Climatic Change (2017) 141:227–241
DOI 10.1007/s10584-017-1897-0

# Understanding climate change and resilience: assessing strengths and opportunities for adaptation in the Global South

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Received: 28 January 2016 / Accepted: 2 January 2017 / Published online: 18 January 2017


**Abstract** Better integration of resilience and climate change adaptation can help building climate-resilient development. Yet, resilience and adaptation to climate change have evolved largely along parallel paths with little cross-fertilization. Conceptual vagueness around resilience makes it challenging to ascertain what elements of resilience thinking have the greatest potential to enhance climate change adaptation and contribute to broader sustainable development goals. This article distills nine principles from the resilience literature to build a framework to assess 224 climate change adaptation strategies proposed by researchers and practitioners in Africa, Asia, and Latin America. Our analysis concludes that adaptation strategies in this data set emphasize initiatives that increase social and ecological diversity, strengthen learning processes, build functional redundancy, enhance connectivity between social and ecological elements, pay attention to the management of slow variables, and provide mechanisms for increasing participation and polycentric governance. At the same time, the adaptation options examined generally lacked a system's perspective, suggesting that there is still important work ahead to move toward a climate-resilient development model.

## 1 Introduction

The sheer complexity of climate change and the scope of its potential impacts require the integration of multiple research disciplines, levels of governance, and societal actors to inform the design of adequate adaptation strategies. Although originating within distinct epistemological communities, over the years, resilience and climate change adaptation have begun informing one another. Notions from resilience thinking are seen as having a potential role in complementing and enhancing climate adaptation, particularly as resilience is well suited to deal with issues of uncertainty and complexity. Explorations on how resilience thinking can be

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applied to the understanding of climate change adaptation have been articulated in the academic literature as early as the 1990s (e.g., Peterson et al. 1997) and continue to the present (e.g., Tompkins and Adger 2004; Nelson et al. 2007; Deppisch and Hasibovic 2013; Wardekker et al. 2010, 2016). Indeed, in the Fifth Assessment Report (2014), the IPCC dedicated an entire chapter to climate-resilient pathways to development. The push for integration is occurring on the ground as well, with climate and development donors promoting "climate-resilient development" through programs such as the Asian Cities Climate Change Resilience Network, funded by the Rockefeller Foundation, or the World Bank's Pilot Program for Climate Resilience.

One of the reasons for bringing resilience insights to climate change adaptation has to do with a desire to move from a predict-and-prevent approach to a resilience-building approach that may respond to a wider range of expected and unexpected climatic risks (Measham et al. 2011; Tyler and Moench 2012). Predict-and-prevent approaches focus on anticipating and preparing for precise climate risks, whereas resilience-building approaches focus on developing robustness to a wider variety of probable shocks. In addition, the system's orientation in resilience makes it suitable to tackle so-called 'wicked' problems, that is, problems that are difficult to define and context specific, impact multiple stakeholders with opposing views, and where solutions are often only temporary (Rittel and Webber 1973). Inasmuch as climate adaptation in the Global South is a highly complex problem, a resilience approach can provide a useful frame for the challenges faced by researchers and practitioners.

While there is ample opportunity for resilience and adaptation literatures to inform one another, not all scholars and practitioners share the enthusiasm for resilience. Some within the climate community have suggested that systems perspectives tend to depoliticize the discourse around sources of vulnerability by obscuring socio-economic drivers (Cannon and Müller-Mahn 2010). Adaptation to climate change has been a human-centered approach influenced by vulnerability, hazard, and risk studies, focusing largely on the role of actors and institutions (Nelson et al. 2007). By contrast, resilience emerged from the natural sciences to understand processes of ecosystem change. Thus, a key focus of resilience has been maintaining ecosystem functions that are critical for human survival while normative concerns have been relatively less central. These two orientations, and the fact that resilience emerges from a natural science tradition, can constitute an obstacle for integration.

Beyond epistemological debates, there is conceptual vagueness around resilience. The 1990s witnessed an upwelling of academic publications on resilience (Xu and Marinova 2013) leading to multiple definitions of the term (Quinlan et al. 2015). In climate change research, resilience has been defined along the lines of the ability of communities to persist, adapt, and recover in the face of climate stresses and shocks (Tanner et al. 2009; Wardekker et al. 2010), with varying degrees of emphasis on the roles of persistence, adaptation, and/or recovery. More importantly, how resilience translates into practical guidelines for implementation depends on the context. For example, Wardekker et al.'s (2010, 2016) resilience principles for urban adaptation are worded in the language of ecology and include homeostasis, omnivory, high flux, flatness, buffering, and redundancy. Whereas Gupta et al. (2010) focus on institutional adaptation to climate change and consider diversity, learning capacity, room for autonomous change, leadership, fairness, and availability of resources.

Our goal with this article is to add to the ongoing dialogue around the use of resilience insights in climate change adaptation within the development context with a view to advancing guidelines for assessment. We do this by first distilling a set of principles from the resilience literature based on Walker and Salt (2012), Chapin III et al. (2009), Biggs et al. (2012, 2015),

and Quinlan et al. (2015). Using these principles, we assess 224 climate adaptation strategies proposed and/or implemented by researchers and practitioners in Africa, Asia, and Latin America between 2005 and 2015. These adaptation strategies emerged out of 54 climate change adaptation projects sponsored by the International Development Research Centre (IDRC)—a Canadian development donor. In doing so, we provide empirical evidence and examples of how resilient principles inform adaptation in the developing world while also identifying areas that offer the potential for further integration.

## 2 What is resilience?

### 2.1 Definitions of resilience

Definitions of resilience follow one of two approaches: The first approach is to consider resilience in the abstract, that is, as an emergent characteristic of a complex system. The second approach is what we call "applied" definitions of resilience, where ideas of resilience are adapted to shed light in particular contexts or areas of study. In this section, we briefly review definitions of applied resilience, but we focus primarily on the definition of resilience as an emergent property of a system, given that our principles for assessment emerge from this literature.

At its most basic, resilience is an emergent property of social-ecological systems that lends a useful lens for studying the dynamics of change (Gunderson and Holling 2002). The term resilience (as used in this article) appeared in the literature of systems ecology in the early 1970s as a way of understanding non-linear ecosystem dynamics that were applicable to natural resource management. The scope of topics studied using a resilience lens broadened in the 1990s to cover issues associated with the understanding of social dimensions and institutions, particularly in relation to communities dependent on natural resources.

Although resilience is an evolving concept, there is consensus around the following definitions: *Engineering resilience* is defined as a system's speed of return to equilibrium following a shock (Holling 1996). Engineering resilience is usually contrasted to *ecological resilience*, which is defined as the magnitude of disturbance that a system can absorb before it shifts to an alternative steady state (Holling 1996). Ecological resilience was introduced in contrast to the previous idea of single steady-state equilibrium, and it emerged from observations of a system's ability to withstand shock and maintain critical relationships and the existence of multiple stable states (Holling 1973). *Social-ecological resilience* has been defined as an emergent property of a system that depends on (1) the amount of disturbance that a system can absorb and still remain within a domain of attraction, (2) the capacity of a system to learn and adapt, and (3) the degree to which the system is capable of self-organizing (Carpenter et al. 2001; Folke 2006). Recently, resilience is being understood as transformability, or as the capacity of a social-ecological system to navigate a transition from its present state to an alternative state following a desired pathway (Folke et al. 2010). Hence, in its latest formulation, resilience highlights the interplay between coping, adapting, and transforming as necessary to preserve the desirable characteristics of a system.

The term social resilience (Adger 2000) was coined as theoretical insights from resilience thinking began to be applied more widely to social issues. The intention in talking about social resilience was primarily to use resilience concepts as analogies to guide the exploration of social and institutional processes. In the more recent years, different forms of applied resilience have emerged, such as livelihood resilience (Marschke and Berkes 2006), development

resilience (Barrett and Constas 2014), socio-economic resilience (Mancini et al. 2012), and community resilience (Berkes and Ross 2013).

## 2.2 Principles of resilience

The need to inform practice has resulted in different efforts to synthesize principles that build resilience. From Walker and Salt (2006), Biggs et al. (2012, 2015), and Chapin III et al. (2009) we identify the following principles: (1) increasing diversity, (2) building redundancy, (3) enhancing connectivity, (4) managing slow variables, (5) managing feedbacks, (6) considering social-ecological interactions, (7) increasing participation, (8) providing opportunities for learning and experimentation, and (9) fostering polycentric governance (see Table 1). There is overlap between the principles, but the first three—diversity, redundancy, and connectivity—are more pertinent to examining a system's structure; the next three—slow variables, feedbacks, and social-ecological thinking—are geared to enhancing complex systems thinking; and the last three—experimentation, participation, and polycentricity—touch on management and governance dimensions.

The principles are supported to different degrees by practical experience. Furthermore, this experience tends to rely heavily on insights derived from ecosystem management. Thus, the data in this article provides additional insights on what these principles may look like as they are operationalized in a broader set of contexts and for the purposes of building social, as well as ecological, resilience to climate change.

**Table 1** Principles of resilience used to assess climate change adaptation strategies (based on Walker and Salt (2006), Chapin III et al. (2009), Biggs et al. (2012, 2015) and Quinlan et al. (2015)

| | |
|---|---|
| System structure | Diversity. Actions that increase or maintain diversity increase the resilience of a social-ecological system. Diversity can mean increasing variety (how many different elements), balance (how many of each), or disparity (how different the elements are from one another). |
| | Redundancy. Resilience is enhanced by mechanisms that build functional redundancy, that is, having components within the system that fulfill similar or overlapping functions that allow the system to continue to operate even if one part of it fails. |
| | Connectivity. Enhancing connectivity within a system means increasing the number of links between the components of the system and/or strengthening these linkages. |
| Systems thinking | Slow variables. The resilience of a social-ecological system is largely dependent on key variables that impact its internal dynamics and that change at a gradual pace. |
| | Feedbacks. A system responds to reinforcing or dampening response dynamics (positive or negative feedback loops) that are the result of management actions. |
| | Social-ecological systems lens. A resilience lens considers the dynamic interplay between social and ecological elements in a system. |
| Management and governance | Experimentation and learning. Learning is the key in situations where there is uncertainty and it can take many forms, including the practice of adaptive environmental management that encourages experimentation, monitoring, and iteration. |
| | Participation. Experimentation is encouraged in resilience usually as a means to an end, that is, more participation means a more complete understanding based on a variety of perspectives that will ultimately result in better decision-making. |
| | Polycentric governance. Decentralized governance where governing authorities act with some degree of autonomy and there is an effort to match the governing authority with the scale of the problem. |

While there is overlap and complementarity, principles are grouped based on whether they are pertinent to the system structure (diversity, redundancy, and connectivity), systemic thinking (slow variables, feedbacks, and social-ecological thinking) or management and governance (experimentation, participation, and polycentricity)

## 3 Methods

We examined climate change adaptation strategies emerging from 54 projects funded through the IDRC. The IDRC is a Canadian crown corporation (an entity that is owned by the state but operates at an arm's length from it) founded in the 1970s with the goal of improving research capacity in the Global South. The IDRC promotes research conducted by institutions such as universities, governments, or non-governmental organizations, in Latin America, Asia, and Africa. The data set that we examined comes from two program initiatives within the IDRC: Climate Change Adaptation in Africa (2006–2012) and Climate Change and Water (2010–2015). Combined, these two program initiatives funded research on adaptation in 66 countries in the Global South over a period of 9 years. The IDRC does not prescribe a particular lens to the projects it funds. Hence, there were a variety of theoretical and practical influences framing the projects that we reviewed; some projects were anchored in resilience, some used alternative approaches. Our sample represents only a subset of global adaptation projects and so our claims need to be understood as such. At the same time, the IDRC is a unique and important development donor. Furthermore, the 54 projects reviewed covered a wide variety of initiatives occurring throughout the developing world at local, regional, national, and international scales, with varying amounts of funding, and at different stages of project progress, from planning, to pilots, to fully implemented projects.

The first step in the study was to identify the adaptation strategies emerging from the set of projects. Adaptation strategies included programs, initiatives, pilots, or practices that stakeholders in the project identified, proposed, or implemented to deal with a perceived climatic risk. Each project typically had a suite of adaptation strategies associated with it. Five research assistants conducted a review of internal reporting documents written by project grantees for the IDRC. Examples of adaptation strategies are shown in Table 2. Typical adaptation strategies targeted climate impacts related to water and favored soft adaptation options that emphasized education and behavioral approaches. Adaptation options prioritized local scales and the purported beneficiaries were municipalities, households, or individuals. A detailed analysis of the patterns observed within this set of adaptation strategies is contained in Burch et al. (2017, under review).

In a subsequent step, the first author reviewed each adaptation strategy and assessed it according to the extent to which the principles of resilience identified above appeared to be addressed. This assessment was conducted using a three-point Likert scale (the principle is present, the principle is somewhat present, and the principle is absent). For example, if an adaptation strategy consisted of working with farmers to diversify their crops to better cope with severe droughts, the principle of diversity would be assessed as present and all others as absent. If an adaptation option sought to diversify crops but the idea came from community groups composed of farmers and researchers, then the adaptation would have an element of diversification as well as an element of participation. Depending on how the actual strategy was worded, there may be signs that the adaptation constituted a transfer of decision-making power to local scales; thus, polycentric governance may be somewhat present. The assessment was based strictly on the descriptions of the adaptation options published in the IDRC's online database, which is a limitation of this study given that descriptions were often short (50 to 200 words).

**Table 2** Examples of the types of climate change adaptation strategies analyzed

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|---|---|
| Strategies emphasizing diversification | In a variety of countries, resource-dependent people, such as farmers, diversify their income sources by taking on short-term off-farm work, which allows them to maintain their livelihoods when climate-related events reduce their yields. |
| | A number of projects sought to provide platforms that bring insights and experiences from different knowledge holders, such as indigenous knowledge, Western science, and traditional ecological knowledge. |
| Strategies emphasizing redundancy | Early warning systems were made more robust by layering several mechanisms with the common purpose of alerting populations at risk of extreme events. This may involve combinations of radio, television and cell phone broadcast technologies. |
| | Households in regions that are subject to frequent flooding tend to use a variety of overlapping methods to keep water away which may include building houses on stilts, digging trenches and channels, and using sand bags simultaneously. |
| Strategies emphasizing connectivity | Several projects created collaborative opportunities for different stakeholders to work together across disciplines (e.g., social and natural scientists), levels of governance (e.g., municipal and national), or countries (e.g., pan-African partnerships) in planning and dealing with climatic risks. |
| | Some projects focused on the management of connectivity between different social groups involved in water governance. Depending on the case, further integration or further decentralization were perceived as advantageous. |
| Strategies emphasizing the management of slow variables | A key focus of projects that build adaptive capacity was changing and challenging existing norms and perceptions of climate change through education and research, which is understood as a long-term, gradual change. |
| | Projects that involved agriculture tended to emphasize the management of slow variables, e.g. through farming practices that maintain soil fertility, in addition to fast variables, e.g. through the introduction of high-yield crop varieties. |
| Strategies emphasizing the management of feedbacks | A number of projects intended to modify consumer behavior by managing the economic incentives to which people responded, e.g. progressive water pricing to reduce consumption in countries that face potential water shortages. |
| | In several countries with rainfed agriculture, farmers modified their planting dates and their crop varieties in response to the amount of precipitation. |
| Strategies emphasizing social-ecological thinking | A simulation model that integrates hydrological, economic, and social indicators to forecast the impact of climate change on different watershed users in Bolivia. |
| | An ecosystem services assessment of the Orotay River basin (Colombia) will provide a baseline of changes in water quantity and quality, identify ecosystem users, document land distribution, and highlight the historical and cultural background of the basin. |
| Strategies emphasizing experimentation and learning | Several projects pointed to climate information gaps and focused on creating baselines for biophysical and social parameters impacted by climate-related risks (e.g., building precipitation records). |
| | A number of projects built or adapted simulation models for particular regions. Models are important tools for experimentation to understand the outcomes resulting from alternative climate scenarios in the future. |
| Strategies emphasizing participation | Many projects adopted a participatory action research approach that emphasized the input of local stakeholders at different points during the research process. |
| | Other projects emphasized participation as an end in itself with the intention of democratizing decision-making processes beyond the scope of any given project, e.g., by creating forums for citizen participation. |
| Strategies emphasizing polycentric governance | Several adaptation strategies were geared toward building the capacity for autonomous decision-making of local-level governance units, e.g., local water management boards. |
| | At the same time, projects also emphasized the need for coordinated action among semi-autonomous governance bodies and some adaptation strategies were geared at improving communication between these. |

## 4 Results

### 4.1 What principles of resilience are present in climate change adaptation strategies?

Figure 1 shows the degree to which the different principles of resilience were present, or somewhat present, in the set of climate change adaptation strategies reviewed. More than half of the adaptation strategies contained an element of learning and experimentation. Almost a third of the adaptation strategies had aspects that improved connectivity, diversity, participation, polycentric governance and considered slow variables. About a quarter of the strategies were geared toward building redundancy. Last, about a fifth of the strategies considered feedback mechanisms and only 10% focused on social-ecological interactions.

Adaptation options geared toward enhancing learning and experimentation covered a broad range of strategies. In some instances, learning was tied to research activities in the sense of collecting and synthesizing new information or disseminating research results. This was often the case in projects where there was no baseline to establish climate trends, e.g., a strategy seeking to assess the saline intrusion in aquifers near coastal areas in the Mediterranean, or

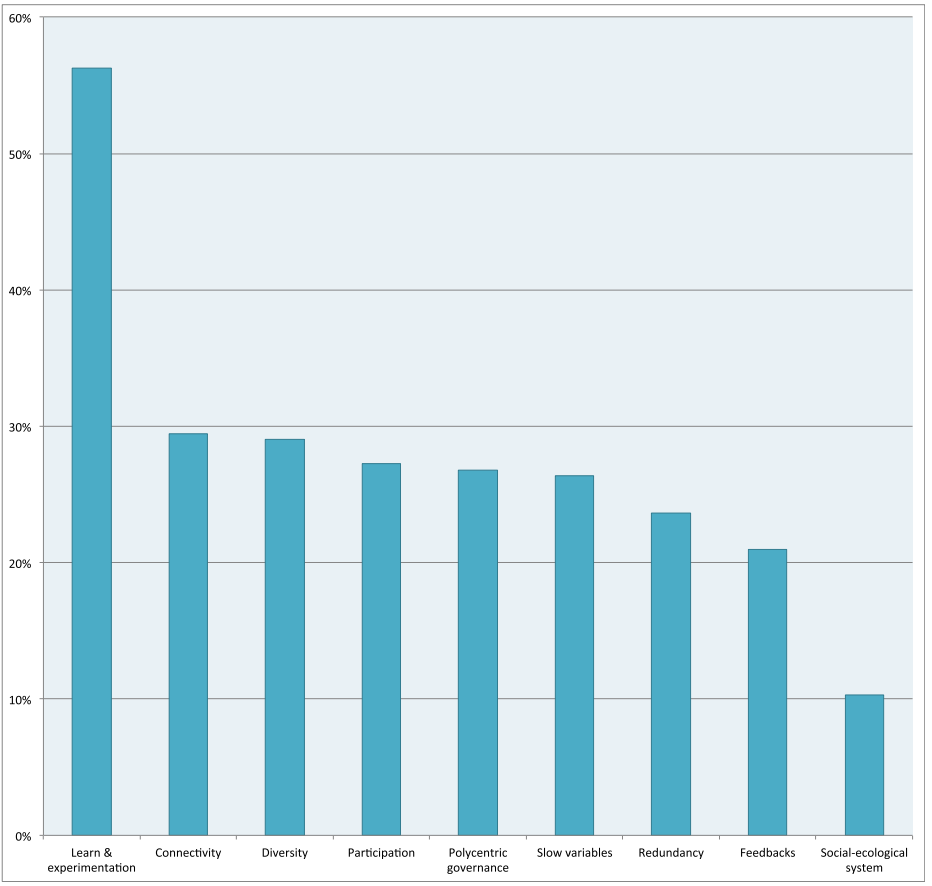


**Fig. 1** Frequency of individual principles of resilience present in the set of climate change adaptation strategies reviewed ($n = 224$)

where the intention was to educate and train the population, e.g., a series of radio-drama episodes that provided climate information to communities in Nepal. In other instances, learning was done through fostering collaborations that, in some cases, considered explicitly the integration of different kinds of knowledges, e.g., the development of a model of sustainable water governance based on indigenous Mapuche values in Chile. In fewer instances, learning was the product of experimentation, e.g., a project that worked with farmers in Ghana to adjust crop-planting dates to the changing climatic conditions.

Enhancing connectivity was present or somewhat present in 29% of the climate change adaptation strategies. Sometimes connectivity had an ecological dimension, for instance, a project in the Chilika Lake region of India aimed to physically join two water bodies to reduce the impact of flooding. At other times, connectivity had a social dimension, for example, the primary objective of the many early warning systems that are designed for adaptation aimed to improve communication channels among vulnerable populations.

Activities that increased diversity were present or somewhat present in 29% of the adaptation strategies. The majority of adaptations that enhanced diversity were geared to providing fallback plans for resource-dependent communities. For instance, farmers were often encouraged crop diversification so that they would not all be impacted by the same climatic risk, or to diversify their sources of income altogether (e.g., by finding jobs in another sector).

Participation was an element of 27% of the climate change adaptation strategies reviewed. There was an array of ways in which participation took form. In some instances, participation was a means to an end, e.g., the engagement of youth groups in river restoration activities that reduced flooding. At other times, participation was seen as an end in itself, e.g., the creation of arenas for knowledge exchange between community water organizations in Colombia.

Polycentric governance emphasizes decentralized decision-making between levels of government acting at multiple scales. Elements of polycentric governance were present or somewhat present in 27% of the adaptation strategies. This meant creating structures for local decision-making, providing tools to support already existing structures at these levels, or increasing the linkages between levels of governance. For instance, in Costa Rica, where local water boards are in charge of water management for rural areas, an adaptation strategy was to assess the capacity of water boards to take decisions in the face of uncertainty about water supply.

The management of slow variables was present or somewhat present in 26% of the adaptation strategies assessed. Typical adaptation strategies that considered slow variables included those geared toward the protection of ecologically fragile processes, e.g., the protection of headwaters via reforestation activities in rural Colombia to ultimately preserve the water supply. The management of slow variables can also include activities aimed at creating capacity within groups of people with the purpose of progressively changing perspectives, such as the creation of a pan-African Climate Change Fellowship program.

Twenty-four percent of the climate change adaptations had elements that aimed at building functional redundancy, that is, they tried to increase the number of elements that are distinct from one another but that fulfill a similar function. For example, it was noted that the official channels for flash floods warnings in Medellin were often slow. Hence, in addition to the official channels, an adaptation strategy was to experiment with social media to alert vulnerable populations quicker. These strategies were often focused on building insurance mechanisms to maintain the livelihoods of the poor. For instance, a project in Benin encouraged farmers to use a variety of agricultural techniques, such as mulching and traditional Zai (digging holes around plants to keep water) in combination to maintain soil moisture.

A focus on feedbacks was present or somewhat present in 21% of the adaptation strategies in the data set. This meant that a strategy considered actions and reactions together, or that the strategy responded to an observation in an iterative manner. For instance, in the Punjab region in India, farmers were given tensiometers to measure soil moisture to help them determine how much irrigation was required. Thus, in this case, the adaptation strategy allowed monitoring of a slow variable and adjusting behavior accordingly. In other cases, the adaptation strategies attempted to create a feedback loop by providing signals that would change people's behavior. For example, the introduction of water pricing schemes to try to curb water consumption in Chile.

Finally, 10% of the adaptation strategies were framed in terms of social-ecological systems. This meant that they considered both biophysical and social components in the design of adaptation. For instance, one adaptation option was the development of a simulation model that integrated hydrological, economic, and social indicators to forecast the impact of climate change on different watershed users in Bolivia.

### 4.2 How do different forms of adaptation build resilience?

Additional insights emerge when we segment the set of adaptation strategies according to the form of adaptation. Based on IPCC (2014) criteria, we classified adaptation strategies into three broad groups: One group encompassed those adaptation strategies that had a structural or a physical component, which were further subdivided into technological (e.g., renewable energy technologies), engineering (e.g., sea walls), or ecosystem-based adaptation (e.g., green infrastructure). A second group included adaptation options geared toward capacity building further subdivided into educational (e.g., awareness campaigns), informational (e.g., hazard mapping), and behavioral adaptations (e.g., livelihood diversification). A third group contained

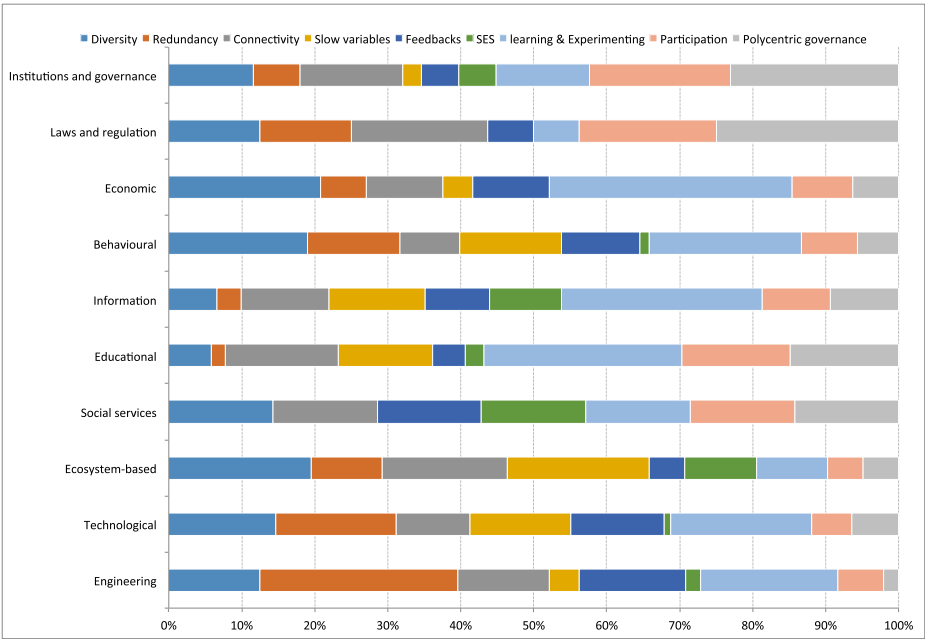


**Fig. 2** Frequency of resilience principles depending on the form of climate change adaptation

institutional adaptation options that included economic tools (e.g., subsidies), adaptations pertaining to laws and regulations (e.g., zoning laws), and adaptations pertaining to governance (e.g., national adaptation plans).

Figure 2 shows how different forms of adaptation emphasize different aspects of resilience. We note that adaptation strategies that had a physical or structural component tended to focus on building diversity, redundancy, and connectivity and on the management of slow variables. However, these adaptations did not usually consider social and ecological components simultaneously (except for ecosystem-based adaptation) and they paid relatively less attention to institutional dimensions. Adaptation strategies geared toward capacity building placed more emphasis on learning and experimentation, particularly those concerned with information dissemination and those that aimed at educational changes. These two also paid attention to enhancing connectivity and slow variables, in the sense of building capacity. In addition, behavioral strategies focused on increasing diversity more than the other two. Finally, the institutional strategies had a balance of resilient elements. Economic adaptations emphasized diversity as well as learning and experimentation, usually in relation to livelihoods, whereas governance and legal adaptations focused on building connectivity, participation, and promotion of polycentric governance.

## 5 Discussion

### 5.1 Common ground: what principles of resilience are currently better integrated in climate change adaptation?

Learning and experimentation were the principles of resilience that appeared more frequently in the climate change adaptation strategies studied. The focus is unsurprising, given IDRC's goal of improving research capacity in the Global South. Learning builds resilience by informing decision-making and by providing further insights into the workings of a complex system (Cundill et al. 2015). However, there is a wide range of activities and processes that qualify as learning that have different potentials for improving adaptive capacity. There has been a growing interest in *social learning*, defined as the sustained learning that groups of individuals undergo which transforms their behavior and attitudes through regular interactions, self-reflections, and deliberative processes (Reed et al. 2010). There is high potential for soft adaptation options, such as the creation of networks of practitioners, to improve the resilience of communities to climate change if these processes are sustained over time. Thus, it is important to consider carefully the type of learning that is being encouraged by adaptation strategies and the quality of the learning processes implemented.

The following principles were encountered in approximately a quarter of the following adaptation options: connectivity, diversity, redundancy, participation, management of slow variables, and to a lesser extent polycentric governance. In many respects, these principles are common to both resilient-building and development strategies because, in a general sense, they serve to reduce vulnerability and improve livelihoods overall. Diversity builds resilience through increasing the options available to respond to a disturbance; put simply, this is the principle of not putting all your eggs in one basket. The same reasoning is behind livelihood strategies that support the diversification of income sources. As a rule, systems with higher heterogeneity are thought to be more resilient than homogenous systems because they are less limited in terms of response mechanisms (Kotschy et al. 2015). Redundancy helps to build

resilience by providing mechanisms that may compensate for one another in case of failure (Kotschy et al. 2015). Again, this is a principle that has been applied to development before, as seen in strategies that are designed to build insurance for the poor, e.g., micro-credit schemes with group collaterals. Connectivity refers to the way in which the parts of a system interact, that is, variables in a system may be tightly or loosely connected. Depending on the type of shock, connectivity increases resilience by either facilitating recovery, for example, in the aftermath of a disaster local networks can be mobilized quickly to provide assistance, or by containing a disturbance, for example, in the case of a disease outbreak isolation may prevent contagion. Given that diversity, redundancy, and connectivity are useful in withstanding disturbances, these strategies are highly compatible with development goals, as vulnerable populations often enact these mechanisms to deal with a variety of shocks to their livelihoods.

The management of slow variables is associated with the maintenance of critical elements connected to the resilience of a social-ecological system. Slow variables control the state of the system and they change more gradually, and perhaps less obviously, than other variables in the system (Walker et al. 2012). Climate change affects both fast and slow variables, yet most adaptation strategies targeted fast variables. Part of the reason for the emphasis on fast variables is that they are easier to recognize and decision-makers have a sense of how to manage them. In contrast, slow variables are notoriously difficult to pinpoint and it often takes a regime shift before they become evident (Biggs et al. 2008). Ecosystem-based adaptation strategies targeted slow variables more frequently, likely because slow variables in ecosystems have been better documented (Scheffer and Carpenter 2003). Thus, we see in here an opportunity to continue to identify what may be slow variables in social processes, e.g., education, and to explore how these may be impacted by a changing climate.

Participation involves expanding the group of actors in a decision-making processes with the intent of extending decision-making power to groups traditionally disenfranchised. Participation became prominent as a development strategy in 1980s when a plethora of approaches emerged advocating for the active involvement of a variety of stakeholders in processes leading to development that was intended to devolve power to local actors. While participation has had its share of criticisms, it remains a key component in many development projects. Arguments for participation in development are usually ideological, that is, participation is intended as a way to democratize decision-making and it is often an end in itself. In resilience, participation tends to be welcome for more pragmatic reasons, that is, participation is seen as a way of arriving at better decisions because an extended group of experts can provide more accurate information and decisions emerging from a participatory process are likely to have a higher degree of buy-in facilitating their implementation. In addition, decisions about climate change adaptation and community resilience embody values. Effective, meaningful participation is required to ensure that these values are explicitly stated and negotiated. This is why resilience approaches encourage insights from participants with different kinds of knowledges, e.g., traditional knowledge and Western knowledge, as well as the participation from different governance levels (Leitch et al. 2015). Aiming to create mechanisms that can build on this tapestry of knowledge is instrumental to foster appropriate climate change adaptation.

Polycentric governance are systems of governance containing several semi-autonomous decision-making units (Folke et al. 2005), as opposed to systems of monocentric governance where authority flows from a single center of power in a top-down fashion (Termeer et al. 2010). The argument for polycentric governance in resilience follows similar lines to the arguments for diversification and redundancy explained above, that is, that having decision-making power distributed over several nodes enhances the ability of the governance system to

withstand shocks. In addition, polycentric systems may allow for more experimentation, in the sense that policies adopted by one governing unit may serve as an example for other governing units, thus opening up opportunities for learning (Schoon et al. 2015). Finally, polycentric structures can also improve the fit between the biophysical and administrative or jurisdictional boundaries of an issue, which is widely believed to improve outcomes in situations of uncertainty (Folke et al. 2007). In climate change adaptation significant attention has been paid to actions targeting the regional and community levels because these are seen as key arenas to achieve adaptation goals seeking to address multiple stressors (Lemos et al. 2007). However, there remains a need to improve horizontal linkages across institutions and organizations working at the same level and vertical linkages across governance levels.

### 5.2 What principles of resilience are currently less integrated in climate change adaptation?

There were relatively few adaptations that considered the interaction between social and ecological systems and the effect of feedback loops, suggesting that adaptation is not often approached from a systems lens. A systems lens can help elucidate the complex interactions between social and ecological systems (Berkes and Jolly 2002; Fiksel 2006; Nguyen and Bosch 2013). Resilience thinking uses a systems lens to tackle situations that are not merely complicated but also complex. Approaching a complex problem with linear logic may result in adaptations that are short sighted or that miss non-linear effects that can lead to surprises down the road. Climate change contains simple, complicated, and complex problems and some definitions are in order. Simple problems are those where following a set of prescribed rules ensures a high degree of successful outcomes, e.g., assembling IKEA furniture. Complicated issues have a higher degree of uncertainty and it is useful to distinguish between technically complicated and socially complicated. Designing a seawall for a one in a one hundred-year event is technically complicated. It requires engineering calculations, knowledge of ocean dynamics, architectonical considerations, and so on, but it is an entirely solvable problem. That is, when what needs to be done is difficult but knowable, the situation is technically complicated (Patton 2011). On the other hand, when there are competing points of view on the best course of action, the situation is socially complicated. In the above example, the need for storm surge protection may be real, but stakeholders could disagree on the best course of action, and so, while some people favor building a seawall, others may advocate for seashore ecological restoration and others may be in favor of relocating impacted communities. Complexity arises when there is uncertainty as well as disagreement between stakeholders (Patton 2011).

Clearly, climate change is a complex issue with social and ecological dimensions. Adaptation strategies that adopt a complex adaptive systems lens build resilience by focusing on dynamic relations that may interact in nonlinear ways to produce surprise at a later time. From a resilience perspective, systems are conceived as social-ecological systems. The construct of social-ecological systems is relevant to climate adaptation because climate change straddles the interface between the social and the ecological. That is, adaptation measures usually seek to cope or adapt to a climatic risk that originates in an ecological phenomenon, e.g., sea level change, with impacts that affect social groups or processes, e.g., fisher communities. Framing this in terms of social-ecological systems allows us to focus on the dynamic interplay between these two interlinked systems. Finally, a systems perspective pushes us to identify and consider feedback loops more intentionally in

our adaptation strategies. A feedback is simply the response of a system to an intervention, which may either reinforce or dampen the original response, creating positive or negative feedback loops, respectively. In simple systems, action and reaction are relatively straightforward to identify; however, in complex systems, an action may have unintended reactions given the presence of thresholds, slow variables, and cross-scale effects. While a systems perspective does not eliminate entirely the possibility of surprise, it better prepares decision-makers to deal with them.

## 6 Conclusion: toward climate resilience

Climate change resilience can be defined as having the ability to withstand shocks and disturbances originating from climatic risk factors to maintain the systems' identity while pro-actively taking advantage of new opportunities that may arise to learn and adapt. With the guidance of principles distilled from the resilience literature, we have assessed which principles are more and less present in a sample of 54 projects worldwide that yielded 224 adaptation strategies for addressing climate change impacts. The assessment reveals key overlaps between development and resilience-building strategies as well as room to better integrate resilience principles into climate change adaptation, particularly by adopting a systems perspective in the design and implementation of climate change adaptation strategies.

The theory, methods, and results presented in this paper have relevance for a variety of stakeholders. For climate change scholars, we have merged theory and practice from two fields of study, development and resilience. The conceptual integration of these fields of study is timely, as terminology lacks precision in practice. For development organizations, we developed a conceptual framework using the principles of resilience. This framework could be replicated to assess proposed/implemented adaptation options within other organizations. Not all adaptation is "good" or universally desirable. A critical next step for academics, practitioners, and governments is to start to assess the *quality* of proposed adaptations. We argue that utilizing a resilience lens to assess adaptation projects and options is a useful starting point to critique the quality of proposed solutions. Finally, for policy makers (and those who inform them), we contend that a systems lens is critical for climate resilience. This deficit has implications for governments and policy makers, as adaptation to climate change is a complicated and complex problem, requiring thoughtful, long-term, and integrated solutions.

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