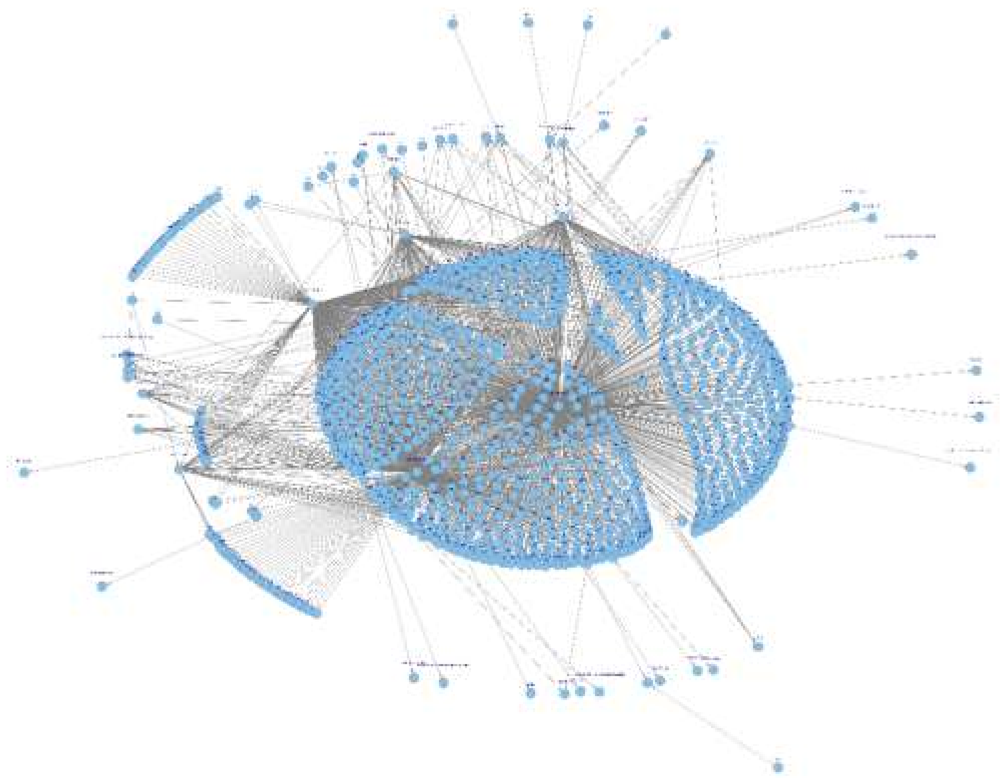

Figure 2: The bipartite network showing all connections between respondents and institutional actors in response to the question "which institutional actors do you connect to in case of an event?"

prominent actors - the fire brigade, the municipality, and civil protection can be seen as being central (see Figure 2.) At this printing resolution, the network is too large to see individual nodes, but the general form of the core and periphery structure can clearly be seen.

Each respondent is also shown as a blue node on Fig 2. In terms of positioning of the respondents, they are grouped closely together based on similarity of their responses.

The degree of similarity can be shown using another network measure known as modularity. Modularity is a measure which targets the detection of community structure, by making partitions of the network into sub-networks that are more densely interconnected. Gephi software was used to produce the following "modularity graph" by using the modularity algorithm to do the colouring of the network nodes.

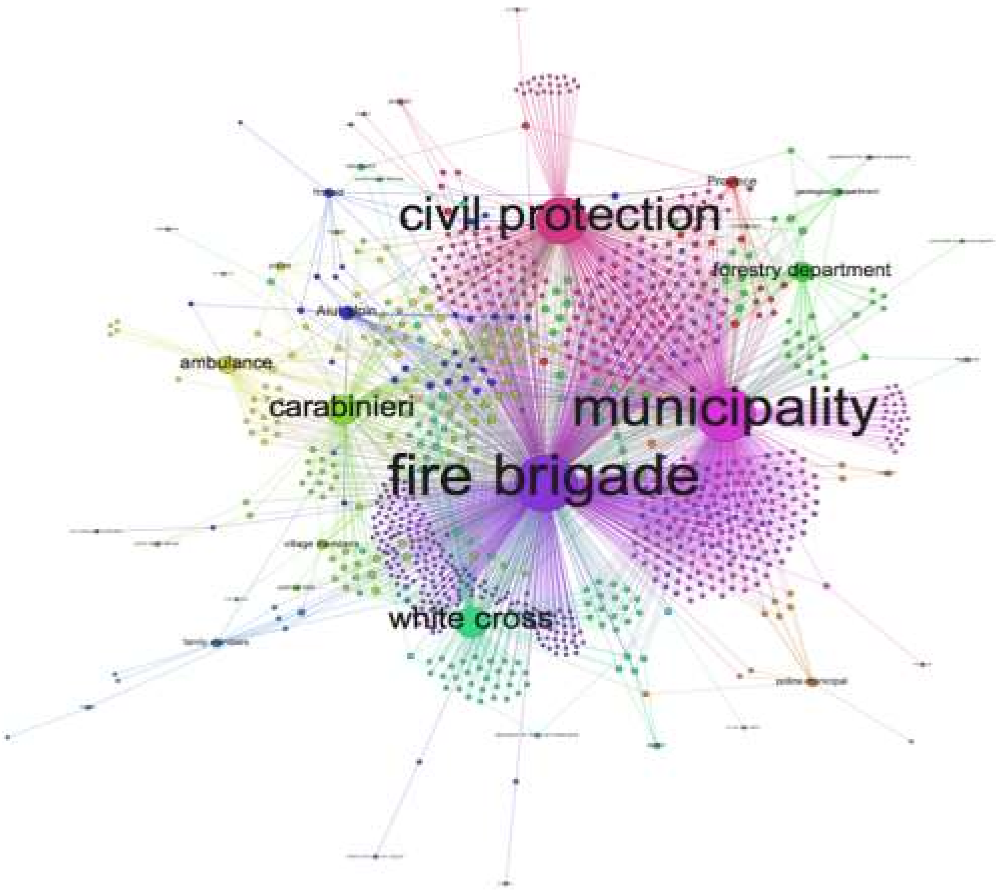

Figure 3: The same data as in Fig 2 but represented using coloured nodes for different institutions

In this graph the nodes are also sized according to their node degree measure. What is noticeable is that the different colours highlight clusters of nodes having the same or similar connectivity; one can also easily compare the relative sizes of the clusters.

A further step was made by using Gephi software to transform the bipartite network into a one-mode network showing only the institutional actors. This network, based on the same data, shows potentially which actors may tend to be contacted together in case of an emergency, thus it would be very important that looking at the network of key actors, they should be well connected in terms of coordinating activities and should avoid providing conflicting information. We investigated these aspects by mapping the network of key actors through a qualitative mapping approach with institutional actors. The results show that the institutions with a high degree of connectivity, derived from population survey data, are also well connected in the network of key actors. This can be interpreted as a strong presence of linking capital, a hypothesis supported by the fact that some members of the community are also key actors and act as linking elements between the two networks, i.e., network of community and network of key actors.

The networks clearly show who the key actors are, according to people living in Badia. The use of a quantitative approach allowed us to include answers from a huge part of the population and visualize their answers in one graph. At the same time, this approach didn't allow to collect further information about quality of the connections or add some qualitative information because people filled in the questionnaire independently and as such the questions had to be short, clear and easily understandable. We therefore applied a qualitative mapping approach with key members of the organisational network (e.g. the Head of the Municipal Coordination Unit, the Commander of the Volunteer fire brigade of Badia, an officer from the Department of Hydraulic Engineering). The detailed methodology is described above. Each interview lasted about an hour when the participants specified the role of their organization within the process of risk management and their personal role within this organization. They also reflected on their ideas about the resilience of the network and possible improvements in terms of missing links or marginalized actors.

The two pictures in Figure 4 show examples of the hand drawn maps by some key members of the organisational network.

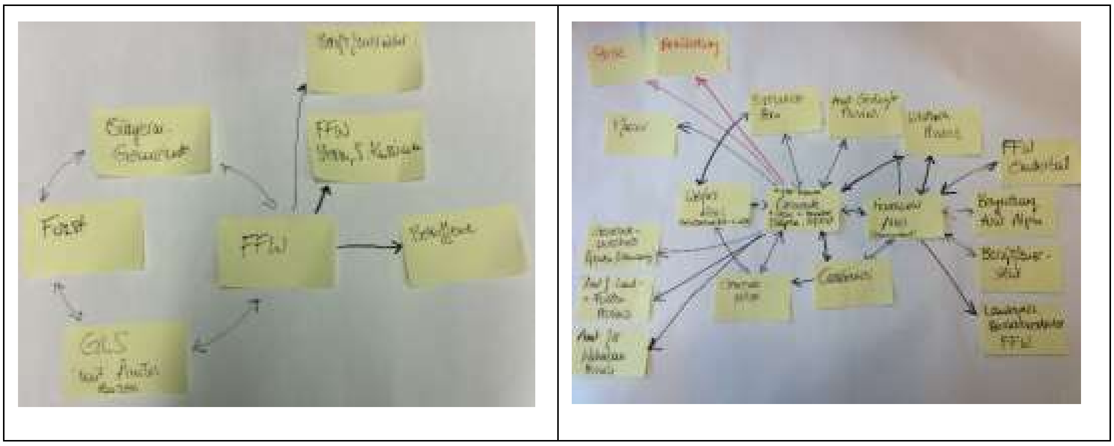

Figure 4: Hand drawn network maps made during individual interview sessions.

These hand drawn "paper maps" were transcribed in order to put them in a format that could be imported into the software Gephi for further visualization and analysis.

This process allowed also inclusion of additional attributes such as scale (local, provincial and national) for each actor. The results are visualized in Figure 5 where each map represents the views of one key actor interviewed. Actors acting at local level are coloured in blue, at provincial level in red and at national level in yellow.

All the maps show a highly interlinked core network involving key actors all connected to each other. There is a high level of coherence between the six different maps. This shows that the different actors have a similar view of the network: this is very important for coordination in a crisis or disaster situation.

Qualitative data from the interviews also reveal that after the event in 2012 the network worked very well. Main reasons for this were the facts that:

a. there were regular emergency exercises prior to the disaster event;
b. the network needed little time to be activated (in case of the landslide event in Badia, it needed only a few hours to be fully operative);
c. the actors from the network already knew each other, which facilitated the work, and helped secure trust in the information and the quality of work provided by other network members;
d. the network was based at the local level and thus had a physical base with facilities for the network members to act upon.

However, there were fewer links to the outside actors, i.e., to the media, the population of Badia, and the organizations at higher levels. This might be interpreted as a lack of bridging ties that are widely recognized being important for building resilience (Granovetter 1973). However, the key actors, during the interviews also expressed the opinion that it was better to have a few links to the outside so that it is

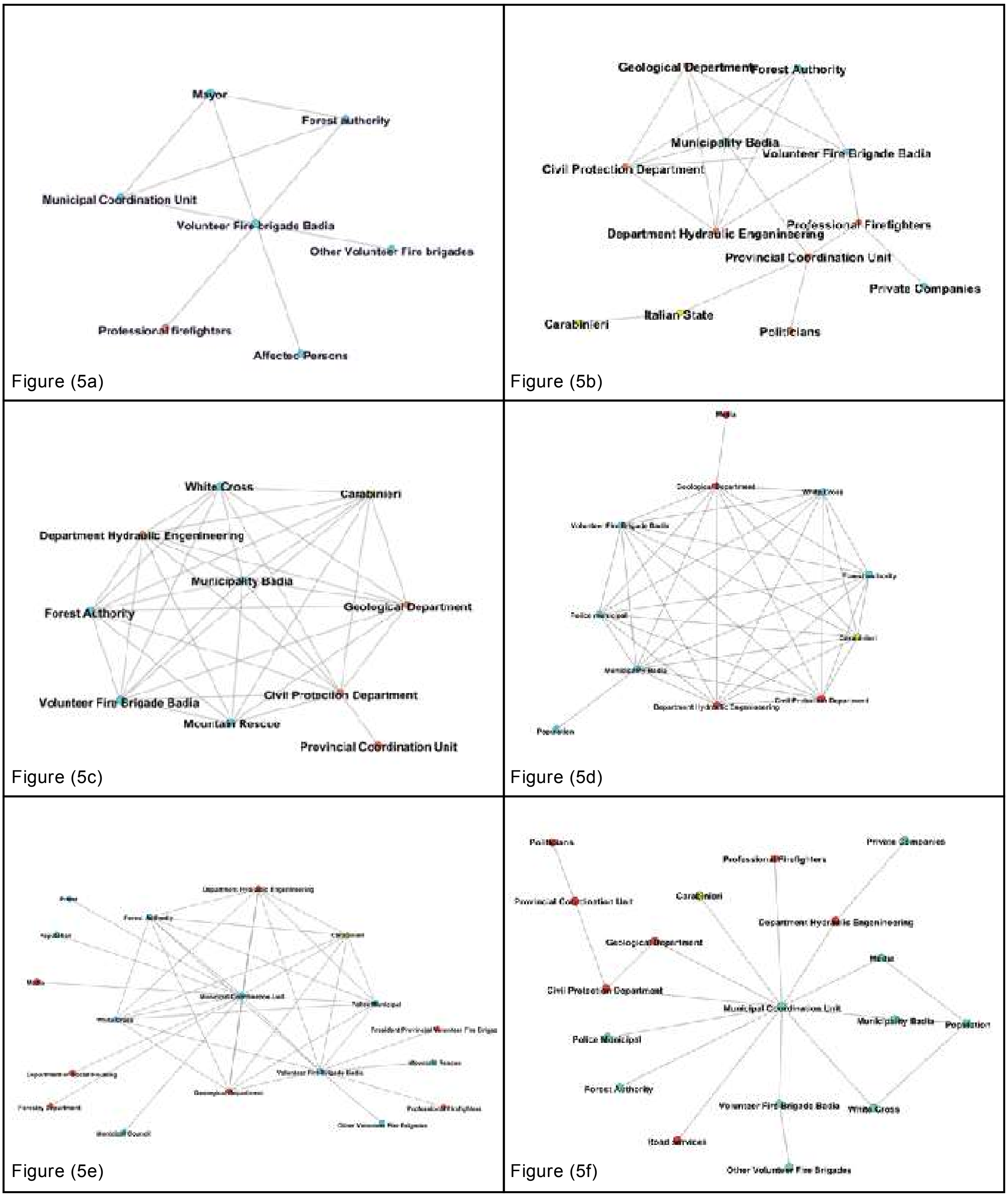

Figure 5: Visualisation of the network of actors based on the hand drawn maps shown in Figure 4. The maps show the interactions between organisations in the response phase. The individual maps reflect different perspectives of the network-in-operation by 6 key actors from: (5a) the volunteer fire brigade, Badia; (5b) civil protection, Badia; (5c) forest authority, Badia; (5d) professional fire brigade, Bolzano; (5e) hydraulic engineering, Bolzano; (5f) civil protection, Bolzano.

clear who communicates with the population and who informs the regional government, compared to having a lot of links with the potential risk of a lack of coordination and conflicts in information delivery. But having only one or two links could also be critical if these links are broken, e.g. where there is no redundancy at all in the system. This dichotomy reflects the nature of a resilience networks and the need for a balanced approach depending on the context.

Discussion

Maps thus produced were an important input for the discussion about "how resilient are existing networks?" and "what are possible measures to increase resilience and improve existing risk management practices?"

The above questions aimed at triggering participants' critical reflections about existing networks and this is also why we choose to adopt individual interviews instead of focus groups or workshops. This facilitated open discussions and allowed avoiding barriers that might arise due to institutional roles, hierarchy or the presence of other colleagues or officers. Furthermore, during the interviews, the maps created from the questionnaire surveys were discussed and participants were asked to check and validate if the institutions contacted by the population were "the right ones" as foreseen by the existing emergency plans.

In terms of resilience of the network, all respondents agreed that the response network resulted to be resilient due to the above mentioned characteristics and that there were no missing links or marginalized actors. It could be argued that some of the characteristics that resulted to be positive for resilience in this circumstance could also weaken the stability and the resilience of the network under other circumstances. The fact, for example, that the network is "highly personalized" meaning that actors are not only representatives of organizations but also "known persons", and the fact that actors know and trust each other and are a well-established and interacting team could become critical for the network if one or more of the actors is not available or has to change positions.

Although the study focused on the networks and their functioning after the landslide event in 2012, the results are also valid for other kinds of hazards. This is because the network structures and their underlying regulations are the same and they should in general guarantee the same protection of people and goods. The composition of the actual network members can vary slightly according to the type of hazards and include additional experts. However, despite this wider validity of the network and its hazard independency, its experiences are strongly linked to alpine hazards, i.e. well-known phenomena. It would be interesting for further research to understand if the network performs in the same way and results as equally resilient if confronted with unknown hazards.

Results show also that the network structure portraying who is part of it and where the responsibilities of each member lie were very clear for the response phase. For the medium and longer term, the network structure and its functioning was not so clear. For example, some members whose tasks clearly linked to the response phase were not involved anymore (e.g. the fire brigade) while new members became part of the network (e.g. the department for social housing). Links and responsibilities, in the later phases of disaster recovery and longer term planning for the future were less defined and less clear, partly due to the fact that the network no more needed to be operative day and night as it was in the first days after the event, and partly because activities for the long term (e.g. financing of rebuilding activities, future zoning and land use of the area) were not as urgent as was the activities soon after the event.

2.2 Floods in Northern England

The context

Cumbria has had a number of well documented historic floods (Whyte 2009). The floods that occurred in January 2005 and the summer of 2009 are the most recent examples of extreme flood events. The 2009 flood (the focus event of this research) caused significant damage to the towns of Cockermouth, Keswick and Workington (the case study locations) and also impacted nearby rural areas on or near the floodplain. The flood took many people by surprise and constituted an extreme weather event - where an unprecedented amount of rain fell over a short period[3] onto an already saturated ground (Cumbria County Council 2011)

The impacts of the flood caused severe disruption across the county and generated national press attention. The flood resulted in severe travel disruption on roads and railways and several bridges collapsed or had to be closed. Across Cumbria a total of

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[3] 314mm of rain fell within a 24 hour period (Cumbria County Council, 2011, p. 8).

2,239 properties were flooded: 80 per cent were people's homes, 20 per cent were shops and businesses, many in the tourist industry, and many schools were forced to close (Cumbria Intelligence Observatory 2010, Cumbria Council for Voluntary Service 2011). Cumbria County Council reported damage to businesses concentrated in Cockermouth, Workington and Keswick[4] and around £100 million worth of damage overall.

Cumbria County Council is the lead local authority for emergency and flood policy for the county of Cumbria. The Environment Agency (government agency with regional offices) and the Council have key responsibility for flood prevention and response. However there are many other agencies that are also involved, including various private sector, government conservation bodies, emergency services and the community, voluntary and third sector. The locally-constituted Flood Action Groups play a pivotal role in lobbying local and central government. Cockermouth and Keswick Flood Action Groups have been particularly successful in advocating on behalf of their communities, this has raised the profile of flooding in these areas politically and helped to secure new flood defences and flood risk management investment in these areas. Cumbria Community Foundation raises money and provides a grants programme for local and community-based projects, including flood projects, and following the 2009 flood event individuals and groups were able to submit an application to receive funding support.

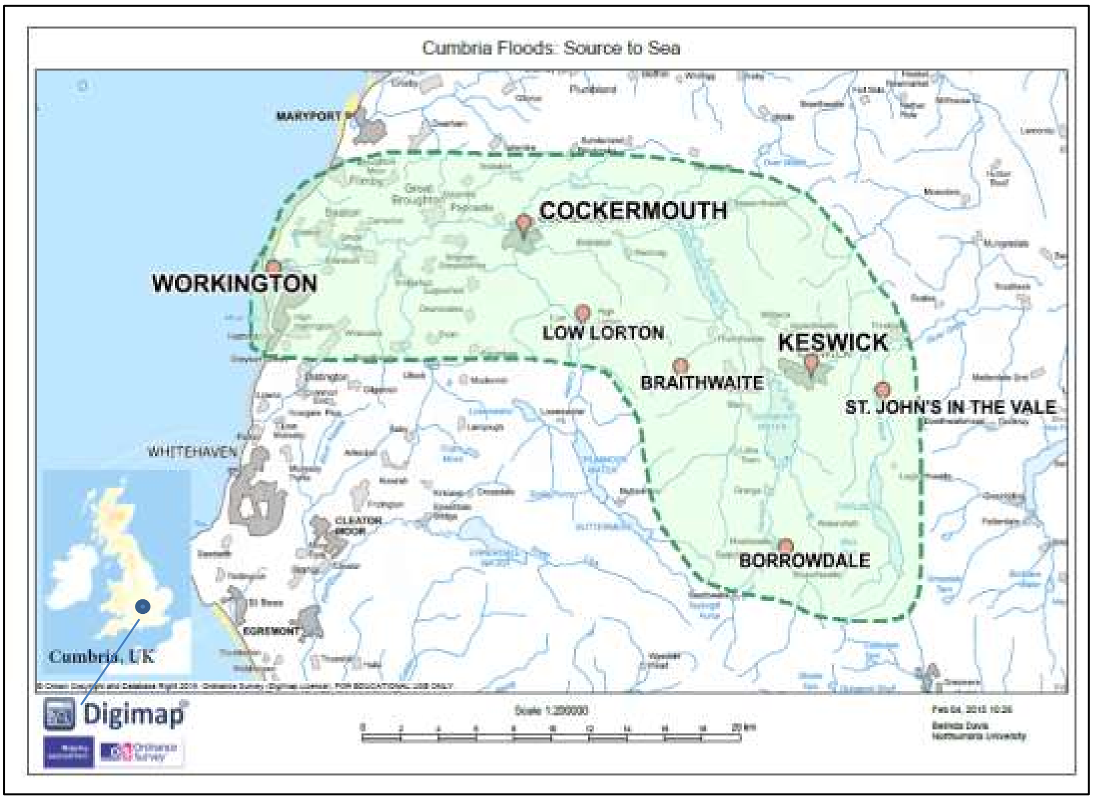
The Study Locations

Cumbria is well known for its high annual rainfall (Cumbria County Council 2011) and more significantly for the Lake District National Park, a popular tourist destination. The Derwent River Catchment, where the case study research took place, is illustrated in Map 2. The Derwent River in this part of the catchment flows from its watershed in Borrowdale and St John's in the Vale, though the towns of Keswick and Cockermouth and towards Workington where it flows into the sea (emBRACE 2014b).

The case study towns of Cockermouth, Keswick and Workington were amongst the worst affected areas in the county though the nature of the impacts differed significantly across locations. Rural pockets of the surrounding farming areas were

[4] See Cumbria County Council website at:
www.cumbria.gov.uk/floods/damageanalysis/economicimpact.asp

also impacted and were therefore included in the research. Rural communities included in the study are Low Lorton, Braithwaite, Borrowdale and St. John's in the Vale.



Map 2: Outline of case study area and research locations in Cumbria showing fluvial systems situated across the Derwent river catchment

Application of social network mapping methods

The overall methodology adopted by this case study constitutes a qualitative study aimed at exploring the wide-ranging aspects of community resilience in relation to community resources and capacities. Data were collected from approximately 60 semi-structured in-depth interviews with individuals. Additional data were also obtained from several small workshops with key community members. Although the case study did not set out initially to undertake social network mapping, social networks emerged strongly from the data as key contributors to community resilience and therefore researchers on the case study decided it would be worth exploring whether the data could be used for social network mapping. As a consequence, data were qualitatively quite rich, yet partial in terms of including all potential nodes and links; in addition, boundaries were not clearly defined. Social mapping therefore represented an experimental exercise that sought to identify what could be achieved with the data already collected. The overall aim of social network mapping was to explore whether it was possible to identify: 1) what type of resources or support (e.g. physical, social, emotional, financial) was sought by actors in the case study communities before, during and after the flood; and 2) which organisations or individuals are providing this support; and 3) who are the central actors within specific social networks. Colour coded links and a descriptive key are used to identify type of resources and support; individuals and organisations are identified by coded nodes and centrality is depicted using larger sized nodes for higher betweenness centrality. Other specific social network features that were identified in the dataset included the following relational aspects:

1) The type of activity (relating to: mitigation, preparedness, response or recovery)
2) The quality of the interactions (1= good; 2= bad)
3) The nature of the interactions (i.e. collaboration, complaint about a service, flood action group activity or professional contact) (identified through colour coded links)
4) The frequency of the interactions (1= one contact. 2= 2 or more contacts. 3= collaboration).
5) If the interaction was identified by both actors in a dyadic link or by one actor only (identified by arrow heads on links)
6) If the relationships are bonding, bridging or linking (identified by line types).

It should be noted here that due to time and data constraint we have not fully analysed all of these characteristics.

Information collated about the actors included:

1) Council service or not
2) Location (e.g. local, regional, national)
3) Sectors to which the actor belongs (e.g. local or central government, third sector, private sector and environmental sectors)
4) Gender

The above information that was collated was aspirational and not all elements were captured in the maps due to methodological constraints. For example, separating the data out into cross-sectional components such as location and disaster phases (mitigation, preparedness, response and recovery) did not work well due to insufficient data, which resulted in graphical distortions in the maps. Areas that were most useful to illustrate on the maps were the types of resources and support sought (shown through colour-coded links); where this support came from (i.e. both individual and organisation-based nodes) and who is central to a given network. The resources were categorised into the following three 'service provider' sectors: civil protection, community and social protection and highlighted on the whole network map. This map also indicates which of these resources are provided specifically by the Council.

In order to maintain participant anonymity a coding framework was developed. For individuals this simply involved using the prefix C followed by a number (e.g. C15). The coding framework for actors belonging to specific organisations or sectors is shown in Table 1.

Table 1: Coding Framework

1	Governance (National)
1A	Environment Agency
1B	County Council
1C	Emergency Services
2	District Council
3-1	Third Sector (National/county)
3-2	Third Sector (District)
3-3	Third Sector (Flood Action Group)
4	Community member
4A	Neighbour
4B	Family Member
5	Private Sector
6	Academic
7	Media
8	Insurance

Understanding who the central actors (or nodes) are within specific communities can provide insight into how resources are obtained and dispersed into a community. The more dense and diverse a person's network connections are the more empowered they will be to access information and resources (Marcus et al. 2011). In this study central nodes constituted well connected individuals who were seen as having a key role in providing support to their local communities through the mobilisation and distribution of resources. The community-based Flood Action Groups were of particular interest due to their ability to access and distribute resources through their well-connected group members. Centrality scores were calculated using both *betweenness centrality*[5] and *degree centrality*[6] scores, and both were used to identify central actors (Table 2). Using centrality scores calculated over the whole network, a cut-off of 500 for betweenness and 25 for degree centrality were used to identify key agents quantitatively. Using the whole data set for applying the measures, individuals that achieved high scores were considered to have high centrality. For the study reported here, ego-network analysis was also conducted, because we were interested in understanding the relationships of some of the more prominent members of the network in more detail. In carrying out this step, it was decided that *betweenness centrality* was most appropriate for gauging an actor's direct and indirect influence within a network (see definition below). However, a final selection of two individuals, C04 and C15, was made based on the researchers' understanding of local realities. C04 (a member of a key Cumbrian community group) scored highly on both betweenness centrality and degree centrality. This is to be expected given the nature of this individual's role that requires high levels of community engagement. Actor C15 (female Keswick Flood Action Group member) scored second highest on betweenness centrality and highest on degree centrality. This centrality finding supported the broader qualitative findings that this member has been influential in the Keswick community in relation to building resilience to flooding.

Betweenness centrality is closely related to the measure of average path length (or geodesic distance) of a network. This latter measure involves finding the shortest path, often indirectly via intermediary actors, between every pair of network nodes. Having obtained this set of shortest paths, it can be seen how much intermediation may be needed to facilitate potential network flows. It can also be seen that some actors are more important for intermediation than others. Betweenness centrality turns this concept of indirect centrality / intermediation into a metric. An actor's betweenness centrality score is number of times that the actor is on the path between the other pairs of agents.

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[5] Betweeness centrality is calculated by counting the number of direct and indirect links or edges that an actor has with other actors in the network and is therefore a good measure of an actor's wider influence within a network.

[6] Degree centrality is simply calculated by counting the number of links an actor has with other actors in a network.

Table 2: Highest Betweenness and Degree Centrality Scores

Actor	Betweenness centrality	Degree centrality	Location
C15	1152.96	49	Local
C57	0	48	Local
C04-1	780.39	39	Local
1A	0	32	County
C03	0	29	Rural
C61	405.62	29	County
C18-1	737.56	28	Local
C62	0	26	Local
C12	659.23	22	County
C10	861.67	21	County
C32	1575.16	23	County

.

Degree centrality is more straightforward measure as it does not depend on the wider connections. It is calculated as the number of direct connections of an actor to and from other actors. The two measures are thought to correlate closely to individual resilience. If an individual has together both direct and indirect connection with the community, and both accesses and contributes multiple resources/capitals, then that individual is likely to be able to better manage adversity and is also likely to be a key resource - individual resilience is thought also to be related to community resilience.

Types of social capital such as *bonding, bridging* and *linking* were also identified from the interview data and were part of the Cumbria case study analysis. Bonded relationships with family and friends and bridging relationships with others bearing differing values are important for emotional support and sharing information; whereas linkage to resources through connections with individuals in powerful positions or who represent formal institutions can provide significant advantages in drawing in key resources into a given community.

The whole network consists of approximate 60 respondents (who participated in interviews) and 400 contacts (who were mentioned as connections). Centrality scores were calculated for all members of the whole network, and including all types of links mentioned.

Analysis

The social network analysis suggests that it is important to have a diverse social network for building resilience to flooding. Of all the case study locations, the data collected in Keswick was particularly useful for illustrating this through evidence of strong community engagement with an active and well organised community-based Flood Action Group. The success of the group appears to be down to the capabilities

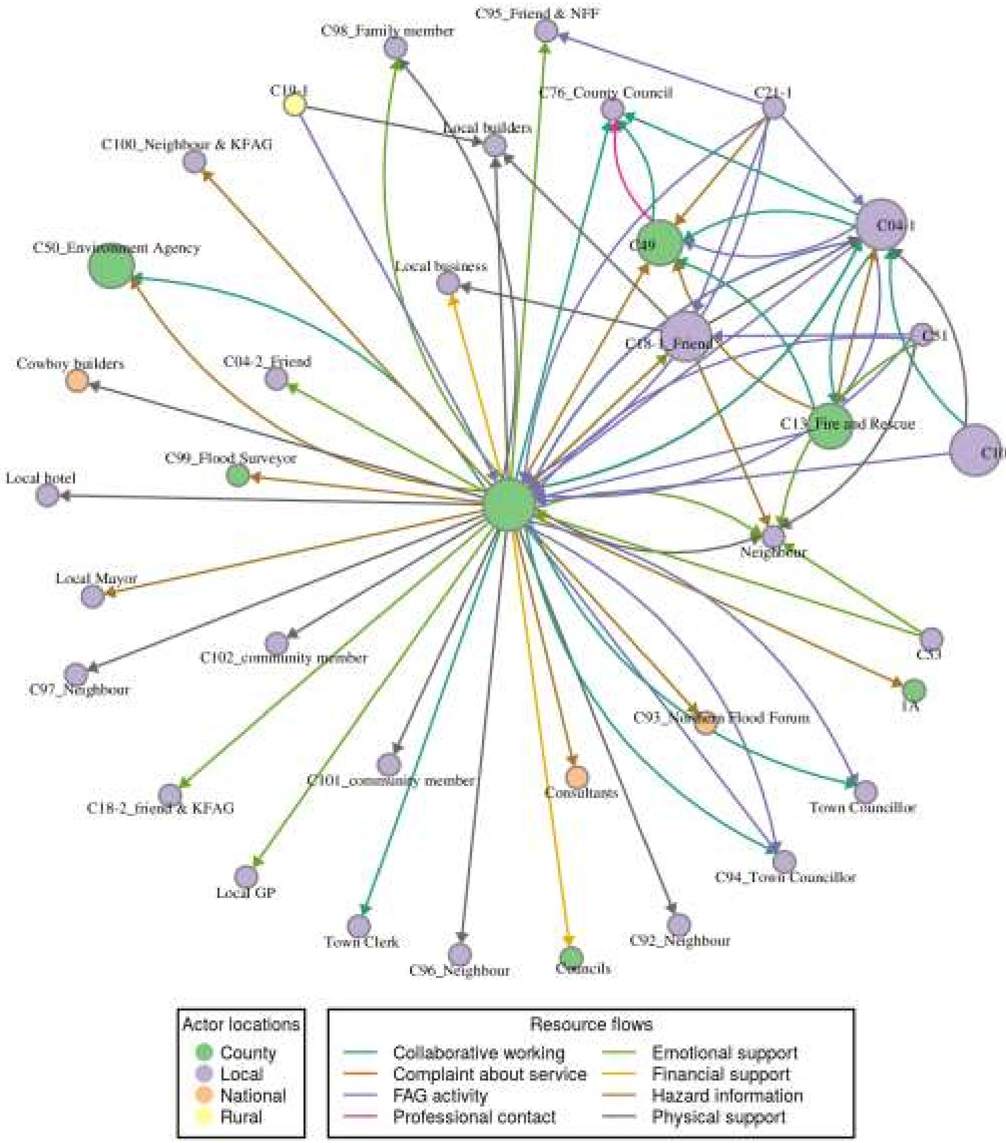


Figure 6: Ego-Network of female Keswick Flood Action Group member (C15)

and personal effectiveness of key individuals who connect to a range of organisational sectors and build strong relationships with individuals that enables them to draw in resources from outside of their community. The ego-network maps[7] (Figure 6 and Figure 7 below) provide a fuller illustration of how two Keswick Flood Action group members (C15 - female and C04 - male) are connected to a range of organisations and individuals that enable them to pull in a diversity of support services and resources into the community.

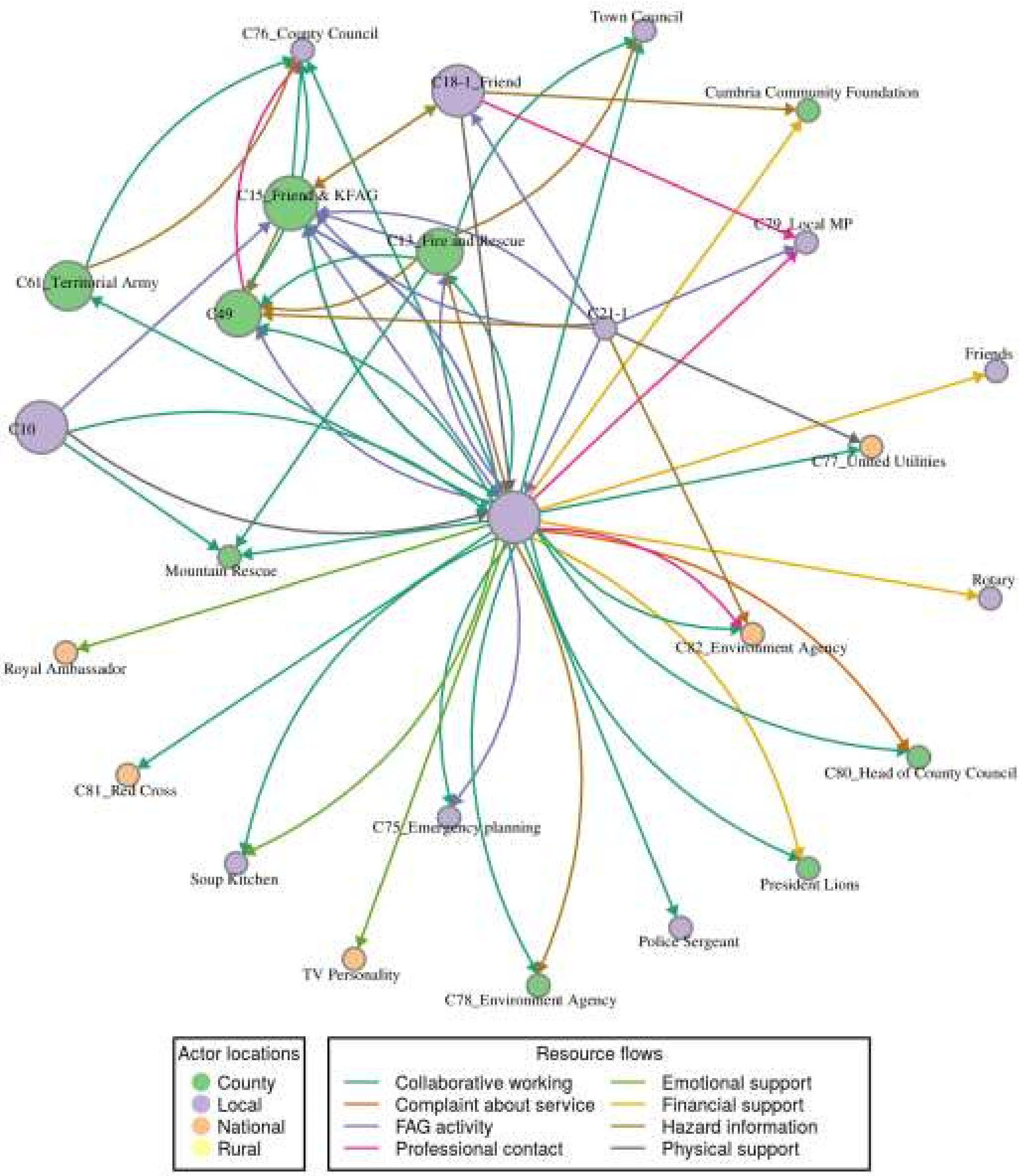


Figure 7: Ego-Network of Male Keswick Flood Action Group member (C04)

[7] An ego network map illustrates the connectedness (or not) of a single node (actor) by giving graphical primacy (e.g. central positioning) to their position in the network.

These two Keswick residents and Flood Action group members (C15 and C04) are represented by the central node in the ego-networks. These two individuals were identified as central actors by achieving high betweenness centrality scores in the research sample - C15 scored the second highest (1153) and C04 scored in the top five (780) out of the total sample. The ego-networks show that these actors are connected to individuals and organisations across a range of sectors, including: government, emergency services, environment, business, insurance and third sector groups. The ego-networks also show a mix of bonding relationships (e.g. friends, family and neighbours), bridging connections between community-based networks and across institutional sectors (faith groups, and local volunteers) and vertical linking connections (town councillor, local mayor and royal dignitaries and spokespeople, emergency 'responders' and with government agency and departmental staff) . The diversity of relationships and connections within these two ego-networks enables the provision of a range of resources (as shown by the different colour ties or links) including: emotional, physical and financial support, which can be mobilised to help build resilience to flooding. The ego-networks also show strong collaborations and professional contacts, particularly with the governance sector, which helps with the acquisition of local and national flood information and promotes the activity of the Flood Action Group within local authority and government circles.

The ego-networks show that both C15 and C04 identified each other as network connections (as identified by the double facing arrow heads on links) and this strongly points to the notion that regular exchanges are occurring between these two individuals. This directed graph does not allow bi-directed ties, but clearly some links are reciprocated. These links are commonly found around clusters of nodes or sub-groups within the ego-networks, where central nodes (e.g. C49, C13 in both ego-networks) are depicted as larger nodes (size based on betweenness centrality measured over the whole network). These sub-groups represent hubs of activity and information or resource exchanges, which could be important to the individuals because the central sub-nodes can extend the reach of the individual's network through their own set of connections, which they can mobilise. Hence connections may generate additional connections. In a few cases an arrow head points towards C15 only (e.g. C53 node in C15 ego-network and this means that C53 identified C15 as one of their networks, but C15 did not identify C53). However, this is more than likely a result of the fact that research participants were not specifically asked to identify their networks.

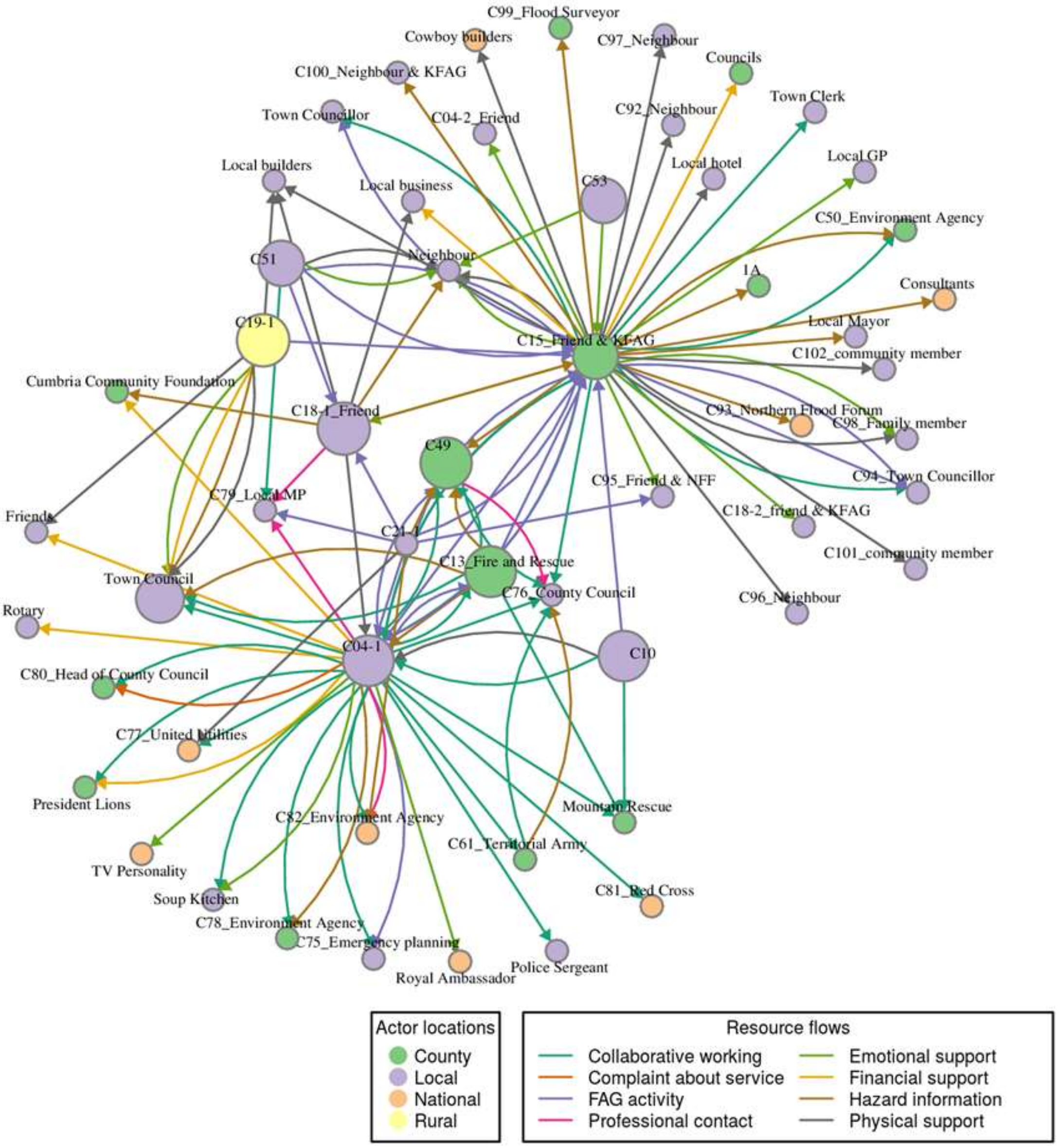


Figure 8: Combined Ego-Networks (C15 and C04)

Bringing together the diverse networks of these two well-connected individuals into an institution like a community flood action group enables for a concentration and pooling of social capital and this appears to provide a powerful social and political resource to the community. The availability of a broad and diverse set of network connections enables the group to target its resources to flood advocacy prior to a flood and respond more effectively during and after a flood. A flood action group that combines networks of several well connected individuals would make the overall group network larger and more extensive, as shown in Figure 8 above, where we have combined the two ego-networks of C04 and C15.

As highlighted by other researchers (Szreter and Woolcock 2004, Dahal and Adhikari 2008, Newman and Dale 2005) this social network analysis revealed the importance of the collective interplay (and mutual interaction) consisting of a range of social relations (here distinguished as bonding, bridging and linking social capital relations). The above social network maps demonstrate strong community representation is enhanced through bridging ties with third sector organisations (e.g. Rotary, Lions and Red Cross). Bridging relations are also made with the health sector, voluntary sector. Linking relations are established with emergency service 'responders', councillors, and council officers, MPs and royal figureheads, as well as government officials who represent key organisations, such as the Environment Agency, which has statutory responsibility for flood investment and policy directions for constituent communities. These different types of relations broaden a network's reach and contribute to its ability to mobilise resources from outside the community.

The female KFAG member's (C15) ego-network (Figure 6) shows that physical (i.e. material) support is mostly sought from local builders but also through neighbours who provided valuable advice and support regarding their own experiences with building companies. Emotional support is mostly drawn from bonding relationships with friends and neighbours and fellow Keswick Flood Action Group members, but also from bridging relationships with the local General Practitioner. The two quotes below support the finding that friends and neighbours (bonding relationships) play a key role in providing emotional support, especially during times where flooding has the potential to occur when people may be away from home, which can cause stress and anxiety and in the immediate aftermath of a flood:

> we've got several of them that have got keys and I can go off happy because I know somebody else that I can rely on will look after it like [George] does usually and [Kim and Adam] would do. But yeah it's a problem. So having good neighbours really helps.
>
> Keswick Flood Action Group member (C15)

> we called in to see [Glenda and Winston] who are friends of ours and realised that they needed help with things like lifting carpets and during the course of the day I think we lifted them for about 4 or 5 people?
>
> Keswick Flood Action Group member (C04)

The male ego-network (C04: Figure 7) shows that he regarded the local church run 'soup kitchen' support centre as a principal source of emotional support to the community following the flood. Although he was not actually flooded himself, he was embedded in the response and recovery processes of the local Keswick community and therefore was able to acknowledge the important role the 'soup kitchen' played for the community members who did flood.

In contrast to the female ego-network (Figure 6), the male also has more connections that perform an emergency-services response role (Fordham 2012, Martin 2005). However, both individual ego-networks show that they were able to draw in socio-political capital and information about flooding through their connections with key regionally based Environment Agency staff (e.g. C49, C50, C78 & C82 in Figures 6 and 7). These key connections with the Environment Agency enabled increased engagement and collaboration to take place in Keswick, which appears to foster a deeper understanding of the hydrological factors underpinning local flood risk as well as government policy and investment in relation to flooding. Such strong linking collaborations between the Environment Agency and community members appear to be factors in the delivery of flood prevention measures and enable a more targeted approach to flood risk management. The following quotes illustrate how these strong collaborations can work to improve flood management in local areas:

> I mean like this weekend there's a bad forecast so [Simon] from the Environment Agency has contacted me and said it's him, [Shirley and Jane], on duty this weekend, they've drawn the short straw. This is the latest weather report and things so although we know them as people and I'm really glad it's those three that are on because I know them really well at the same time they are Environment Agency and they are going to make quite sure that the gates get closed, so today I've got two drains that I've got to photograph that are collapsing, I've got to go down to the camp site because I know people at the campsite and they don't understand properly what to do I don't think , so [Simon] asked me to go and see them.
>
> Keswick Flood Action Group Member (C15).

The above quote demonstrates that this individual (C15) is on first name terms with members of the Environment Agency (which for this individual provides a socio-political resource) and has developed a good personal relationship. Without such strong collaboration it is less likely that such specific localised information (i.e.

relating to a local campsite) and instructions about flood preparedness and recovery could be circulated to a given community.

Environment Agency workers (i.e. node C49) and Keswick Flood Action Group members, constitute central actors within the individual networks (as denoted by the larger nodes and surrounding network clusters or sub-groups), which often sit within their own sub-networks or clusters. Socio-political capital is also drawn in through vertical linking relationships with influential politicians as shown by connections with the local Mayor, local MP and local Councillors. In addition, linking relationships are also established with environment agency and government officials who may be able to influence economic and political decisions regarding flood policy within their institutions. These linked connections, in addition to connections to TV broadcasters and Royal affiliations, have been important in generating an increased public profile for Keswick and its flood risk problems, which can help to draw in financial resources through government and community-based grants or donations. This ability to receive good quality information from effective bridging and linking relationships appears to enable the community to act effectively and to feel a sense of empowerment through these actions. This is in contrast to how community members, who lack such connections, feel:

> I mean that woman that was on the television, they'd been flooded and she was crying because they had no help. That's how we felt, you know, totally lost, it was like Brigadoon down here; nobody was interested.
>
> C56: Workington resident.

In Workington the flood action group, formed after the 2009 event, its membership has not achieved the same political capacity as the Keswick group. Hence Workington does not benefit from the group in the same way as Keswick, as it lacks that town's concentration of pooled human, socio-political and financial resources, which helps it to influence government institutions and agencies.

The research findings resulting from both the qualitative analysis of social networks and social network mapping suggest that, in order for a community to prepare for flooding and be truly resilient, it needs to have a good understanding of its local flood risk and to be able to make informed decisions on what actions to take. As can be seen from the two Keswick Flood Action Group members discussed above, the formation of social networks between community leaders, local council resilience staff and regional environment agency staff plays a crucial role in developing this understanding and expertise. This cooperation between community members and formal institutions can foster community resilience by building up expertise within the community through information sharing, which helps to inform key decisions that need to be taken, as illustrated by the following quote from a member of the Keswick Flood Action Group:

> …even before then there were all the emails flying backwards and forwards to the Environment Agency, the volunteers, the Flood Group, everybody was getting heads up watching what was going on, Met office reports al that sort of thing. So we were thankfully well organised with contacts that most of whom we knew quite well from the previous flood and from building up kind of like a library of information I suppose.
>
> C15: Keswick Flood Action Group member

The above individual ego-networks demonstrate that communities require a diverse array of resources to assist in building resilience to flooding and social networks can play a key role in attaining these resources. The presence of strong human capital inhered within well-connected community members fosters actively engaged community groups and third sector presence (e.g. formally constituted Flood Action Groups), which helps to build good collective social and political capital in a community. This diversity and concentration of social networks in Keswick appears to have contributed to the community's effective mobilisation of a range of resources including: emotional, physical and financial as well as the ability to acquire up-to-date information on flooding and professional links with key government agency staff. These elements amalgamate to strengthen the ability of the Keswick Flood Action group to successfully lobby for local flood defences and other forms of support on behalf of the local community of Keswick to strengthen the town's resilience to future flood events.

The study also identified that the array of resources required for community resilience can be classified into three broad sectors: community, civil protection and social protection. The overall social network map below (Figure 9), constructed from the aggregated responses of approximately 60 interviews, depicts the overall network structure in terms of resources and support services, and the organisational sectors that provide these services, across the entire community that took part in the research. The map illustrates the diversity of resources that are being acquired by the community to help build resilience to flooding. The resources are being drawn from within the community itself as well as the civil protection sphere and wider social protection sphere of support services. Community-based support includes resources such as Flood Action Group advocacy and community awareness raising, third sector activity and capacity building, and support offered by local church groups. Civil protection includes receiving useful and hopefully accurate information about flooding such as up-to-date localised flood warnings and about how to obtain assistance with evacuation from the emergency services. The wider social protection resources

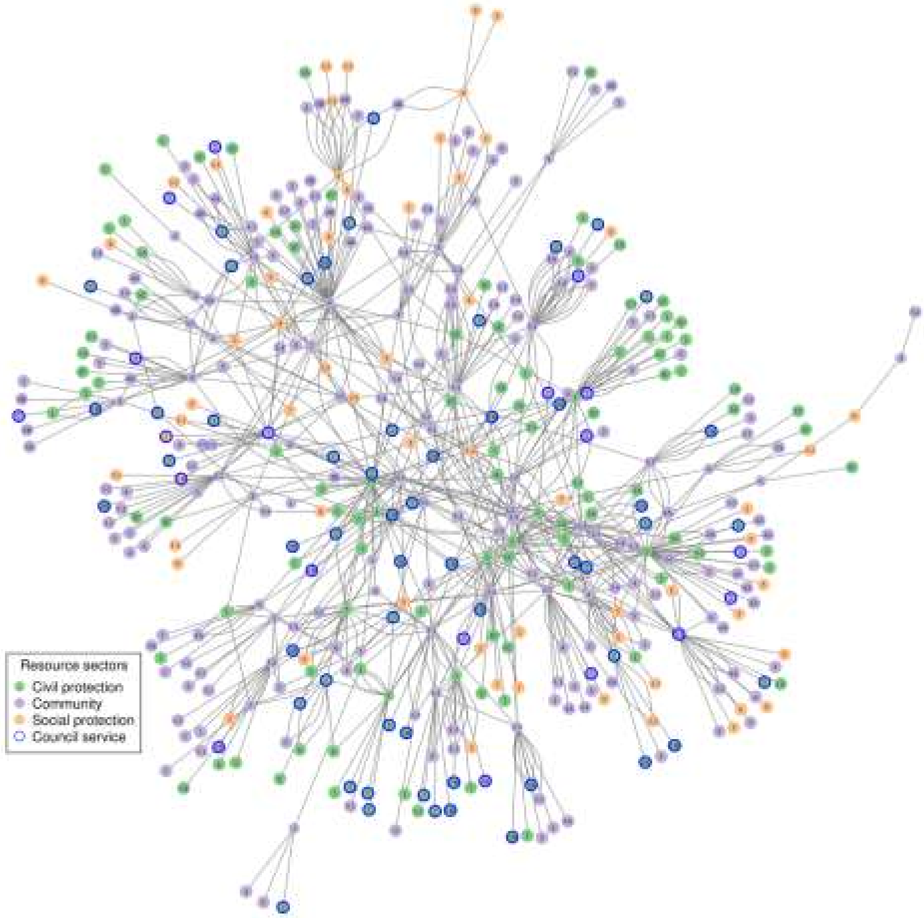


Figure 9: Network map of all connections in sample (defined as community, civil protection and social protection.

include health and well-being services, financial protection, access to public transport and general citizens' advice and anything else that is not traditionally associated with civil protection against hazards

In terms of longer-term recovery the social protection services are likely to play an important role, so it is important to consider this wider complement of resources. The map shows which services are provided by local and county councils (as shown by the blue border around the relevant nodes). Many of these services that the community is relying upon are provided by councils. This highlights the importance that communities attribute to councils' ability to provide a range of resources. Such findings could be used to support investment decisions by local authorities exposed to high natural-hazard risk profiles.

Discussion

The outlined approach involved a combined methodology of qualitative data analysis to capture information on social capital, social networks and social network mapping. As described above, social network mapping was carried out in the terms of a post hoc exploratory approach. The advantage of this approach was the richness of the data, which offered the opportunity for analysis of many facets of disaster networks and their complexity. The disadvantage was the need to compile a set of maps from the qualitative data when the dataset did not meet the usual requirements of social network mapping, e.g. whereby key questions were identified at the outset of the research – particularly in terms of its statistical representativeness there were inevitable gaps in the data set). Having an incomplete dataset can be problematic for drawing statistically valid – or even qualitative – conclusions about specific network maps, as it distorts the data and this can result in significant variations in the graphical depictions of networks qualitative data is best used for analysis of process and contextual features within a network, whereas quantitative data lends itself to structural analysis (Conway, 2014).

Despite these methodological difficulties, the social network mapping exercise was useful in drawing out some interesting information and for providing additional evidence for some of the qualitative findings of the research. One advantage of the post-hoc approach was that it eliminated the potential for interviewer bias, whereby participants could be led into answering particular questions in a certain way, as the data on networks emerged organically from the data. The graphical illustrations of the two individual ego-networks from the Keswick Flood Action group members highlighted useful evidence regarding the diversity of resources that these individuals have used to build resilience to support the qualitative narrative. The maps act as helpful visual aids to show during stakeholder presentations and conferences for illustrating the results of the broader qualitative analysis.

The social network analysis suggests that the higher the numbers of connected members are in a given community, the better off the community will be in its potential to access resources. When a number of well-connected individuals come together in a group, such as a flood action group, this grouping results in a pooling of resources through increases in the overall reach of the group and strengthens its ability to pull in even more resources. The social network analysis highlights the advantages of the mutual cooperation between the Keswick Flood Action Group and institutions such as local councils and the environment agency, especially when the process of engagement is based on social norms such as empowerment, equity, trust and learning (Reed 2008). This cooperation between community members and formal institutions such as the Environment Agency allows local and scientific knowledge to be combined to build a more comprehensive understanding of complex and dynamic social-ecological systems and processes that underpin flooding in a local community. This can promote the development of locally based technical and community-based solutions (Reed, 2008). However, this effective community advocacy and ability to draw in a diversity of resources gives rise to questions of fairness, given that the ability for effective advocacy tends to depend on having a certain number of actors present in a community that are well educated and possess the expertise and skills (human capital) to enter into political dialogue. Communities that lack these resource capacities are typically excluded from this type of policy process that created social and environmental injustices (Thaler and Priest 2014).

The overall social network map highlights the complex array of social interactions that took place in the community and supports the research finding that people draw on a range of resources that are provided by a wide range of organisational sectors, including 1) community-based support (e.g. Flood Action Group activity, local faith groups and community-based funding schemes), 2) civil protection (e.g. information about flooding and localised flood warnings and assistance with evacuation from emergency services) and 3) the wider social protection (e.g. health and mental well-being services, access to public transport services and general citizens advice).

Further research could follow up these findings using methods more suited to a structural social network analysis (Reed et al. 2009) such as structured focus groups or questionnaires tailored to obtain specific information on the resources people acquire. In particular, information could be obtained on specific types of resource domains (e.g. human, socio-political, physical, financial) and comparing differences in how these resources are prioritised and accessed (e.g. through bonding, bridging and linking social resources) across different communities of place or communities with different socio-economic or demographic profiles. Further research could also delve deeper into the specific socio-political resource sets, which the community requires to build resilience to flooding, such as, legal advice, employment protections, access to information on flooding, emergency management training, knowledge of local flood plans, health and safety advice, access to community action groups, etc. Future research could also draw out differences in the need for certain resources across the different hazard phases (mitigation, preparedness, response and recovery) or more generally before, during and after a hazard event. Finally, it would be worthwhile building up a better understanding about which resources provided the greatest help and support to create a prioritised typology and to identify any barriers contributing to the access to particular resources and support services with a potential focus on strong and weak ties within networks.

3. Discussion

Social network maps have proved very useful for structuring diverse knowledges of a range of different actors and representing that knowledge in a way that is relatively easily understandable and usable by other actors in different positions in space and time. The graphical depictions of these social networks help stakeholders to locate their place within a wider network of actors and offer a useful communication tool.

Our approach was grounded within a practitioner-relevant approach. Here we emphasised the visual display of social network maps to help understand how community resilience to natural disasters can be created. While acknowledging the physical threat to communities from natural hazards, we recognised that natural hazards also damage social systems, such as resource systems and support systems including emergency response systems. Hence understanding social systems was important as they were the means by which communities respond; and, they were also one of the aspects of community that were at risk. Organisations working for enhancing community resilience must not only adapt social networks to deal with the impacts of natural hazards but they must design these social networks in ways that make them resilient to the impacts of hazards. Participatory social network mapping that was followed in emBRACE case studies, allowed us not just to map relationships between actors but also to qualitatively assess the social value of these relationships, and explore more resilient options. Further, we noted that co-creation of social network maps, with participation of stakeholders, could potentially facilitate community resilience through transformative social learning, as was evident during the participatory mapping exercises with key actors in South Tyrol.

A useful way to study complex adaptive systems is to look at the whole system: top down; bottom up; and from the outside in (Seddon 2003). Mapping social networks from different perspectives can help us to start doing this. If the system is described from the top down, and an agent within that system describes it from the bottom up, and if their views are compatible, then we may assume that the system is working as designed. This assumption was indeed empirically validated in the case of South Tyrol.

SNM may also provide a way to address issues of scale: understanding if communities are making the right decisions at the right level, and linking across the levels of governance. This has been fundamental to the emBRACE agenda: we sought to find out if structured maps could be used as a 'mirror' for the multi-level communities to be able to recognise the structure and dynamics of their social systems. Our findings suggest that social network mapping can be an important tool to discuss multi-level interactions with multiple stakeholders.

Further, comparing across different social systems is traditionally difficult. Reducing the complexity of a human social system to a structured map allows us to make *some* level of comparison across different social systems. In emBRACE we compared two different case studies, Cumbria and South Tyrol, to see if the maps can help to identify resilience indicators that could apply to both situations and might have wider resonance. Different network features that help us explain resilience (or lack of resilience) were evident from the social network maps. The network features are: density and diversity of nodes; dynamics and modularity of network structure; and redundancy of ties. Below we discuss these indicators, along with their caveats, as they unfolded in the case studies. We do not propose that these indicators are generic, as indicators often seem to emerge from the contexts.

Density and diversity

In both the case studies we noted that the diversity of central actors, the existence of dense connections among these actors and to the wider network were important in creating community resilience. The more these three factors were present the better off the community was in terms of accessing resources, sharing information and cooperating during the crisis. The Cumbria study noted that when a number of well-connected individuals came together in a group, such as a Flood Action Group (having connections within the group), pooling of capacities increased the overall reach of the group and strengthened its ability to pull in even more resources (having diverse connections to the wider network). In South Tyrol we noted that different kinds of experts, actors, organizations and authorities worked together, shared information and collaborated during the disaster. We also noted that the most effective pathways towards facilitating more resilient social networks were the key local 'gatekeepers' in the community (i.e. the connectors or knowledge brokers) and the functions they performed. It was also critical that in order to work smoothly and effectively the ties must be bi-directional: that is the 'connector' must acknowledge their role but they must also be accepted in that role by putative recipients of information. We have used social capital terminology in defining these ties as the bonding, bridging and linking capital, which communities activated for resilience during a crisis. As the case studies suggested, working with key trusted local knowledge brokers and connectors significantly increased access to critical resources and reduced the timescale to adapt to unfolding crisis situations. Additionally, networks with many connectors were also characterised by high density. This reflected findings in other studies that have suggested that a high social capital emerges from the density of interactions at the level of individuals, and is often related to the capacity of individuals to organize in order to better manage natural resources (Crona 2006 pp. 135–155).

However, effectiveness of bonding and bridging links among nodes within a network and among various networks in the real world often depend on the power balance among members within a community or among the communities. Theories suggest, the evolution of the topology (structure) of a network is 'invariably' linked to the state of the network (i.e. changes in the nodes and links) and vice versa (Gross and Blasius 2008 p. 259). However, the feedback loops between the state of nodes (that might change in a disaster situation) and the network structure may remain unresponsive depending on the *a priori* distribution of socio-political powers. Using the density of nodes and links among them, more importantly, the quality of the links underlying the network structure as a proxy, we attempted to capture this distribution of power among the communities. An example can be drawn from the Cumbria case study, where two networks are compared; one in Keswick and the other in Workington. In Keswick, bridging and linking social capital was effectively drawn in through creation of relationships with influential politicians, such as, the local Mayor, local MP and local Councillors as well as with environment agency and government officials. These multiple links have been important for generating an increased public profile for Keswick and enabled the community to act effectively to ameliorate its flood risk problems. This was in contrast to how networks in Workington operated. Workington is a highly deprived area in the region and unlike Keswick, it is not a popular tourist destination and does not gain much economic benefit from the tourist sector. It was apparent that communities here did not have much political leverage to draw upon. The fact that flood warnings were issued to Keswick, and not Workington[8], meant that Workington residents were taken by surprise when the floods broke out and this put them at a disadvantage in terms of their ability to prepare and respond to the flood event. The lack of power for the Workington communities appeared to be critical. Although the state of the local actors changed when the floods hit, the quality of links that local network of Workington had with influential agencies and officials (i.e., Councils and Environment Agency networks) remained relatively static[9]. *A priori* distribution of power among the communities prevented the much needed 'adaptive co-evolution' of the network state and network structure as the disaster hit.

[8] This was due to the risk assessment, prior to the 2009 floods, suggesting that an automated flood warning system on this stretch of the river did not meet the Environment Agency's cost-benefit criteria. Warnings were broadcast here via (e.g.) local radio, but not automatically to household telephones

[9] Context should be noted, however. This was also influenced by the differing nature of the floodplain in Workington and Keswick, i.e. the construction of hard physical defences in Keswick achieved a significant benefit-cost ratio and was approved. Whereas in Workington this was not the case and it was rapidly acknowledged to be unaffordable to protect the relatively small number of flood-exposed households with such structures

Dynamics

In South Tyrol case study we sought to understand social networks in terms of its dynamics in relation to the transition of disaster phases, e.g. when emergency response evolves into a recovery phase. The results show that the network structure portraying the actors who are part of it, ties between them and the responsibilities of each actor were very clear for the response phase. For recovery phases in the medium and longer term, however, the network structure and functions were not so clear. Actors whose tasks clearly linked to the response phase (e.g. the fire brigade) were not involved anymore in the recovery while new members became part of the network (e.g. the department for social housing). Links and responsibilities, in the later phases of disaster recovery and longer term planning for the future were less well defined and less clear. This was due to the fact that the network no longer needed to be operative day and night as it was in the first days after the event. More importantly, network functioning and actor responsibilities for the long term recovery and preparedness for possible future disasters (e.g. financing of rebuilding activities, future zoning and land use of the area) reverted back to bureaucratic paraphernalia that were less amenable to changing disaster phases. This may be explained as a characteristic of ‘coupled adaptive complex networks’ following Shai and Dobson (2013) as discussed in section 1.3. In these situations, while the individual networks (local emergency networks) are adaptive within themselves in response to disasters, their dependencies on other networks (agencies responsible for more regular activities) are often permanent and non-adaptive. This imposes a limit to the individual network’s ability to adapt in response to changing needs in a disaster situation, as it can change its own structure but not its dependence on other higher level or geographically distant networks. The more coupled the networks are the longer the switching between states takes. Thus expecting a social network to move seamlessly between disaster planning, response or recovery phases becomes a little optimistic. As real world networks tend to be highly coupled, in our effort to make them adapt to the changing phases of disasters, we should plan for a ‘transition’ between states. This seems to be a 'latent' aspect of a network which is not easily identified, except when the situation changes or when new information is added. It is difficult to discover from analysing the network maps, which may often only provide a static picture, without deeper understanding of the case context: to understand dynamics we usually rely more on qualitative understandings and expertise.

However, the transition process between the states of disaster planning, response and recovery is one of the questions that require further research.

Modularity

Modularity is often cited as a characteristic of robust social networks (Norberg and Cumming 2008, Beilin et al. 2013). It shows the extent to which a system is composed of more or less separated sub-networks or functional components within a larger system that could change and evolve to some extent in an autonomous manner. Sometimes termed as intermediate modularity, it helps reduce the spread of a disturbance in a system and thus can increase its resilience. Norberg and Cumming (2008) suggest that weak links inherent in a topology with intermediate modularity may stabilise systems. This internal stability may impact the ability of a system to respond to outside disturbance, though it is not clear whether or not this stability translates to system robustness (pp102-104). In the South Tyrol case, modularity was measured to detect the community structure by identifying sub-networks that are more densely interconnected. This exercise clearly showed who the key actors were in the disaster response phase. The fire brigade, municipality and civil protection agencies were the main component of the response network. The structure and links of these components were clearly visible from Figure 3.

However, unpacking the function of modularity in resilience of networks, Gonzales and Parrott (2012) note that a highly modular network composed of completely separated modules can make a more robust system as disturbances would not spread beyond the cluster where it happened. On the other hand, the lack of connectedness of the system components may limit its effectiveness by restricting the flow of information or resources through the entire network. These two characteristics are thus opposite to each other. Thus a balance must be achieved between modularity and an effective sub-group connectivity for resilient systems (Webb and Bodin 2008). We didn't do a mathematical exercise to assess this balance for South Tyrol. Rather, we verified the functioning of the modules in subsequent participatory network mapping sessions. The common verdict was that the modules, i.e., fire brigade, municipality and the civil protection agencies worked well. They had strong ties among themselves to facilitate internal coordination, but they also were sufficiently connected with other subgroups, such as, carabinieri (national military police), white cross, or forestry department, as and when necessary.

Redundancy - functional

It is commonly assumed that the more the components (or nodes) perform similar functions in a network, the higher are the chances that the system will keep functioning despite the elimination of some of its components or nodes. Norberg and Cumming (2008) explains that redundancy in an individual's personal network are the alternative paths to reach a particular actor. A nonredundant link is assumed to be more valuable than a redundant one for an actor possessing it. However, seen from a network perspective, nonredundant links decrease the robustness of the network. "If nodes possessing nonredundant relations are removed, the network experiences defragmentation". (ibid p. 97).The combination of diversity of network nodes and their redundancy in terms of their function in the system can be closely related to the network resilience.

Social network maps can show diversity of nodes clearly, but they are limited in projecting functional redundancies. However, the maps can be used in participatory workshops with stakeholders to identify the links that are critical to network functioning. Probing further if these functions can be replaced or performed by other nodes can shed light on how resilient the network is. Beilin et al. (2013) suggested a 'what-if' scenario where key nodes were theoretically removed from the networks. Networks would begin to fragment as key nodes were removed unless some other nodes can take up these functions.

In both our case studies, it was noted that some of the characteristics, i.e., close personal links that resulted in resilience in one circumstance, could also weaken the stability and the resilience of the network under other circumstances. In South Tyrol, the local networks were "highly personalized" as actors were not only representatives of organizations but also "acquaintances". In Cumbria, often local actors were on "first name terms" with members of the Environment Agency (a highly regarded socio-political resource) and have developed good personal relationships. Without these links it was less likely that specific localised information or resources for flood preparedness and recovery would be available to a given community. The fact that actors know and trust each other and work as a well-connected team is critical for resilience. However, it could become risky for the network if one or more of the actors become unavailable, or if personal factors change and become a liability.

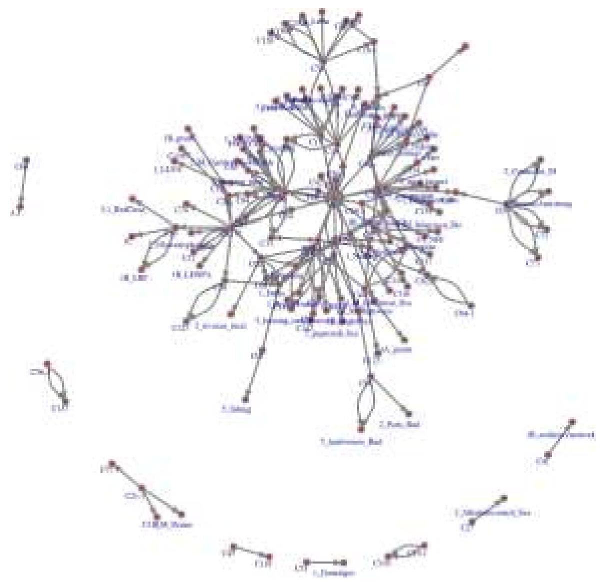
Redundancy - structural

Here we discuss 'structural' redundancy in terms of the way actors are connected using the concept of bi-components that are a potentially useful measure for assessing network redundancy. Networks with large bi-components can be characterised as robust because "they are invulnerable to the withdrawal or manipulation of a single vertex ... no person can control the information flow ... because there is always an alternative path that information may follow. ... each person receives information from at least two sources (in an undirected network) so he or she may check the information" (De Nooy et al. 2011 p. 141). Bi-components have more than one path between each node, so no one node is responsible for conducting all information to any other node, which is possible in a component. This 'structural' redundancy could be important in some disaster contexts; some degree of redundancy is probably important in all stages of disaster management, but it could be critical in some more than others as described below.

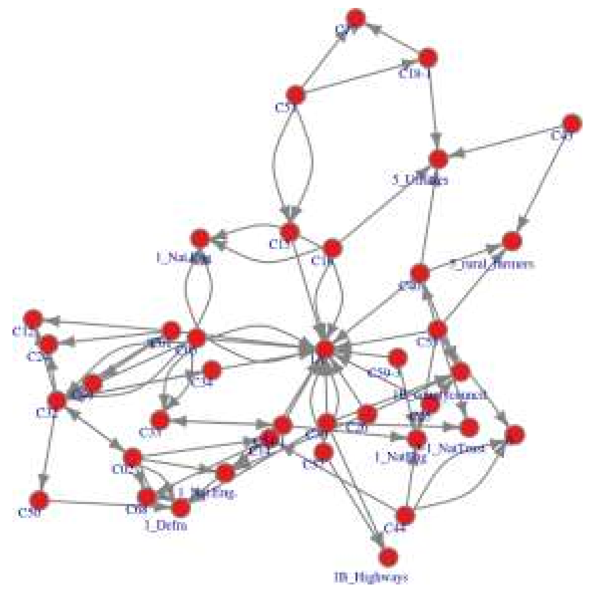
In order to explore this, we discuss the sub-networks for mitigation and response using the Cumbria case study data. As mentioned in section 2, there are issues with the representativeness of these data particularly for statistical analysis. We therefore designed this section more as a demonstration of techniques with the important caveat that the results may be applicable in reality.

As Figure 10 shows that the mitigation network – the particularly large bi-component (38 nodes) suggests significant redundancy, compared to the response network which has a smaller bi-component, implying low redundancy and potential vulnerability to disconnection. Figure 10(a) shows all components of the mitigation network and Figure 10(b) shows the largest bi-connected component only. The bi-component is relatively large and densely connected (82 links). The relative positions of nodes in mitigation network are the same; the central portion of the network (actor 1A: Environment Agency seems to be very central) is recognisable in both graphs.

Figure 10(c) shows the response network, and Figure 10(d) shows the bi-component of response network which is relatively smaller and less well-connected (57 links). The trace of the response bi-component can be seen in the response network; the

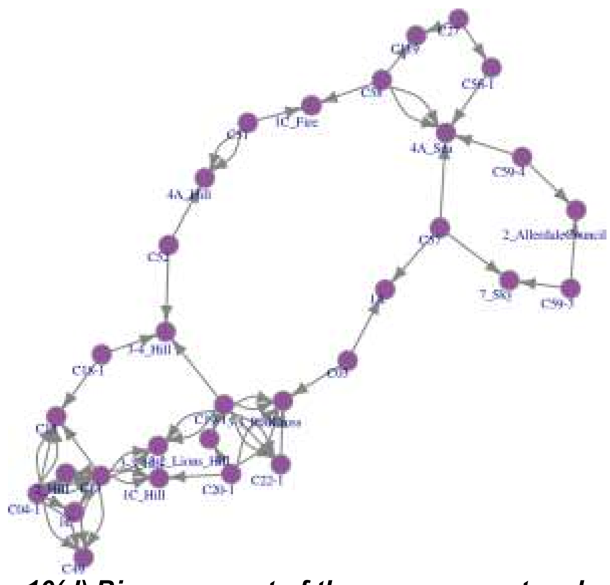


10(a) Mitigation network



10(b) Bi-component of the mitigation network

10(c) Response network



10(d) Bi-component of the response network

Figure 10: Bi-components of mitigation and of response networks

central ring-like structure appears potentially vulnerable to disruption. Comparing the top and lower figures shows quite well the differences in structural redundancy: the mitigation network appears to be more redundant than the response network.

In conclusion, although given the data limitations the results reported here may not represent the real situation in Cumbria, we can argue that use of measurements such as bi-components are potentially useful and seem to deserve further investigation. A network analysis specifically designed to identify redundancy in different types of network - and its relation to resilience - could be carried out.

4. Conclusions

The main focus of this report, adhering to the emBRACE Description of Work, was to describe the process and application of the theory of social networks to disaster risk management. In particular, it aims at exploring the application of social network visualisation and mapping as a measure of community resilience following natural disasters. The core of this deliverable is the two emBRACE case studies where SNM inspired methods were applied. These are Alpine Hazards in South Tyrol, Italy (emBRACE, 2014a) and Floods in Northern England (emBRACE, 2014b).

These case studies have sought to link the effectiveness of disaster preparedness, response and recovery efforts to levels of trust, mutual cooperation and social capital dynamics in the communities as embodied in their social networks. The evidence shows how bonding, bridging and linking ties in social networks have provided resource flows and assistance in the aftermath of disasters. These ties were important in sharing of diverse knowledge and skills, and for acting together when the crises hit. Overall the studies show that the density and diversity of relationships enabled the provision of a range of resources, including, emotional, physical and financial support, which were crucial to building and maintaining resilience. The horizontal and vertical ties helped the communities with the acquisition of local support and national resources from higher level government circles. Thus the ‘strength of weak ties’ that Granovetter (1973) suggested as having the potential to generate far more positive outcomes and inclusive benefits across and between different communities is once again validated.

Theoretically speaking, the social networks that emerged from our case studies, show traits of a number of characteristics that are currently discussed among network researchers. They include notions of complexity, dynamism, adaptation, and coupling with larger and distant networks. In Section 3 we have discussed the evidence from case studies that connects to these characteristics and their relevance to resilience research. These characteristics allow us a powerful insight into explaining how our social networks function, and how complex, adaptive and stable such networks need to be to enhance community resilience. One critical point that emerged from this discussion is that one cannot understand the network-of-interest without understanding the broader context within which this network operates.

The case studies also addressed, albeit partly, some methodological concerns described in network literature. As Butts (2009) has aptly pointed out (see Section 1.5), making assumptions and approximations on the nodes, links and time scale in network analysis can be problematic in capturing the real world networks. Findings from our case studies show that participatory approaches to network analysis based on a combination of narratives, interviews and surveys can address these problems to a significant extent. These combined methods can enable the networks to enlist nodes across multiple boundaries, qualify the ties and constantly re-work them, and define the time scale in which the processes of interest unfold. Networks co-created in this way can, at least, have practical relevance in providing a space for blending of scientific facts with individual experiences, values and emotions.

Finally, we can offer network maps and visualisations, particularly when co-created by the users themselves, as a way to understand mechanisms through which the indicators of community resilience can be portrayed. Most important among the indicators, as surfaced from our case studies, are density and diversity of nodes, dynamism and modularity of network structure, and redundancy of ties. Together they can allow analysis of the nature and level of community resilience. They can also be an important channel in linking local communities to policy makers and knowledge brokers at multiple levels. We have shown that maps are indeed a powerful tool for structuring knowledge of a range of actors on what makes them resilient and communicate this knowledge to other actors in other positions in space and time. Further research is needed on how to integrate various quantitative and qualitative methods to collect relevant data for accurately presenting the network maps and for a deeper understanding of the indicators of resilience that emerge from them.

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