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Review

Panarchy and community resilience: Sustainability science and policy implications

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ABSTRACT

How does the resilience concept of nested relationships (panarchy) contribute to sustainability science and policy? Resilience at a particular level of organization, the community level in our case, is influenced by internal processes at that level. But it is also impacted by actions at lower levels of organization (individuals, households), and by drivers of change originating at higher levels (national level policies, globalized market forces). We focus on community level social-ecological systems, looking upwards and downwards from there. Our objective is to explore the connections of the community to other levels, the ways in which community resilience is impacted, and the implications of this for sustainability. Conventional disciplines specialize at different levels, a barrier to investigating multi-level interactions. Use of the panarchy concept helps contribute to the interdisciplinary understanding of resilience at the community (and other levels) by drawing attention to cross-scale relationships. From the effect of individual leadership to the implication of pandemics that move swiftly across levels, examples illustrate a diversity of ways in which community resilience is shaped in a multi-level world.

1. Introduction

Consider the charge of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES): to assess biodiversity and ecosystem services at local, regional, and global levels (IPBES, 2016). Consider the vision for rebuilding after the 2011 Japan earthquake and tsunami: rebuilding bottom-up, customized by region, and centered on local communities, with focus on *satoyama* (forest) and *satoumi* (coastal marine) social-ecological systems (Takeuchi 2011). What these examples have in common is an emphasis on the multi-level nature of a problem, calling for the panarchy approach, that addresses nested levels. Scale issues are a key to understanding and managing social-ecological systems, and the panarchy concept provides insights regarding scale. As Allen et al. (2014: 578) put it, panarchy "provides a framework that characterizes complex systems of people and nature as dynamically organised and structured within and across scales of space and time".

Resilience is the ability to respond to stresses and shocks while preserving system identity and main system functions (Walker et al., 2004). Resilience thinking has been part of sustainability science for some time, and panarchy is a key concept of resilience; in fact, it is the main title of the classic book on resilience (Gunderson and Holling, 2002). However, there has been relatively little use of the panarchy concept in environmental science and policy discussions until recently, although there are examples that illustrate the concept well. Wild sockeye salmon fisheries of Bristol Bay, Alaska, are well managed at the local stock and regional levels. However, this fishery has been in crisis because of declining revenues due to competition from globalized salmon farms that produce a large and steady supply of high-quality salmon, even though it is not sockeye. Hence, international aquaculture at the global level can negatively impact a well-managed wild salmon fishery and fisher livelihoods in Alaska, which itself has no salmon aquaculture (Robards and Greenberg, 2007). Marine ecosystems provide good examples of cross-level and interdisciplinary interactions. Jacques (2015) pointed out that stresses often grow in scale from local to global, for example, from pollution and warming in the water column, to single stock collapses, to degraded marine ecosystems. Thus, it may be important to think of fishery systems as a hierarchical global integrated system, or panarchy, to avoid casting policy at the wrong scale (Jacques, 2015).

Initially conceived as an ecological concept of nested adaptive cycles, panarchy ideas can be applied to social-ecological systems,

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human-environment systems in which the social (human) and ecological (biophysical) subsystems are considered together. Both subsystems consist of multiple levels, for example, a small watershed inside a larger watershed, or a nested set of institutions from local to international (Ostrom, 2009). The social and the ecological subsystems are linked by mutual feedback and are interdependent and co-evolutionary (Berkes and Folke, 1998).

In recognition of the growing but scattered literature on panarchy in social-ecological systems, this paper explores multi-level resilience with examples considering both social and ecological aspects. We focus our discussion to community resilience, rather than trying to cover all aspects of resilience. Hence, our objective is to explore the connections of the community level to other levels, and the ways in which these may influence community resilience. Our emphasis is on the relationship among levels within nested social-ecological systems, using a community-centered focus, rather than dealing broadly with resilience theory or narrowly with panarchy itself.

One practical aspect of the paper is that it seeks to raise issues that are relevant to both of the two strands (or bodies) of literature on community resilience. These two strands share common objectives even though their literatures are quite distinct (Norris et al., 2008; Berkes and Ross, 2013; Welsh, 2014). One strand has behavioural science origins and is derived from psychology of development and mental health (focused on individuals). It is frequently used in the disaster management literature (Norris et al., 2008). Many authors contributing to this literature extrapolate from one level to another uncritically. The second strand has ecological science origins. The present paper is written principally with this second strand in mind, social-ecological resilience (or Holling resilience). Given our emphasis on communities as social-ecological systems, the paper focuses on communities of place, while acknowledging the importance and relevance of communities of interest and recognising the social complexity of many communities.

Following a section on community resilience in the context of resilience theory, and a section on elements of the panarchy concept, the main part of the paper pursues illustrations of multi-level interactions. This is followed by a discussion on the implication of the cases for environmental science and policy, and a conclusion. The seven cases are chosen to represent different kinds of resilience and sustainability management involving a range of settings: lake ecosystem management; disaster management; river basin management; wetland protected area management; impacts of multiple environmental stresses; impacts of global economic drivers on local social-ecological systems; and pandemic disease management. They come from different geographical regions: North America, Australia, and Europe. The cases are chosen to represent the diversity of levels in a panarchy; they are chosen also because they are richly detailed and because we have first-hand knowledge or familiarity with most of them.

2. Community resilience within resilience theory

As defined by Magis (2010, 401), community resilience is the "existence, development and engagement of community resources by community members to thrive in an environment characterized by change, uncertainty, unpredictability and surprise." It is this potential ability to deal with change, uncertainty and surprise that has made resilience a promising concept in a number of disciplines and applied fields (Brown 2014, 2016). Social-ecological resilience recognizes the nested character (one inside the other) of social-ecological systems and the challenge of connectivity across levels (Chapin et al., 2009; Gunderson and Holling, 2002). Through its conceptualization of nested levels and multi-level interactions, this approach is suitable for analysing the effects of drivers originating at various levels, including the interplay among levels of governance. It can generate insights regarding policies to enhance resilience at appropriate levels (Brondizio et al., 2009; Allen et al., 2014).

Communities are not isolated. Resilience at the community level is strongly influenced by the actions and interactions of individuals and groups within the community. Thus, social aspects of resilience research need to pay attention to agency (Brown and Westaway, 2011). Also often neglected in resilience research are issues of power. Communities are rarely egalitarian, and power structures within a community, including power in decision-making, can strongly influence community resilience outcomes (Christensen and Krogman, 2012). However, communities are often also impacted by various drivers of change originating at higher levels of organization.

For example, the global demand for coffee may drive land use changes in Vietnam (Eakin et al., 2009), illustrating that the social component cannot be isolated from the ecological component of the system because of interactions between the two. Both ecological systems (Ahl and Allen, 1996) and social systems (Cash et al., 2006) are hierarchical (nested or multi-level) along various scales, as in a stand of trees within a forest, or a municipal government nested in a provincial/state government. Both function at several different levels along each scale. Here we adopt the definition of scale as the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon, and levels as the units of analysis that are located at different positions on a scale (Cash et al., 2006; Gibson et al., 2000).

Social-ecological resilience thinking has been an emerging topic in environment and sustainability discourse, and has experienced a dramatic increase in the number of publications since the 1970s and especially since 1999 (Li and Marinova, 2013). Social-ecological resilience has an interesting history of transformation from an ecological idea to a concept used across a wide range of disciplines and policy areas concerned with crisis management and change in general (Welsh 2014). As Brown (2014, 107) puts it, "resilience is everywhere in contemporary debates about global environmental change". Walker and Cooper (2011, 144) note with some sarcasm that resilience is threatening to become "a pervasive idiom of global governance".

The original idea of ecological resilience (Holling, 1973) is derived from complex adaptive systems thinking. Resilience is a systems property, technically an emergent property of a system, one that cannot be predicted or understood simply by examining the parts of the system (Gunderson and Holling, 2002). It may be formally defined as the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks (Walker et al., 2004). Holling (1973) sought to develop a notion that could account for the ability of an ecosystem to remain cohesive even while undergoing perturbation. Parting with the notion of stability, he argued for a science of dynamic ecosystems which could deal with drivers and change, and which did not have deterministic outcomes such as "bouncing back" to a pre-determined equilibrium.

According to this line of reasoning, assumptions of stability were ecologically naïve, and the equilibrium approach created management risks by often trying to eliminate natural variability. For example, maximizing resource yields (e.g., maximum sustained yields), fashionable in post-World War II resource management science in fields such as forestry and fisheries, ignored natural variability. Further, by trying to obtain a constant, predictable yield from year to year, it inadvertently ran the risk of eroding system resilience. The resilience approach, with a focus on system integrity and due attention to natural variability and uncertainty (as opposed to maximizing physical yields) has far-reaching implications for management practice (Holling and Meffe, 1996).

The consideration of social variables gradually entered resilience thinking through the 1990s, and scholars started using social-ecological systems as the main unit of analysis (Berkes et al., 2003; Berkes and Folke, 1998). However, social dimensions of resilience have been under-theorized (Brown, 2014). The consideration of "social" in social-ecological resilience has shortcomings in its dealings with power and agency (Brown and Westaway, 2011; Davidson, 2010). For example, in the area of development studies, Béné et al. (2014) found the resilience approach useful for diagnosing socially defined thresholds in poverty analysis. However, they cautioned against the uncritical use of the concept, in particular, the assumption that resilience building could substitute for poverty reduction. They argued that resilience building could or should not replace the political processes important for fighting poverty, such as networking and advocacy. Rather, such political processes could be considered a central component of capacity-building toward resilience (Béné et al., 2011).

3. Panarchy: nested adaptive cycles

Nested levels and multi-level interactions in social-ecological systems are expressed in one of the key concepts of resilience thinking, panarchy (embedded scales = pan-archies) (Gunderson and Holling, 2002). The notion of panarchy extends the adaptive cycle idea (see below) to deal with a wider range of systems, and to accommodate nested systems (Fig. 1). Holling and colleagues drew on the image of Pan, Greek god of nature, and invented the term, panarchy, rather than using the term hierarchy which is burdened by the rigid, top-down implications of its common meaning. With panarchy, Gunderson and Holling (2002) were arguing that all social-ecological system dynamics can be approached heuristically as iterations of an adaptive cycle with four distinct phases, and that a nested set of adaptive cycles may be used to represent nested systems, with dynamic interactions among large and slow ones and small and fast ones, in different phases of their cycles. Scholars recognize that the figure eight *is* a heuristic; obviously not all social-ecological systems conform to this pattern.

Holling's notion of an adaptive cycle was initially modelled on boreal forests (the circumpolar northern forest dominated by conifers). In these forests there is no end point or climax, as some

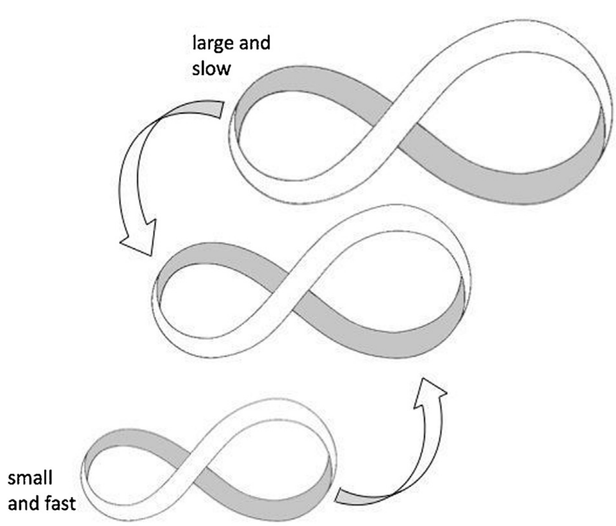

Fig. 1. A panarchy consisting of a nested set of adaptive cycles.

classical ecologists had assumed. Rather, the renewal and regeneration of the ecosystem depends on a perturbation, usually a fire event. The adaptive cycle, Holling argued, was characterized by four stages: rapid successional (1) growth phase, followed by a slow (2) conservation phase in which the ecosystem (or forest) matures. These two phases are well known in classical ecology. The innovation of the Holling adaptive cycle was the contention that the mature ecosystem may endure for a while but eventually breaks apart after a disturbance or perturbation, involving a (3) release phase of creative destruction, followed by a spontaneous (4) reorganization phase that leads to a new growth phase (Gunderson and Holling, 2002).

Fig. 1 shows a panarchy of three reclining figure eights representing the adaptive cycle, the white areas indicating growth and conservation phases, and the grey areas indicating release and reorganization phases, also known as the "backloop" (Berkes et al., 2003). The adaptive cycle at the top may represent a large forest social-ecological system, with its forest-dominated economy and forest-dependent communities. Here processes tend to be slow; the fire cycle may be 300 years in duration system wide, and the life cycle of the forest industry may be several decades or more. By contrast, the adaptive cycle at the bottom represents a small system, for example a stand of trees, where the seasonal growth cycles of individual trees is one year, and the use of non-timber forest products such as berries and medicinal plants by local communities may be in the order of an annual cycle or shorter.

For our purposes, the significance of the panarchy concept is that it allows for the possibility of interactions across levels and thresholds through system feedbacks (Gunderson and Holling, 2002). There may be many kinds of interactions among the levels of a given panarchy. Two of them are particularly important, "revolt" and "remember". Where fast and small events (see Fig. 1) overwhelm slow and large ones, as in the spread of a fire from the ground to the crown of a tree and then to a whole stand of trees, such a feedback is referred to as "revolt". In a system with multiple nested adaptive cycles, "revolt" feedback or series of feedbacks may "cascade" in a series of steps all the way up to the highest (Kinzig et al., 2006). Examples include the use of social media by grassroots demonstrators on the street to topple governments, or environmental actions undertaken by individual citizens that may have cumulative global effects (Rudel, 2011).

"Remember" is the opposite of "revolt", a feedback from larger and slower levels downward to smaller and faster levels, indicating a stabilizing function. Once a change is triggered at a particular level, opportunities and constraints for its renewal are strongly influenced by the conservation phase of the next level which is slower and larger. This connection draws upon the accumulated wisdom and experience of maturity of the higher level, hence the choice of the word, "remember". These two kinds of connections between levels of a panarchy are critical in creating and sustaining adaptive capacity (Armitage and Plummer, 2010). "Revolt" connection can cause a critical change in one level to cascade up to influence a larger and slower one at a vulnerable stage. The "remember" connection regulates the renewal cycle at a given level by drawing on the potential that has been accumulated and stored in a larger, slower one.

The levels in Fig. 1 are conceptually distinct or discontinuous. There are both similarities and differences between levels, and different principles and considerations may apply to each, following complexity theory which holds that "more is different" (Anderson, 1972). The panarchy of major interest in this paper is the connection between the community level and adjacent levels. Some of the same principles may apply to building resilience at the community level as at other levels, but additional factors and principles may also come into play, for example, at the community level in comparison to the individual level (Berkes and Ross, 2013).

Of key importance are the interactions among levels, both revolt and remember kinds, and cascading interactions that sweep across levels. Such an endeavour is necessarily interdisciplinary. Conventional disciplines specialize at different levels, e.g. the individual, the region, the nation state – a barrier to investigating multi-level interactions and ultimately the study of sustainability in a multi-level world.

Here we aim to dismantle these disciplinary divides and contribute to the interdisciplinary conceptualization of community resilience. Fig. 2 schematically indicates the scope of the present paper. However, the neat hierarchy of levels implied by the diagram is in reality not so clear-cut; the relationships among levels may be in the form of networks, more web-like than layered (Cash et al., 2006; Olsson et al., 2004). The relationships may involve horizontal linkages among actors at the same level of organization, as well as vertical linkages across levels of organization in the panarchy (Berkes, 2009). From a social resilience (Adger, 2000) point of view, the diagram also hides the all-important social capital, connectedness in social networks related to trust, reciprocity, cooperation and norms (Coleman, 1988; Pretty, 2003). As well, Fig. 2 runs the risk of implying a simplification of scales: in reality, there is a multitude of scales that can be considered (Cash et al., 2006).

The cases in the next section focus on community-level social-ecological systems, looking "upwards" and "downwards" from the community as the reference level. Arguing that interactions among levels have been insufficiently studied in the community resilience literature, we seek to contribute to the understanding of panarchy applications for sustainability. Further, these interactions have not been considered in a systematic way by much of the literature in the psychology strand of community resilience in which "environment" often refers to the social, rather than the biophysical environment.

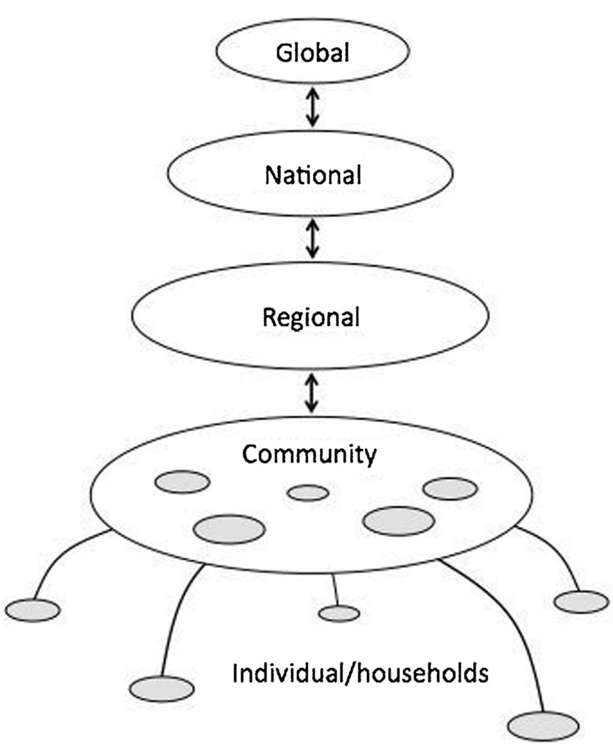

Fig. 2. A hierarchy of levels.

4. Illustrating the panarchy concept

In order to examine the ways in which the community level connects with higher and lower levels in the panarchy, we have selected a set of examples across the two strands of community resilience literature, including some natural disaster cases (Table 1). The examples show a diversity of interacting levels, starting with a case driven by an individual leader, through a range of cases with different combinations of multiple levels, and ending with avian influenza, a pandemic case, which spans the full range of levels from the individual human/pathogen to the international. Table 1 allows, first, a focus on the question, what are the relevant levels affecting community resilience? Second, it helps address how the levels link, that is, what connects the levels in the panarchy. The connecting processes selected are mainly of the social kind, reflecting the fact that we are discussing community resilience in a globalized world. Using a different set of cases, one could alternatively end up with a mainly ecological set of connecting processes, such as landscape connectivity and pollination.

The psychology strand of literature focuses on how an individual becomes resilient, through a combination of personal strengths and interactions with their (usually social) environment. However, Westley's (2002) account of the influence of one innovative and well-connected manager in the Great Lakes case demonstrates that there is far more to consider. Here an individual's agency and leadership mobilises networks of managers and resource users at various levels in the panarchy in order to increase the resilience of the social-ecological system as a whole. Kristianstads Vattenrike Biosphere Reserve case (Olsson et al., 2004) also refers to the agency of an individual leader, taking advantage of a window of opportunity and operating through established institutions of protected area governance to create a bridging organization, a forum for the interaction of parties (Berkes, 2009). The major change in the system involves a shift in perception about wetland values, from "water sick" to "water rich".

The examples in Table 1 show that community level resilience is connected to a diverse array of other levels, consistent with a large and growing literature. For example, globalized markets for such commodities as coffee (Eakin et al., 2009) have major impacts on the resilience of communities that produce them or the communities displaced by the new economy, raising issues of power relationships (Rocheleau et al., 2001). Whether national level policies mesh with existing local adaptations to climate variation, or undermine them (Adger et al., 2011) makes a big difference for community resilience.

The connective processes used by an individual, group, or bridging organization are revealing. Westley (2002) makes a distinction among the connective processes of managing "in" (managing self, bureaucratic process), managing "up" (political process), managing "through" (adaptive science-based process) and managing "out" (community outreach process). Management agencies, stakeholder groups and actors in political processes each have their own dynamics, requiring different strategies on the part of the innovative individual manager. The case of cyclone affected communities in northwest Australia, conducted within the psychology strand but recognising ecological connections, shows more classically how individuals, groups and the entire community influence one another, upwards and downwards.

Indeed, the same strengths, such as social networks and positive outlook, involve individuals contributing to the community, and receiving reinforcement from the community's social networks and associated support or its constructive outlook. The same strengths thus connect across levels: they are not limited to a single level. In both the cyclone case and the Stanthorpe case in Australia (Buikstra et al., 2010; Hegney et al., 2008), these

Table 1
Selected examples showing ways in which community may be connected to other levels in the panarchy.

Cases	Levels involved and what connects them
North American Great Lakes An individual manager responsible for fisheries management juggles multiple strategies and goals across social and ecological aspects of the system, dealing with politics and values as well as science. His leadership in adaptive management has a number of impacts at regional and international (USA–Canada) levels (Westley 2002)	Individual–management institution–regional–international Connections: agency; leadership; management strategies; resource governance
Cyclone-affected communities, northwest Australia Comparison of four towns affected by cyclones shows interaction between individual and community resilience. Sense of community and 'community competence' (marshalling resources, collaborating and acting) relate to individual self-efficacy, coping styles, and social networks. Intervention can be valuable at either level, for instance increasing attachment to community and the community's competence may alleviate individual disaster stress and increase potential for psychological growth following a disaster (Pooley et al., 2006)	Individual – community Connections: disaster response; agency (community and individual); self-organising, sense of community
Murray-Darling River Basin, Australia Long-term clearing of land in the Goulburn-Broken catchment drives significant hydrological changes in which rising water tables bring salt to the surface, threatening farmland. Pumping salty water away from individual farms transfers problems to catchment and basin levels. Solutions may emerge in landscape-level collaborative approaches both within the catchment and across the Basin (Walker et al., 2004; Walker and Salt, 2006)	Farm – catchment – major basin Connections: water flows; trade-offs between farm and catchment levels; livelihoods; collaborative approaches
Kristianstads Vattenrike Biosphere Reserve, Sweden A wetland landscape in southern Sweden is reconfigured into a resilient social-ecological system in ten years, through individual agency stimulating social networks, self-organization, trust-building, and understanding of ecosystem management. The Ecomuseum of the Biosphere Reserve acts as the bridging organization, bringing together the parties in a social learning process, and acting as hub and facilitator (Olsson et al., 2004)	Individual – municipal – regional – international Connections: water; protected area governance; bridging organization
Cree goose hunters of James Bay, Canada Cree hunters have been adapting to changes brought about by hydroelectric development projects and changes in migratory Canada goose flyways. The Cree recognize impacts of multiple factors on the goose hunt, including climate change effects, whereby too much heat "cooks" the berries which are the fall food of geese; they now pass through the region without stopping to feed, thus impacting the hunt and local livelihoods (Peloquin and Berkes, 2009)	Local – regional – national Connections: livelihoods; migratory species; major habitat change due to hydroelectric development along with climate change
Alaska salmon fisheries, United States The viability and sustainability of the salmon fishing system depends on the export of high value wild sockeye salmon to global markets. However, the global demand for salmon is increasingly satisfied by international aquaculture operations, which are able to produce high quality inexpensive salmon, even though their sustainability is questionable. This threatens the viability of Alaska fishing communites which (ironically) have been fishing sustainably (Robards and Greenberg 2007)	Community – regional – global Connections: global market demands for salmon; livelihoods
Pandemic diseases Pandemics, such as avian influenza, connect social-ecological systems, and all levels of the panarchy, rapidly. Localised outbreaks affected by changes in local conditions (such as weather) transmit rapidly through vectors such as migratory birds, food trade and human travel. Global health response requires international communication and coordination of national, community, household and individual level responses (Cumming, 2010; Si et al., 2010)	Micro-organisms with hosts – individual – regional – global Connections: ecological connectors (mobile pathogens); migratory species; global health governance

strengths, social networks and sense of community help the community to self-organise. This connectedness suggests that management intervention can be carried out at any of the levels (individual, group, or community) with impact on the others.

As illustrated by the above examples, leadership, self-organization and social networks are key connecting processes among levels of the panarchy. For example, the importance of social networks as a basis for self-organization and leadership emerging in a crisis shows up in Goldstein's (2008) account of the San Diego Fire Recovery Network. The network of local citizens with diverse skills to organise recovery emerged spontaneously across pre-existing networks after the San Diego fires of 2003.

Livelihoods are a clearly important connector between the social and the ecological, and connect readily across levels through marketing and distribution arrangements, and through collective action to manage resource use. There may be problems of fit (Young, 2002) between livelihood and broader resource use. Livelihoods apply at individual and household levels, but resources may be used in common (jointly) at community, regional or other levels, as in the Murray-Darling case and in many other examples (e.g., Marschke and Berkes, 2006). In the Murray-Darling case, trade-offs emerge between farm-level management and catchment-level management: pumping away the salty groundwater from each farm creates problems for the rest of the catchment; hence, solutions may require negotiation and use of collaborative approaches at the catchment level.

In other cases, drivers emanate from higher levels. The James Bay example shows how regional habitat change and a regional/global climate shift rendered wild food resources (migratory Canada geese) unavailable to the community of indigenous hunters. Global market shifts can equally change community (and other level) social-ecological systems profoundly, as in the case of the Alaska salmon fisheries mentioned previously. Here, wild salmon management appears sustainable, and so is the local social-ecological system, the fishery. However, the large supply from international aquaculture operations has changed the market structure and the demand for salmon, and the sustainability of the Bristol Bay fishery in Alaska is for naught. All this goes to remind the sustainability analyst of the importance of economic drivers, seldom acknowledged in single-level social-ecological system analysis. In the multi-level analysis, it becomes clear that communities do not have the power to negotiate with the players involved in global economic drivers (Robards and Greenberg, 2007).

In such cases, solutions may emerge from local-level adaptive responses (Armitage and Plummer, 2010). The shift to local-level adaptation coincides with the change of emphasis with regard to climate change from mitigation to adaptation: if you cannot control the direction of change, the only remaining response option is to adapt to it. Hence, a great deal of recent resilience research concerns adaptation to climate change in contexts such as rural resource-dependent communities and urban communities (Tyler and Moench, 2012).

Governance and participatory processes connect levels in at least three of the cases. In the Great Lakes example, governance is implicit. In the case of the Murray-Darling Basin, Australia's "food bowl", collaborative processes take a whole-of-landscape approach to deal with trade-offs regarding the soil salinization crisis. Co-management by definition connects levels (Berkes, 2009), and Kristianstads is time-tested co-management (adaptive co-management). This particular case has another policy lesson: it involves a bridging organization to provide an independent forum where co-managers from various levels (individual farmers; stakeholder groups, national and international agencies) come together. However, collaborative governance processes do not necessarily involve formal co-management. For example, a participatory process was used to reconcile interests in Solomon Islands water management, and bring about multi-level collaboration between community, regional and national organisations. This enabled communities whose catchment supplied water, and the government organisations managing water supply to the capital city, to develop a shared system of understanding, and to build relationships towards co-operative management (Chan et al., 2010; Hoverman et al., 2011).

Mobile agents and mobile resources are major connectors of levels. Water in the Murray-Darling and Kristianstads cases is a mobile natural resource, connecting ecological processes and human uses through the hydrological cycle, and connecting multiple levels in social-ecological systems in the process. Pandemic diseases provide a more dramatic case of mobile connectors. Consider the social-ecological processes involved in pandemics such as avian influenza and swine flu (both zoonoses, diseases that transfer between animals and humans). AIDS (not a zoonosis) is believed to have mutated from a primate virus strain. The case reminds us that the host-disease relationship is a kind of social-ecological system, operating within and between individual humans. Yet outbreaks spread through communities spatially and among interest groups, and transfer from place-to-place globally through a variety of mechanisms, often involving migratory species, trade or travel. Response for prevention of pandemics goes beyond the medical response for treatment; it involves multi-level international cooperation. The One Health International movement (Mackenzie et al., 2013), which brings together medical, veterinary and environmental sciences, is an important global learning response to these pandemics. It is changing the way health management is organised, by joining up human, animal health and ecosystem processes in a multi-level social-ecological system perspective.

5. Implications for sustainability policies

It can be argued, as Brown (2014, 107) points out, that resilience may perhaps represent a "new wave of thinking around sustainability in an age of economic and political instability". However, care must be taken not to overextend the argument and advocate resilience as the "pervasive idiom" for governing all things (Walker and Cooper, 2011). All concepts have limitations in their applicability. In particular, it must be remembered that resilience, like sustainability (Norton, 2005), is a normative concept. Further, resilience is not always a positive or desirable outcome. The *Panarchy* book gives the example of the Indian caste system to make the point: this socially inequitable system, despite all efforts at least since the time of Gandhi to eradicate it, has remained resilient (Gunderson and Holling, 2002; 97–98).

The strength that the panarchy idea brings to the study of sustainability is a structure or framework for the study of multi-level or nested relationships. Some of the elements of such an approach are not novel. The concept of drivers has been widely used since the Millennium Ecosystem Assessment (MA, 2005), and hierarchy theory is well known in ecology (Ahl and Allen, 1996; Gunderson and Holling, 2002). However, the panarchy concept is useful in informing multi-level analysis. It sets some standards for the analysis of integrated and interdependent social and ecological systems, as the examples in Table 1 show.

As Blythe (2015) observed in the case of social thresholds (as opposed to ecological ones), natural sciences focus on identifying structural properties of the system. But such an approach cannot capture social capital and power relations, agency, historical and cultural contexts within which social relationships are experienced and negotiated among the levels in a panarchy. Many of these relationships are place-specific and culture-specific, and they involve value judgments, social norms, trust and reciprocity. Hence, understanding social aspects of social-ecological relationships in community resilience requires the use of social science concepts and use of a variety of research methods that go far beyond ecological research (Ross and Berkes, 2014).

Consideration of social aspects of panarchic relationships adds an extra layer of uncertainties. The diversity of ways in which community resilience is impacted by other levels (Table 1) provides evidence of this. Further, the levels in panarchy in these examples and others are not neatly nested, or even geographically consistent. The concept of panarchy assumes nested (hierarchical) systems where the levels are distinct and discontinuous. But in real life, these assumptions do not always hold. Further, a particular change process does not necessarily engage all levels, and may actually skip some of the adjacent levels. For example, pandemics can move swiftly across levels in a panarchy, potentially skipping some levels (e.g., going from individuals to communities and then directly to outbreaks on other continents), or can jump laterally from one set of communities to others far away (Cumming, 2010). HIV/AIDS is informative in the extent to which communities of interest (starting with gay men in western countries, and its prevalence in migratory fishing communities in Africa), rather than communities of place, are involved (Westaway et al., 2007).

As well, the direction of influence may not be as simple as in Table 1 examples. Drivers can be top-down, but they can also be bottom-up, or both ways simultaneously. For example, Eakin et al. (2009) showed how national policies in Vietnam enabled smallholders to increase coffee production ten-fold between 1990 and 2000. This resulted in a restructuring of global coffee markets and a sharp decline in prices, hurting not only Mexican and Central American growers but also Vietnamese producers themselves when the coffee market collapsed in 2003. The example shows how globalisation enabled local action to become a revolt loop and cascade up to higher levels in the system (Fig. 1) impacting resilience at multiple levels.

Thus, multi-level panarchy processes often involve two-way relationships, but caution should be exercised not to jump to deterministic conclusions. Communities are not passive victims of global influences, such as climate change or global market processes. They often respond, by adapting to changes, so there often are feedback relations and two-way interactions between processes that impact community resilience and the response of the community itself. Further, linking factors across levels may be considered positive, negative or neutral. The examples of individual agency in Table 1 examples are positive influences, but it is equally possible to envisage negative ones driving change in social-ecological systems. As Anderies and Janssen (2011) argue, resilience analysis is weak on considering trade-offs. However, our examples show that trade-offs are pervasive, for instance between farm-level and catchment-level costs and benefits in the Murray-Darling Basin case.

Relationships among levels may be harmonious, that is, in the same policy direction, as in the example of cyclone-affected communities in Australia. Governance activity is a multi-level influencer. For example, global health sector responses to pandemics involve international agencies working with national and local agencies, and often NGOs and community groups, influencing activity in each country and outbreak area. The synergy or lack thereof between official government and community-level self-organising, often under customary arrangements and leadership, is also important. Adger et al. (2011) present nine cases of climate change adaptation in different countries, finding that in a few cases national government policies or government-led efforts synergised well with community-level adaptations. In most of the other cases it ran counter to, or undermined, community-level adaptive responses.

Examples in Table 1 and elsewhere showing a variety of processes linking social-ecological systems within a panarchy highlight some concepts which are underdeveloped in social-ecological systems literature but well known in other domains (Brown and Westaway, 2011). Power, especially in forms such as colonisation and global commercial power, is typically considered as a top-down driver. However, communities may respond to unequal power relationships through agency, social learning, and the development of alternate livelihood strategies (Marschke and Berkes, 2006). Hence, panarchy analyses need to incorporate considerations of power in a historical context. This is because both change processes and the exercise of power have unique political and historical backgrounds.

The temporal scale is a challenge. A single panarchy figure is a snapshot in time. But all social-ecological systems are impacted continuously by change processes. Levels are interacting through time, as in global market influences (e.g., the Alaska salmon case), and agricultural modernization. Cases like Kristianstads and the Murray-Darling are continuously evolving through changing policies and practices. Pandemics show rapid change and will often resurge even after being dormant for some time. The complex adaptive patterns of social-ecological systems, and hence their resilience, are influenced by combinations of drivers. It is therefore important to capture the dynamics of panarchies. Scholars have used time series of figure eights to depict change over time (Gunderson et al., 1995).

A key political process affecting community resilience has to do with global social-ecological transformation occurring initially through colonisation, and later through globalisation. In an example from the political ecology rather than the resilience literature, a regional agroforestry landscape in the Dominican Republic was reshaped by colonisation, then by conversion of landscapes for cash crops for export, especially sugar. Later, a well-intentioned NGO program in partnership with a peasant federation to produce timber cash crop for smallholders created further landscape changes and socio-economic redistributions. As an emergent property in this system, biodiversity distributions on farms came to reflect social stratification and power, with landholder strategies in adopting agroforestry reflecting their degrees of control over land and labour (Rocheleau et al., 2001). This example shows connections driving downwards from global to farm and household levels, involving colonisation, world trade, political processes at many levels, NGO interventions, regional self-organization and agency, as well as household livelihood strategies. These are not simply economic drivers in action, but examples of power relationships, often missed in resilience analysis (Brown and Westaway, 2011).

6. Conclusions

Resilience thinking can be used as a part of the analysis and the policy process in striving towards sustainability, making the important contribution of analysing multi-level or nested relationships. But resilience does not automatically inform political decision-making, nor does it (or should it) replace political processes such as those for fighting poverty (Béné et al., 2011). Rather, resilience building can be thought of as a natural ally of political processes towards empowering communities. As part of a resilience analysis, the concept of panarchy provides an integrative approach for understanding the linkages and dynamics within and across levels of social-ecological systems, in a way that is useful for integrated policy understanding and interventions. Resilience building may often involve trade-offs among levels; for example, community resilience may be at odds with resilience at other levels (Robards and Greenberg, 2007). Policy, however, should not be conceived as coming from outside the system of interest, but as coming from another level within it, for instance national governments introducing policies and programs to improve community well-being outcomes. Indeed “top-down” and “bottom-up” are cross-level decision processes within a multi-level system, while multi-party collaborations and co-management consciously work across levels.

There are often normative dimensions that involve value judgments about priorities: Whose resilience? Which social-ecological system? Should social and economic benefits, especially short-term, be privileged over ecological values? When is it desirable to focus on strengthening the adaptive capacity of a social-ecological system, and when is it appropriate to consider transformative change? Findings of resilience analysis need to be tailored to policy processes at appropriate spatial and temporal scales, what Young (2002) has called the problem of fit. Some decisions are best deliberated or negotiated at the local level; others may require national level policy changes, or even international agreements, as in the case of pandemics.

Taking a critical view, our analysis suggests we should question whether it is possible to join the levels of social-ecological systems up as neatly as panarchy figures may lead us to believe. The interactions are far more varied and complex than panarchy figures suggest. The view that one should focus mainly on the levels above and below the level of interest are contested by observations of direct vertical jumps from local to global, and also of horizontal processes within the same level. These issues are of more than theoretical interest and have implications for sustainability policies. They suggest the need for some form of sustainability management of nested systems, difficult though that may be. But they also suggest the consideration of impacts of interventions at any one level on potentially disparate other levels, as in pandemics that seem to be able to skip levels.

Resilience is unlikely to become a pervasive idiom of global governance but is an important approach to deal with unpredictability. Hence, the idea of community resilience has been widely adopted in disaster management (Haque and Etkin, 2012; Norris et al., 2008). However, there is still much to learn about what makes social-ecological systems resilient or not, and how to intervene effectively. Too often well-intentioned interventions at one level, or on some specific components of the social-ecological system, have led to unanticipated consequences. In particular, we need to improve the understanding of multiple kinds of influence across levels. Our preliminary analysis suggests the linkages involve concepts known in some disciplines but underdeveloped or underused in the resilience literature. Resilience thinking needs to engage more thoroughly with the accumulated insights of other disciplines, by identifying concepts such as social capital, agency and power, and processes such as colonisation and globalisation that act as significant drivers within and across levels in social-ecological systems.

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