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A framework for using autonomous adaptation as a leverage point in sustainable climate adaptation

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ABSTRACT

Planned adaptations are commonly adopted by governments considering large-scale socio-economic and political interventions, while local communities innovate their adaptive responses using locally available resources – also known as autonomous adaptation. Congruence between planned and autonomous adaptation is needed to develop a concerted and effective effort to minimize the negative impacts of context-specific vulnerability. This paper offers a systematic framework for building congruence between planned and autonomous adaptation using a six-step approach to guide their integration while maintaining an environment for future autonomous innovations. We applied this framework to previously conducted case studies in Spain, Bangladesh and Canada, revealing key lessons for using autonomous adaptation as leverage points for sustainable climate adaptation.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) provides a two-pronged definition for adaptation, one for human systems and another for natural systems:

> In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2019) (p. 869).

This definition supports the concept of coupled social-ecological systems (SESs), defined by a confluence of ecological, economic, political and cultural properties, connected through complex, dynamic, and context-dependent relationships. In the SESs, livelihood

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related adaptation decisions that are made considering only climate change impacts and not considering the context-specific nature of resources required and activities undertaken for living may bring unintended consequences (Rahman and Hickey, 2020). One common example of such consequences is vulnerability shifting from one group to another and from one time scale to another – a property known as 'maladaptation' (Barnett and O'Neill, 2010; Ishtiaque et al., 2017; Janssen and Anderies, 2007; Juhola et al., 2016). In contrast, 'sustainable adaptation' aims to address the linkage between climate vulnerability and poverty by identifying measures that can positively modify socio-economic and socio-political inequality for ensuring equitable access to livelihood resources without negatively affecting ecosystems (Brown, 2011; Chhetri et al., 2019; Eriksen and O'brien, 2007).

Two of the most common approaches to livelihood related adaptation decision making are planned and autonomous adaptation (Fankhauser et al., 1999). Planned adaptation is the result of a deliberate policy decision (IPCC, 2007) which is made based on future climate projections (Brown, 2011; Fankhauser et al., 1999). Planned adaptation decisions are commonly made at a larger scale like government policies and practices, which have been criticized for their inadequacy to take into account context-specific vulnerability-poverty linkages (Rahman and Hickey, 2019b; Rahman et al., 2018c). Autonomous adaptation, on the other hand, is not a conscious response to climatic stimuli but is "triggered by ecological changes in natural systems and by market or welfare changes in human systems" (IPCC, 2007) (p. 869). Autonomous adaptation is generally context-specific and often emerges from locally available knowledge and resources, considering local socio-political, cultural, economic and ecological properties (Bawakyillenuo et al., 2016). Autonomous adaptation actions are mostly undertaken by climate affected communities for sustaining their livelihood activities. Both planned and autonomous adaptation can be prone to maladaptation, but often for different reasons: while planned adaptation can go wrong because of poor design and a lack of understanding of local context, autonomous adaptation can be maladaptive when implemented with limited information, lack of support from social networks, or cross-interference between actors who fail to communicate with each other (Fenton et al., 2017; Schipper, 2020).

Minimizing the impacts of different climate extremes (e.g., flood, drought, etc.) on lives and livelihoods is at the core of planned adaptation (Brown, 2011; Eriksen and O'brien, 2007). Decisions made using this narrow conceptualization are often linear, and as a result, pay inadequate attention to local socio-political and socio-economic properties and livelihood activities. Thus, most planned adaptation interventions across the world aim to solve atomized objectives of a sector, society, or ecosystem, even though most climate challenges are interconnected and subject to cross-scalar decision making (Abson et al., 2017; Ribot, 2014). Successful autonomous adaptation, on the other hand, is the outcome of local socio-political, economic, and cultural interactions to determine the norms of access to livelihood resources. Therefore, planned adaptation may require improved congruence with autonomous adaptation to account for social-ecological contexts, avoid maladaptation, and to ensure equitable access to resources required for sustaining livelihood activities (Juhola et al., 2016). While learning from and co-opting autonomous adaptation can improve the efficiency of planned adaptation, in order to do so, opportunities for local innovations need to be created and/or maintained in an ever-changing climate context.

To maintain a fertile climate for autonomous innovation, some planned interventions may be required for changing local socio-political processes to ensure equitable power, knowledge, and resource distribution (Andrachuk and Armitage, 2015; O'Brien, 2011). Meadows (1999) suggests that there are sites of intervention – 'leverage points' – where a small shift can bring significant changes to a system. Though, all leverage points do not possess the same capacity for change; 'deep' leverage points that impel changes to the purpose and mind-set of a system are best suited for making long-term sustainable transformations (Meadows, 2008). Identifying and using these leverage points can help enhance innovation for diversifying adaptation options and addressing poverty-vulnerability linkages. Building on the concept of leverage points, Fischer and Riechers (2019) suggest that it is important to specify what purpose an adaptation measure can serve to minimize climate change impacts. For example, rural community members rarely decide to adopt an autonomous response based on how efficient the innovation is in minimizing the root causes of climate change (e.g., carbon emissions). Rather, they make their judgement based on what outcomes the innovation can bring to contain their climate change impacts (e.g., crop loss, property loss, market failure, etc.). Local communities' adaptation actions are based on their understanding of climate change impacts and pragmatic considerations about contextual realities (Rahman and Hickey, 2020). Hence, many locally innovated adaptations are not always widely accepted due to their likelihood of bringing uneven outcomes to community members. Therefore, decision makers need a systematic approach that can identify leverage points capable of building congruence between planned and autonomous adaptation and stimulating more widely acceptable and applicable autonomous adaptations.

Building on the conceptual premises stated above, this paper aims to develop a framework, built upon an idea that a climate-vulnerable social system can generate innovative, sustainable livelihood adaptation actions so long as planned adaptations do two things: 1) learn from autonomous adaptation and 2) create or maintain conditions for future autonomous innovation. Since climate change impacts are dynamic and continuous, adaptation policies and actions must be innovative and adaptive. The framework we are proposing in this paper aims to respond to this demand, helping to avoid policy rigidities commonly observed in planned adaptation approaches in both developed and developing countries. To exemplify how this framework functions and what insights it can offer, we applied it to three case studies selected from developed and developing countries. The next section presents the overall architecture of the framework which is followed by the description of case studies. Before concluding, we showcase what adaptation policy makers and practitioners can learn from this framework.

2. Building congruence between planned and autonomous adaptation for sustainability: A framework

Building harmony between planned and autonomous adaptation can be framed as a process, in which planned adaptation can systematically learn from and incorporate innovative and diverse autonomous adaptation options for sustaining livelihood activities in the face of climate change impacts, and where planned adaptation actions enhance communities' capacity for innovation using the resources available in a social-ecological system (SES). We propose a framework for actualizing this process across six stages: (1) Context, (2) Innovation, (3) Diffusion, (4) Filtration, (5) Incorporation and (6) Intervention (see Fig. 1). The stages are connected in a cyclical process wherein 'intervention' impacts 'context'; each stage is discussed below in turn.

2.1. Context

Rural livelihoods depend on resources available in a SES (Charles, 2012). The context of a SES is shaped by the presence of resources and the formal and informal institutions that manage these resources. The ecological sub-system of a SES comprises resource systems like forests, wetlands and agricultural lands (Ostrom, 2009), which have defined boundaries, sizes and thresholds of productivity (McGinnis and Ostrom, 2014; Ostrom, 2009). A resource system provides different spatio-temporally distributed resource units like fishes, trees and agricultural outputs. The management and use of resource systems are highly contingent on the properties of the resource units (Goulden et al., 2013), which can be mobile (e.g., fish, wildlife) or sedentary (e.g., trees, agriculture) with a certain level of replacement rate (McGinnis and Ostrom, 2014; Ostrom, 2009). Both resource systems and units are themselves invariably exposed to climate change impacts (Pandey and Bardsley, 2015). Thus, Cinner et al. (2013) suggest that the management of a SES needs to consider the extent to which a resource system is exposed and sensitive to climate change impacts and what its recovery potential is.

To shape communities' resource use behaviour, self-organized and/or externally imposed rules are needed – known as informal and formal institutions respectively – to ensure resource use is within the productivity and cultural threshold of a system. Institutions that are informally developed often use local and traditional knowledge as their foundation (Rahman et al., 2019). These institutions are of particular importance to managing access to, and distribution of, common pool resources, market-based organizations and private property rights (Rahman et al., 2012; Rahman et al., 2018c), and therefore play a critical role in determining the adaptive capacity of local communities (Agarwal et al., 2012; Engle, 2011; Smit and Wandel, 2006).

Building on formal scientific knowledge including quantifications of climate change impacts, formal institutions develop rules and decisions to guide and regulate societal responses (Hahn and Nykvist, 2017; Rahman et al., 2019). A key challenge is such decisions

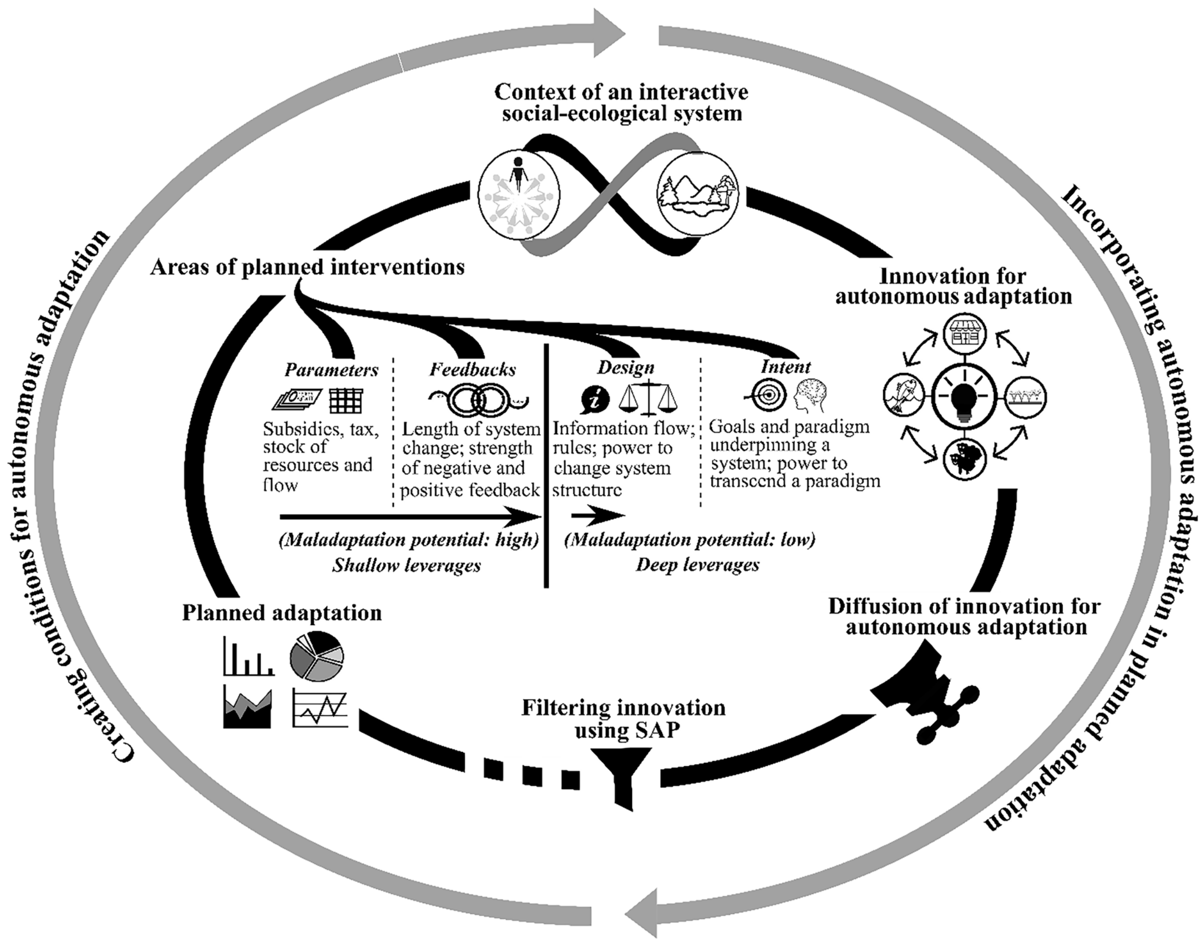

Fig. 1. A framework for building interactions between autonomous and planned adaptation.

may fail to fully understand and address the complex process of climate induced social-ecological changes (Eriksen et al., 2015). For example, many resource systems provide multiple resource units which have different user groups. The socio-cultural practices, social status and power distribution within and between these groups are often complex and contested. It is common, particularly in developing countries, that the formal institutions are poorly informed about local socio-political realities (Rahman et al., 2014). Therefore, it is difficult to determine what resources and groups of resource users are to be prioritized for enhancing communities' capacity to innovate responses to climate impacts (Eriksen et al., 2015).

2.2. Innovation

Innovation for autonomous adaptation is a context-dependent process of reacting to a range of environmental stimuli, and can involve various forms of livelihood intensification, extensification, and diversification depending on resources available within a given context (i.e., SES) (Paavola, 2008). Autonomous adaptation is often perceived as a reactive response to locally felt climate change impacts influenced by cross-scalar and context-specific SES properties. Forsyth and Evans (2013) suggest that if adaptation is perceived as a livelihood-seeking practice in a resource scarce SES, adaptation cannot only be viewed as an autonomous response. Pre-existing local institutional and political context, properties of resource systems, resource availability and distribution, agency and social networks among community members, knowledge about a system and experiential observations are some of the cross-scaler and context-specific properties that influence innovation for autonomous adaptation (Hahn and Nykvist, 2017).

Innovations also need actors who can accommodate required resources and take a leadership role to innovate new technologies and create opportunities for wider societal benefits (O'Brien, 2015). These actors transform their observational knowledge about climate change impacts into operational responses to climate change impacts. For example, smallholder farmers in the wetland areas of Bangladesh cultivate short-rotation crops like mustard and coriander in suitable places to replace long-rotation crops like rice that are vulnerable to early flood and this practice was initiated by only a small number of farmers (Rahman et al., 2018b).

Communities use new technologies and practices for intensifying, extensifying and diversifying livelihoods (Dorward et al., 2009; Paavola, 2008; Rahman et al., 2018c). Intensification is a strategy that reinforces communities' pre-existing practices (Paavola, 2008). Some common strategies may involve enhancing crop productivity by using high yielding varieties, diversifying and cultivating short-rotation crops, using advanced technologies (e.g., harvesting and irrigation machines, aquaponics), fertilizers, pesticides etc. (Connolly-Boutin and Smit, 2016; Rockström et al., 2017). For example, the introduction of large-scale irrigation in Navarre has favored the concentration of land and property and displaced family-run and small-scale farming (Albizua et al., 2019). In contrast, extensification is the strategy that expands production opportunities by bringing marginal resource systems and market opportunities into use. For example, creating new arable land for farming is a common strategy of extensifying agricultural practices. Developing a farming-plot portfolio for selective cultivation in different plots to minimize the risk of production loss is also a widely practiced extensification strategy (Connolly-Boutin and Smit, 2016; Paavola, 2008; Richardson, 2005). Diversification involves the portfolio of both farm and off-farm activities to minimize the risk of total farm production loss (Paavola, 2008). For example, some members of a household in the northeastern flood plain communities of Bangladesh seasonally migrate to urban areas and abroad to maintain their income opportunities, particularly during the rainy season when farm activities are limited (Rahman et al., 2018c).

Apart from the above livelihood adaptation strategies, communities also develop collective-action driven informal institutional strategies for livelihood diversification through product marketing, new approaches for getting access to livelihood assets or for generating seasonal or permanent migration opportunities to abroad or urban areas where there are more opportunities available (Rahman et al., 2018c; Rodima-Taylor, 2012; Soubry et al., 2020b). Although these institutional innovations may not ensure livelihood sustainability, they offer alternative livelihood strategies through the redistribution of resources required for innovation (Agarwal et al., 2012; Agrawal and Perrin, 2008; Karlsson and Hovelsrud, 2015). Institutional innovation can also function to leverage resources from external sources like government agencies (Agarwal et al., 2012; Karlsson and Hovelsrud, 2015). For example, the local cooperative in Navarre, apart from storing the crops and providing cheaper inputs such as fertilizers, seeds etc., also helped farmers get subsidies coming from the regional government or allocate land from landholders to irrigators (with the labor and the machinery) (Albizua et al., 2020). However, the external agencies also need to identify and acknowledge collective action-based informal institutions to comply with local norms and values for avoiding conflicts and uncertainties (Rahman et al., 2017).

2.3. Diffusion

Once the context of a SES sets the stage for innovations for autonomous adaptation, diffusion is necessary for innovations to be disseminated and adopted. Innovators combine new and already existing practices to diffuse innovations horizontally (Biggs et al., 2010). An innovation is diffused in a society through the ties of embeddedness, where vertical and horizontal social networks and social capital are viewed as the medium of exchange (Prasad, 2016). The interpersonal embeddedness of individuals in a society can be described as a continuum from extremely high social embeddedness to extremely low embeddedness limited within family and peer groups (Chinying Lang, 2004). Community members, along with their embeddedness in a society, are mostly influenced by the information, behavior and opinions of the persons with whom they most repeatedly interact (Chinying Lang, 2004). It is also likely that community members are influenced by the people in their most proximate social, cultural, economic and perceptual groups. Thus, some individuals (e.g., civil society members, traditional and scientific knowledge holders, community leaders) going beyond the conventional social and economic roles, and engage their leadership and agentic capacity to disseminate innovations (Meijerink and Stiller, 2013; Prasad, 2016; Westley et al., 2013).

Beyond the interpersonal embeddedness of leadership roles, an innovation must possess certain characteristics if diffusion is to be successful. The extent to which an innovation will be diffused and adopted depends on five attributes: *relative advantage, compatibility, complexity, trialability* and *observability* (Bawakyillenuo et al., 2016). An innovation needs to have *relative advantage* over the one it is superseding to be adopted in a society. Innovations also need to be *compatible* or consistent with the existing norms, values, past experience and needs of potential adopters (Kapoor et al., 2014; Kapoor et al., 2013). In many instances, the creation and adoption of new adaptation practices are contingent upon social structures maintained by culture, norms and value systems (MacGillivray, 2018). *Complexity* is the degree to which an innovation can be understood by its potential users (Kapoor et al., 2013). The complexity of adopting new technology may be enhanced by the lack of social, economic and cultural capacities in a rural context. *Trialability* is the degree to which an innovation or idea can be piloted or experimented over a shorter period. Trialability helps reduce uncertainty and allows adopters to gather more information regarding an adopted practice. Finally, *observability* is the degree to which the outcomes of an innovation are clearly visible to the adopters of the innovation (Kapoor et al., 2013).

2.4. Filtration

Innovation for autonomous adaptations, despite being rooted in local context and wider diffusion, can be unsustainable and maladaptive (Schipper, 2020). For example, livelihood diversification can bring differentiated outcomes to rural smallholders, as the resources and capacities required for adopting such activities may not be evenly distributed (Forsyth and Evans, 2013). Therefore, scarce resources may be expended on risky and unsuccessful interventions. Several studies have revealed that seasonal migration to urban areas, which is commonly identified as a useful way of adapting to seasonal stresses, exposes people to new kinds of vulnerability (Adri and Simon, 2018; Martin et al., 2014; Rahman et al., 2018a).

Since one of the core objectives of this proposed framework is to systematically integrate autonomous adaptation into planned adaptation processes for wider promotion, we suggest that the autonomous adaptation actions need to be assessed by—and 'filtered' through—the principles of sustainable adaptation in order to avoid maladaptation and to address the unequal distribution of resources for adaptation (Eriksen et al., 2011; Rahman and Hickey, 2019a; Rahman and Hickey, 2019b). Eriksen et al. (2011) propose four principles of sustainable adaptation: i) recognizing the context for vulnerability, including multiple stressors; ii) acknowledging different values and interests affecting adaptation outcomes; iii) integrating local knowledge into adaptation responses; and iv) considering potential feedbacks between local and global processes.

First, a SES can be exposed to both climatic and non-climatic stresses (Albizua et al., 2019; Rahman et al., 2018b), and the risk of exposure can be intensified by additional stimuli such as environmental pollution and epidemics (McDowell and Hess, 2012; O'Brien and Leichenko, 2000). Understanding how non-climatic factors like poverty, local institutional dynamics, social structures, power relations, and market participation interact with climate vulnerability is essential to conceptualizing sustainable adaptation actions. In addition, O'Brien and Leichenko (2000) highlight how economic globalization contributes to shaping local vulnerability. The key challenge is that the innovators and adopters of autonomous adaptation often do not possess the information required for encountering the multifaceted nature of vulnerability, and there remains a chance that some of their innovations might produce ineffective and unsustainable results in the long-term. Therefore, to be incorporated into planned adaptation, an autonomous adaptation action needs to have the capacity to address both the climatic and non-climatic factors.

Second, autonomous adaptation actions need to consider the diverse values and interests prevailing in a SES. A diversity of resources will be extracted and/or used by different user groups and the use of one type of resource may have significant positive or negative influence on another. For example, excessive use of fertilizers and pesticides for dry season agricultural intensification in wetland ecosystems affects the ecosystems' fish habitat quality during the rainy season (Rahman and Hickey, 2019a). In general, these practices enhance resource conflict among user groups, which most commonly benefit more powerful resource users. Therefore, autonomous adaptation needs to be harmonious for different user groups.

Third, it is more likely that sustainable innovations for autonomous adaptation are based on local knowledge. Community members, living in a climate vulnerable SES, observe and frame the impacts of climate change in ways that may differ or align with scientific framing (e.g., meteorological analysis) (Nidumolu et al., 2015; Soubry et al., 2020b). While scientifically framed climate studies explore the extent, frequency and duration of climate stresses, local knowledge-based vulnerability framing takes into account what, where and when local production activities are undertaken and how extreme climate events affect the production (Bele et al., 2013; Rahman et al., 2018b), leading to the adoption of new technologies and practices based on these observations (Iizumi and Ramankutty, 2015). Thus, autonomous adaptation needs to be informed by local knowledge and observation regarding climate change impacts and should be intended to minimize climate change impacts on livelihood activities.

Fourth, due to the increasing globalization of resource and information flows, individual contexts are becoming more reliant on distant systems for the supply of production inputs and product marketing. Eriksen et al. (2011) posit that adaptation can affect, and be affected by, large-scale processes. The idea of double exposure[1] and SES teleconnections[2] describe the cross-scalar and cross-context interactions. A sustainable autonomous adaptation should have the capacity to interact with global drivers, although it may largely

[1] According to O'Brien and Leichenko (2000) "double exposure refers to cases where a particular region, sector, ecosystem or social group is confronted by the impacts of both climate change and economic globalization" (p. 227) O'Brien, K.L., Leichenko, R.M. (2000) Double exposure: assessing the impacts of climate change within thecontext of economic globalization. Global Environmental Change 10, 221–232.

[2] According to Newig et al. (2020) "telecoupling is concerned with how human-induced processes in one part of the globe impact in specific ways on a distant part (or parts) of the world" (p. 1) Newig, J., Challies, E., Cotta, B., Lenschow, A., Schilling-Vacaflor, A. (2020) Governing global telecoupling toward environmental sustainability. Ecology and Society 25, 21.

depend on how information and knowledge are channeled to local communities.

2.5. Incorporation

Once filtered by policy processes via sustainable adaptation principles, autonomous adaptations are suitable for incorporation into planned adaptations. The aim of planned adaptation is not to fully prevent adverse climate impacts, rather it offers recommendations considering the degree of change in future climatic and non-climatic factors, the influence of present decisions on future situations, and appropriate timing of actions (Füssel, 2007). In summary, planned adaptation functions under uncertainties and uses available knowledge to minimize the risk of such uncertainties. Planned adaptation is often expected to contribute to socio-economic development, while non-climatic development plans unrelated to climate change impacts can also contribute to climate adaptation by reducing socio-economic disparities and increasing adaptive capacity as an outcome of poverty reduction (Davies et al., 2008; Huq and Reid, 2004; Lasco et al., 2009).

Some studies have revealed that not all adaptation actions contribute to poverty reduction and not all poverty reduction strategies can help enhance capacities to minimize climate change impacts (Lemos et al., 2007; Sherman et al., 2016). For example, Nelson et al. (2016) found that the government of Brazil implemented an aggressive poverty alleviation program in the country's drought prone northeastern region, expecting that the program would reduce drought vulnerability. The program contributed significantly to poverty reduction, but climate vulnerability remained unchanged. Dasgupta and Baschieri (2010) revealed the limitations of poverty reduction strategies in minimizing climate vulnerability, stating that standard money-metric poverty evaluation indicators often overlook the properties of vulnerability. It is also evident that climate independent development plans and policies often pose barriers to innovating new climate-proofed livelihood strategies. For example, the open water fisheries resource management policy of Bangladesh limits the capacity of resource dependent communities to participate in sustainable fisheries resource management as a livelihood diversification strategy (Rahman and Hickey, 2019b; Rahman et al., 2015).

It is necessary to build a synergy between poverty and vulnerability reduction strategies in planned adaptation approaches since they can enhance capacities to minimize specific climate change impacts by reducing societal inequalities and injustices (Lemos et al., 2007). These synergies can help encounter the multiplicity of stresses discussed in Section 2.4 (Eakin et al., 2014). However, the adoption of strategies needs to be specific to certain vulnerability and poverty reduction targets and be based on the ability of communities to afford the strategies (Hansen et al., 2019). Since the adoption of strategies are context specific, local level interventions seem most effective (Hansen et al., 2019; Lemos et al., 2007). Thus, emerging from a specific context, autonomous adaptation strategies can offer suitable adaptation options that are easy to adopt and aim to address both vulnerability and poverty reduction targets (Rahman and Hickey, 2019a; Rahman and Hickey, 2019b). Planned adaptation can systematically incorporate autonomous adaptation strategies by justifying their merits based on their capacity to meet long-term social, economic, and environmental goals and minimize climate impacts (Sherman et al., 2016).

2.6. Interventions (to enable future innovation)

Identifying where to intervene in a SES is necessary for building congruency between autonomous and planned adaptations and shifting the SES in directions that create and/or maintain the conditions that are vital for future innovations in a changing reality. External support, in the form of planned adaptation, should identify key areas of interventions to help maintain local innovation (Rahman et al., 2018c). However, the identification of such areas requires insights into how to transform a SES to a more self-reliant system for sustainable climate adaptation, as opposed to relying on externally prescribed quick fixes (Abson et al., 2017).

Meadows (1999, 2008) identified 12 leverage points for intervening in complex systems, places in a system best suited for planned interventions (Table 1). These leverage points consider the nested, interconnected nature of system properties. Some interventions are easier, but do not bring effective, lasting change in a SES – known as shallow leverage points. Deep leverage points, on the other hand, are more difficult to alter, but once modified, can bring transformative changes (Abson et al., 2017). Meadows' 12 leverage points can be aggregated into four categories, based on system properties: *parameters, feedback, design,* and *intent* (Abson et al., 2017).

Parameters are the mechanistic elements of a system like taxes, subsidies or the physical properties of a SES like the stock and flow of resource units, such as acres of a forest (stock) and the rates of logging and regrowth (flow). Buffers are included here, such as dams, which can provide an effective but limited stabilizing power (Meadows, 2008). Considering these properties, such interventions are often atomized and therefore, sector specific. For example, reinforcing coastal flood protection infrastructure may increase land price allowing only richer people to buy coastal properties. Also, such reinforcement may cause erosion to other areas. Thus, the positive outcomes of implementing such adaptations are only enjoyed by a small segment of coastal population, while vulnerability is shifted to the other sect of a society (Barnett et al., 2015; Juhola et al., 2016). This, therefore, raises questions regarding environmental justice and equity (Irvine et al., 2013; Wolch et al., 2014).

Feedbacks are the interactions between the elements of a system that drive its internal dynamics, dampening or reinforcing system functions via feedback loops (Abson et al., 2017). A simple example is room temperature, measured by a thermostat, and a furnace that turns on when a certain temperature is reached, the maintenance of room temperature is dependent on the strength of this negative/balancing feedback loop (Meadows, 2008). Systems can be described by their 'state variables' that interact in an interconnected SES, where system change results from the relationships between these variables, as well as the influence of external drivers (Walker et al., 2012). For example, crop production, which in an agroecosystem is a state variable, is controlled in part by external drivers like rainfall (Walker et al., 2012). A drought event can be managed by an emergency groundwater-based irrigation system. However, every system has its threshold to absorb the negative impacts of a climate extreme. If the threshold of groundwater extraction is exceeded, the system

Table 1
Leverage points and their examples in terms of empirical actions (()).

Classes of leverages	System properties	Definitions of system properties	Leverage points	Examples of actions
Shallow	Parameters	Modifiable and mechanistic characteristics that are generally prescribed by policy makers	12. Parameters like subsidies, and taxes	In the US, house buyouts have been used by the Federal Emergency Management Agency in flood-vulnerable urban areas to relocate coastal house owners to safer places (Binder and Greer, 2016)
			11. Size of buffer stocks relative to their flows	Physical stock of timber has been considered as the basis for managing production forests in many parts of the world (Luckert and Williamson, 2005)
			10. Structures of resource stocks and flows	Approximately 22% of projects proposed under NAPAs* – a UNFCCC** guided adaptation planning scheme for LDCs*** – aimed to take actions like reducing nutrient outflow through soil erosion and conserving water (Pramova et al., 2012)
	Feedbacks	Interactions between system elements that drive the internal dynamics of a system	9. Length of delay relative to the rate of system change	Disaster risk reduction is a common approach to respond to extreme climate events. This approach commonly involves emergency disaster responses and recovery services (Solecki et al., 2011)
			8. Strength of negative feedback loops	Most of the projects proposed in its NAPA, the Government of Bangladesh aimed to invest resources to help maintain rural primary livelihood activities like agriculture and fisheries rather than incentivizing livelihood diversification (Rahman and Hickey, 2019a)
			7. Gain around positive feedback loops	Due to increased soil salinity in the coastal areas of different parts of the world, agricultural systems are transformed to fisheries and aquaculture systems. Such transformation requires investment in new resources and capacities (Faruque et al., 2017)
Deep	Design	Structure and hierarchies of information flows, rules, power and self-organization	6. Structure of information flows	Climate related disaster preparedness is obtained by establishing early warning mechanisms (Collins and Kapucu, 2008)
			5. Rules of the system	The provincial government of British Columbia, Canada has developed a guideline to be followed by municipal governments in enacting municipal by-laws for flood risk management (Stevens and Hanschka, 2014)
			4. Power to change system structure	The coastal villagers of Monkey River, Belize organized an informal tie with development workers, academics and journalists to communicate with the higher levels of government to obtain support for erosion control (Karlsson and Hovelsrud, 2015)
	Intent	Norms, values and goals embodied within a system and the underpinning paradigms out of which they arise	3. Goals of the system	LDCs that developed NAPAs showed a strong tendency to align their national development agendas with short-term climate adaptation planning, although the quality of alignment remains questionable (Hardee and Mutunga, 2010)
			2. Paradigms underpinning the system	Poverty reduction is considered as a foundational concept for vulnerability reduction in the adaptation plans of many developing countries (Huq and Reid, 2004)
			1. Power to transcend paradigms	Many developed and developing countries have been adopting ecosystem-based coastal adaptation approaches because of their cost-effectiveness and sustainability compared to hard-infrastructure based coastal protection (Temmerman et al., 2013; van Stokkom et al., 2005)

* NAPA = National adaptation programme of action.
** UNFCCC = United Nations Framework Convention on Climate Change.
*** LDCs = Least Developed Countries.
adopted from Abson et al., 2017; Fischer and Riechers, 2019; Meadows, 2008

may show positive/reinforcing feedback creating new state variables along with their new forms of interaction. Overinvestment in maintaining current system properties may ‘rebound vulnerability’ (Juhola et al., 2016).

Design of a SES entails the hierarchies of information flows, rules, power and self-organization. *Design* refers to properties which govern a SES, regulating the interaction between social and ecological sub-systems. *Design* of a SES entails information flows and rules, as well as relations of power and self-organization (Abson et al., 2017). Rules and information flows, as the design of a SES, determine the distribution of and access to resources required for innovation to adapt to climate change impacts. Both planned and autonomous adaptation approaches may follow the structure of developing rules. When developed with inadequate or ineffective public participation (a type of information flow), planned adaptation can restrict the equitable distribution and use of resources for innovation. On the other hand, if autonomous adaptation follows an institutional structure that disempower socio-economically marginalized community members using local cultural, social and political instruments, resource distribution for adaptation can be highly challenged. In contrast, if a synergy between planned and autonomous adaptation is built, autonomous adaptation can inform planned adaptation regarding the power distribution and political properties of a community to serve effective public participation, while planned adaptation can develop rules to govern the equitable distribution of resources for autonomous adaptation.

Intent refers to the norms, values and goals embedded in a SES and the paradigm from which the norms, values and goals arise (Abson et al., 2017). *Intent* can be a social construct that emerges from how individuals in a society frame and construct climate change and its impacts. Framing influences the responses of communities to climate impacts. Further, when considering complex problems, individuals in a society draw from a kaleidoscope of varying worldviews when they consider an adaptation option, acting intuitively as scientists, economists, politicians, prosecutors and theologians (Alexander et al., 2012). Norms and values prevalent in a society help construct individual choices in terms of adopting and modifying adaptation options in a changing SES (Gifford, 2014). Climate-sensitive innovations may require societal modification of norms and values, initiated by communicating climate change impacts (Gifford et al., 2011; Sherren, 2020) and enhancing capacity to imagine alternative solutions that are more contextually grounded (Bennett et al., 2021).

2.7. Framework summary

Our framework presents a cycle whereby autonomous and planned adaptation interact and reinforce each other. Firstly, the initial *context* of both formal and informal institutions within an SES must be understood; they affect the baseline vulnerabilities and capacities of actors in an area. Secondly, autonomous adaptations develop through *innovation*, emerging from experimentation, new ideas, and technologies. Thirdly, autonomous innovations are *diffused* across societies through actors with a high degree of embeddedness. For diffusion to be effective, these innovations require certain characteristics, namely relative advantage; compatibility with local contexts; low complexity; trialability by others; and observability of results. Fourthly, policy processes may *filter* innovations through the principles of sustainable development to ensure that they do not lead to maladaptation or other negative impacts on development goals. This filtration process should include understanding vulnerability contexts; acknowledging different values and interests across actors; integrating local knowledge; and considering feedbacks between global and local processes. Fifthly, autonomous adaptations can be *integrated* into planned adaptations. Integration can involve autonomous adaptations to negotiating a balance between poverty reduction and climate vulnerability reduction strategies. Finally, these integrated adaptations lead to further *interventions* to enable further autonomous adaptations, where planned adaptation can identify key leverage points within SESs to make it possible for autonomous adaptations to flourish.

Our framework links planned and autonomous adaptation by proposing an understanding of their dynamic, and potentially generative relationship. We do not mean to suggest at the outset that either form of adaptation is immune to maladaptive outcomes (Schipper, 2020). Instead, we propose to consider the potential effects of their interactions. Rather than understanding each form of adaptation as existing in their respective vacuum, considering the feedbacks between the two leads to an understanding that adaptation and innovation in SES can benefit from both (Ostrom, 2009). By building in characteristics such as trialability, observability and compatibility into their diffusion, autonomous adaptations can benefit planned adaptation by demonstrating their utility throughout their elaboration. Formal planned adaptation, on the other hand, can act as an essential filter for autonomous adaptations, ensuring their impacts adhere to the principles of sustainable development.

This framework is best understood through examples. Below, we present three case studies of planned-autonomous congruence in adaptation planning.

3. Methods and case studies

We applied the above framework to three previously conducted case studies which span three continents, demonstrating how congruence between planned and autonomous approaches can help minimize the negative impacts of context-specific vulnerability. The three case studies are from Bangladesh (the northeastern floodplain), Spain (the region of Navarre in the Ebro River basin) and Canada (the Canadian Maritimes). All the case studies fall into the respective countries' highly productive albeit extremely climate vulnerable agroecosystems. Although the geographic features and subsequent vulnerability contexts are different, they are all agricultural systems. However, both planned and autonomous adaptation interventions in the case study areas are different because of their respective social, economic, cultural, political, institutional and governance practices. Thus, the case studies can offer different scenarios of congruence between planned and autonomous adaptation interventions and their effectiveness to encounter climate change impacts (see supplementary material 1 for details on the background and key climate challenges for each case).

All the case studies used qualitative data collection approaches including key informant interviews, surveys and focus group discussion and policy document analysis (see Supplementary material 2 to know more about the data collection technique). A snowball technique was used for the interviews and focus groups, which involved government agents, cooperative workers and other kinds of actors apart from the farmers. All the actors involved had substantial knowledge of the organization's activities and held enough authority to comment as a representative of that organization. The time in the field varies from one case study to another, averaging 6 months of intensive data collection, sometimes with the help of research assistants.

Our interview protocols contained questions designed to elicit respondents' farming experience, the stressors perceived and the progress of adaptation actions in which they were involved, as well as how they coordinated and collaborated with other organizations

Table 2
A compilation of interview and focus group questions, each used in one (or more) of the case studies (questions are organized to demonstrate how the data was examined using the proposed framework).

Stages of the proposed framework	Examples of questions that help to understand each stage	Respondent
1. Context (e.g., institutions that may enhance communities to innovate)	1. Could you please describe your agricultural system and agricultural practices? 2. What are the major challenges of cultivation? 3. Do flood, drought, storm or other natural calamities affect your production? If yes, how? 4. What are the government agencies you commonly interact with for the purpose of cultivation, and how would you describe your relationship with the agencies? 5. Do the government and non-government agencies communicate with you to learn farming related concerns? 6. Which agencies do you consider of key importance to solve farming related problems, and why? 7. Do you have community-based organizations? If yes, how do these organizations help you solve the farming related problems?	Community members, local political leaders
2. Innovation (intensification, extensification, diversification)	1. Apart from farming what are the other common income generating activities you perform? 2. Do you participate in any community-based or individual activities for product marketing, **such as** information collection for enhancing your income generating activities? 3. Which factors determine your actions? Are they determined by ecological features such as soil type? Personal knowledge and skills? Personal problem formulation? Social networks? Family? Personal financial situation (savings, debts, subsidies)? 4. On what does access to resources required for new activities depend, and is there any organization that helps you get access to the resources?	Community members, local political leaders
3. Diffusion (ties of embeddedness, vertical and horizontal ties)	1. What are your main sources to learn about new cultivation techniques and crops? 2. Please mention up to 5 people that you trust and who may influence your decision-making regarding land management and your farm in general (for a social network analysis). 3. How do you come to know other income generating activities? 4. Do you follow how others in your community are improving their lives and livelihoods?	Community members, local political leaders
4. Filtration	1. Explain your experience if you follow adaptation practices undertaken by local community members 2. Do you think the adaptation practices contribute to poverty alleviation? 3. How do you explain local social structure and political environment? 4. Do you observe any conflicting interactions among different resource user groups? If yes, how are they mediated? 5. Is there any opportunity for you to learn from local community members regarding their farming and livelihood practices? 6. Do you have any information channeling process to local community members designed by the government? 7. Do you have any information channeling process to the government from the local communities?	Government officials, policy documents and non-government organization representatives
5. Incorporation	1. Were the policies developed following intensive public participation? 2. Did the policies thoroughly study local social, ecological and economic context? 3. Did the policies reflect local innovations?	Government officials, policy documents and non-government organization representatives
6. Intervention	1. Is there any financial aid or compensation associated with the government's adaptation policy and practices? 2. What are the major adaptation interventions taken by the government, and why?	Government officials, policy documents and non-government organization representatives

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Table 2 (*continued*)

Stages of the proposed framework	Examples of questions that help to understand each stage	Respondent
	3. On what does access to different resources depend? Are there formal organizations establishing conditions to get access? 4. How are the government's adaptation interventions influencing land, labour and market access? 5. Do the government agencies help develop community-based organizations? How do they contribute? 6. Do the government agencies have any program, mechanism or activity to enhance community knowledge about climate change impacts, new adaptation technologies, skills or market information?	

to sustain their livelihoods, and the factors and processes that make adaptation successful or challenging. Table 2 gives some examples of interview questions. We transcribed the interviews and focus group discussions and coded them. In a deductive approach, we associated our case studies data with the framing through a discussion among the involved researchers. Our criterion of association was based on similarities and differences among the cases.

The case studies match the structure and components of the framework, describing: i) the social-ecological context of the case study; ii) local innovations for autonomous adaptation; iii) diffusion of the innovations; iv) sustainability of the innovations; v) planned adaptation approaches; and vi) planned interventions for maintaining innovations for autonomous adaptation. The case studies were analyzed based on what outcomes are obtained when two fundamental propositions of the framework are considered or unconsidered in adaptation planning: i) the incorporation of autonomous adaptation in planned adaptation; and ii) creating conditions for maintaining innovation for autonomous adaptation.

4. Case studies

The framework presented in this paper is built upon two main points: (a) the incorporation (or not) of autonomous adaptation into planned adaptation, and (b) the fostering and maintenance (or not) of conditions for future autonomous adaptation. As a result, we reveal a matrix of four potential scenarios (see Fig. 2): (1) autonomous adaptation is incorporated in planned adaptation and conditions for maintaining autonomous adaptation are created; (2) autonomous adaptation is incorporated in planned adaptation but conditions for maintaining autonomous adaptation are not created ; (3) autonomous adaptation is not incorporated in planned adaptation, though conditions for maintaining autonomous adaptation are created ; and (4) autonomous adaptation is not incorporated in planned adaptation nor are conditions for maintaining autonomous adaptation created. We have organized our results based on these four scenarios where the three case studies presented in this section correspond with scenarios 1, 3 and 4, while scenario 2 cannot be explained using the available data (though we offer an explanation of this scenario based on available literature and our conceptual understanding).

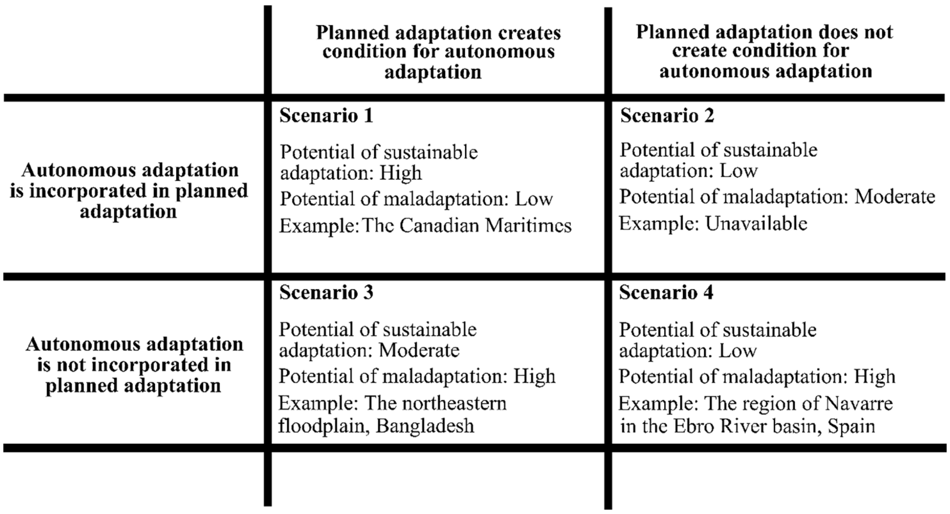

Fig. 2. Adaptation optimization matrix.

Table 3
Analysis of case studies.

Analytical criteria	The Canadian Maritimes	The northeastern floodplain, Bangladesh	The region of Navarre in the Ebro River basin, Spain
Communities in a social-ecological system context			
Type of resource system	The Canadian Maritimes include agricultural systems exposed to sea-level rise	Dry season agriculture is practiced in this wetland dominated ecosystem	This is an agricultural landscape supported by a large-scale irrigation system
Type of resource unit	Various kinds of agricultural outputs are derived from this agroecosystem	Rice is predominantly cultivated in this area, although new crops have been introduced for agricultural intensification	Traditional farming which included wheat, barley, vineyards, olive and almond trees is now transforming to large mono-crops fields (e.g., corn cultivation)
Formal institutional management	The provincial and federal governments have a lack of climate adaptation provisions for food systems	The government of Bangladesh manages this wetland system by both climate adaptation and rural development policies	Large-scale subsidized irrigation has been developed for the production of cash-crops
Informal institutional management	Community-based informal institutions allowed to build farmers' co-operatives and helped to manage the market systems of the agricultural products	Community members have formed different informal arrangements for access to land and developed community-based cooperatives to support agricultural land use	Traditional common property-based irrigation system used to support small-scale farming
Innovation for autonomous adaptation			
Types of innovation	The community members have built collective action-based community organizations for marketing their products to minimize the climate-related risks of production and sale	To substitute agricultural loss, communities intensify, extensify and diversify their livelihood practices	Innovations comprise agricultural intensification with increased use of pesticides and fertilizers, and transformation towards pro-industrial farming (abandoning small-scale family farms)
Leadership role	The community members use their own networks for building collective actions, where some community members play the leadership role to organize marketing activities	Community co-operatives are often dominated by rich farmers who can control and manipulate community decisions and maintain communication with different government agencies	Intensive farmers maintain strong communication with government and get relatively easier access to subsidized agricultural inputs and knowledge, and maintain control over information and resources provided by the government
Community knowledge capacity	The co-operatives provide opportunities for knowledge exchange and companionship	Community members use their local knowledge for selecting alternative crops, although they are not reflected in the national adaptation or rural development plans	Traditional knowledge is less useable due to changing cultivation practices
Diffusion of innovation for autonomous adaptation			
Relative advantage	The co-operatives build and stabilize market niches, leading to higher and more stable sales in direct markets	Community members can see the relative advantage of agricultural intensification, livelihood extensification and diversification strategies	New irrigation and institutional structures are less favourable to traditional farmers and more favourable to intensive farmers
Compatibility	The community-based innovation is compatible as it offers to sell products under a single banner, share responsibilities for sale and transportation of food	Most of the locally innovated strategies are compatible with the communities' local norms and values, although there are chances of elite dominance over poorer community members	New irrigation and institutional structures have less connection with traditional farming norms and values
Complexity	The co-operatives reduce complexity in product selling	Since the communities in the area are from similar cultural and social background and the innovations are locally developed, they are understandable among the community members	The adoption of new irrigation system is relatively complex for the traditional and recreational farmers, encouraging them to terminate their traditional farming practices
Trialability	The co-operatives have thrived for several years through several trials of members	Trialability of the innovations depend on availability of required resources like knowledge, network and ownership of land resources	The new irrigation system is not triable for smallholder farmers who have limited capacity to experiment with new crops and irrigation system
Observability	The positive outcomes of the co-operatives are visible to both communities and government agencies	The relative advantage of the three livelihood strategies is observable among community members as they are connected through social and cultural networks. However, the adoption of these strategies depends on availability of assets	Although the observability of short-term production increase is high, it does not inspire smallholder farmers to adopt a new adaptation approach
Filtering innovations using sustainable adaptation principles			
The context for vulnerability, including multiple stressors	Both sea-level rise and unstable market mechanism are constructing the vulnerability context of the area	While a flashflooding is considered the main climate extreme, vulnerability is intensified by environmental	Changing precipitation pattern, temperature rise and increasing frequency of extreme events are the main climate

(*continued on next page*)

Table 3 (*continued*)

Analytical criteria	The Canadian Maritimes	The northeastern floodplain, Bangladesh	The region of Navarre in the Ebro River basin, Spain
		degradation, socio-economic disparity and agricultural market uncertainties	hazards, while market price instability is a non-climate stressor
Acknowledging different values and interests	Different values and interests of the community members are negotiated in the co-operatives	The interests of poorer and less empowered community members are often ignored in the autonomous adaptation strategies because the informal institutional structure is highly stratified and there is no formal mechanism to protect the interests of the poor	Local smallholders' longstanding traditional practice and interests have been compromised
Integrating local knowledge	Local knowledge is a key component of collective actions and co-operative management	Agricultural intensification and livelihood extensification strategies are local knowledge based	Local irrigation knowledge has not been incorporated while designing the new irrigation system
Considering potential feedbacks between local and global processes	Producers in co-operatives react to consumer demands, adapting marketing strategy to current global food markets	Non-natural resource-based livelihood diversification depends on labor market demand. In addition, agricultural market fluctuation determines the adoption of appropriate adaptation strategies	Smallholder crop production using the traditional irrigation is not enough to produce yields that can be stored in order to deal with market price instability
Planned adaptation			
Contribution to local adaptation	Existing government policies have not paid much attention to food system vulnerability and adaptation provisions	Although flood protection strategy planned by the government has been contributing to short term adaptation, most of the adaptation strategies are external resource dependent. However, this limitation is substituted by rural development strategies	The new irrigation approach is designed for the adaptation of large-scale agricultural production
Contribution to local development	Adaptation to market shocks through collective action allows local food systems to build financial resilience	Adaptation supports provided by the plans are contributing to local development, although the distribution of supports is highly segregated and dependent on informal institutional roles	Local smallholders are abandoning their agricultural practices, whereas intensive farmers are happy about the new yields, but they find new challenges such as autonomy loss as single crop production is increasing
Contribution to environmental conservation	Small-scale farmers working cooperatively aim to share knowledge about best practices, including conservation	Building embankments along the watersheds for flood protection is considerably altering the environmental properties of the wetland ecosystems	Intensive agriculture is declining local environmental quality like groundwater depletion and destroying agrobiodiversity through the homogenization of the landscape
Areas of planned interventions			
Parameters	The government has funded supports required for maintaining agricultural production	The government is emphasizing a traditional approach of building flood protection infrastructure and subsidized inputs for agricultural intensification	A new subsidized irrigation structure has been built to maximize agricultural output
Feedbacks	The idea and collective actions of the co-operatives have been taken up by the government as they positively contribute to maintaining agricultural production	Access to subsidized agricultural inputs through development plans is creating an opportunity to create community organizations, although they are dominated by local elites, creating new political dynamics and power discrepancies in the community	The irrigation system has been developed to transform smallholder farming to industrial farming
Design	The government has built a collaboration between the co-operatives	The government's interventions to help create community-based organizations is the core action in design, although the absence of appropriate regulatory mechanism for supervision is enhancing opportunities for the local elites to exploit the government's services	Local traditional institutions for managing the irrigation system have been compromised to facilitate the new irrigation system
Intent	The government, by building collaboration with the co-operatives, has provided a positive incentive to community members for creating more climate adaptive innovations	No government intervention through planned adaptation has been observed to help propagate community members' preference to identify their own goals, paradigms and norms	The new irrigation system and the government's incentives for industrial agriculture has been demoralizing to smallholders striving to maintain their livelihood

4.1. Scenario 1: Autonomous adaptation is incorporated in planned adaptation and conditions for maintaining autonomous adaptation is created

4.1.1. Case study: The Canadian Maritime provinces

Climate adaptation measures for the food system in the Canadian provinces of Nova Scotia, New Brunswick, and Prince Edward

Island (hereafter "the Maritimes") are largely nonexistent (Soubry et al., 2020b). Current adaptation policies from the Canadian federal government and the Maritimes' provincial governments make no provision for climate vulnerabilities of the food system, which increases the vulnerability of local communities.

Due to this lack of support, farmers have undertaken autonomous collective action in order to build adaptive capacity within the food system. They have engaged in a number of formal and informal cooperative networks across the Maritimes, including marketing co-operatives. In market co-operatives, small farms sell together at market under one banner, share responsibilities for sales and transportation of food, and take part in collective programmes. Farmers have remarked that selling as a co-operative creates a more attractive offer for customers, leading to higher and more stable sales in direct markets. They also emphasized that working co-operatively across the Maritimes provides opportunities to exchange knowledge and companionship, as well as to have support during emergencies (Soubry et al., 2020a) (Table 3).

In one salient example, a co-operative in southeastern New Brunswick pooled its resources to hire a pest specialist for orchards, which was necessary but would have been cost-prohibitive for individual farmers. The co-operative allowed its members to benefit from the service at no additional cost to individual farms, reducing financial burden while providing access to expert advice. The programme ran for ten years, after which the provincial government's Department of Agriculture proposed to the co-operative that it could take over funding. The pest specialist service is now available province-wide through the Department. Collective action allowed the cooperative to address the immediate needs of its farmers while increasing access to expert knowledge, thus increasing adaptive capacity for the farms and food system. The provincial government, meanwhile, was willing to take on the programme in its policies because it was clear that it was both necessary and effective (considering the programme's success over the past decade).

Thus, co-operatives in the Maritimes food system have initiated several innovative interventions which were then taken up into provincial policies and adaptation activities, hinting at possibilities for collaboration between farmers and government. Autonomous adaptation yields immediate benefits for farmers as well as cascading benefits for the food system, both of which enhance adaptive capacity.

4.1.2. Case study analysis

The Canadian case study can help explain the outcomes of the first scenario. Despite the absence of any provision by the federal and provincial governments of the country, the farmers of the Maritime provinces initiated collective action-based market innovations for sustaining their livelihoods and market mechanisms. The co-operative we describe established a platform for galvanizing effective collective action, making it more effective in markets than individual sellers and reducing market uncertainty. In addition, this innovation is compatible with the demands of the climate affected communities, as it distributes the roles and responsibilities among the participants of the marketing mechanism based on their capacities (Soubry et al., 2020b). Since the innovation has created a positive impression among farmers through repeated trial, it has gained easy observability among the farmers, encouraging participation.

The innovation considers local vulnerability contexts that include both climatic and non-climatic stresses (e.g., pest infestation, market uncertainty). By considering farmers' different desires and values, like making more attractive offers for customers and enhancing stability in the market (particularly necessary for small-scale farmers), the innovation enhances sustainability. It also integrates multiple knowledge sources, combining farmers' own observations regarding insect infestation and subsequent incorporation of expert knowledge.

By acting on deep leverage points and integrating long-term community innovations, the provincial government contributed to maintaining a generative environment. While the case studies described below show their respective governments emphasizing externally developed adaptation strategies like engineered flood protection or irrigation support, the governments of the Canadian Maritime provinces manage institutional design and stimulate community intent by strengthening knowledge and encouraging small-scale farmers to join community-based organizations (Soubry et al., 2020b). These settings can facilitate the development of new innovations required for future climate and socio-economic change.

4.2. Scenario 2: Autonomous adaptation is incorporated in planned adaptation but conditions for maintaining autonomous adaptation are not created

Although we do not have data that illustrates what happens when autonomous adaptation is incorporated in planned adaptation but conditions for maintaining it are not created, we can draw some inference from existing literature. Both climate vulnerability and adaptation are dynamic phenomena (Kabir et al., 2017). With changing climatic conditions new adaptation strategies are sought and innovated (Rodima-Taylor, 2012), and therefore, learning local innovations from a specific time may generate inequality in climate vulnerable communities. For example, a SES generates multiple ecosystem services for different user groups. Resource user groups innovate their respective adaptation strategies not only considering their own vulnerability, but rather interacting with other socio-political properties. Thus, adaptation is not only an innovation rather an outcome of socio-political interactions and negotiations. Once incorporated into planned adaptation, even when filtered through sustainable adaptation principles, these innovations may create winners and losers, where the winners are the beneficiaries of innovations, and the losers bear the expenses. If the required environment is not maintained for future autonomous adaptation innovations, the benefits from planned interventions may contribute to maintaining an uneven distribution of resources.

4.3. Scenario 3: Autonomous adaptation is not incorporated in planned adaptation though conditions for maintaining autonomous adaptation are created

4.3.1. Case study: North-eastern floodplain of Bangladesh

The autonomous adaptation strategies of farming communities of the northeastern floodplain of Bangladesh can be broadly categorized into three classes: i) agriculture-based livelihood intensification strategy; ii) livelihood extensification strategy; and iii) livelihood diversification strategy (Table 3).

The farmers have been intensifying their agricultural practices by cultivating short-rotation crops and high yielding rice varieties. The short-rotation crops are usually cultivated in relatively higher elevated lands, although poorer farmers have limited or no ownership of such lands. Landless farmers often gain access to land by an informal seasonal agreement with landowners for shared cropping. These intensification strategies require additional inputs like irrigation, pesticide, seeds and fertilizers for desired production, which are commonly expensive for the farmers. To support agricultural intensification, the government of Bangladesh occasionally provides subsidized supply of these inputs distributed through farmers' co-operatives.

Under livelihood extensification strategies strategy, the farmers usually expand the use of fallow land for cultivation, duck rearing and cattle grazing. Although these strategies have been practiced in the area for a long time, their intensity has recently been expanded. While these extensification strategies have been helping farmers adapt to climate change impacts, they overuse natural resources resulting in environmental pollution, soil erosion in the wetlands and siltation of watersheds. The water discharge and retention capacity of the watersheds have been significantly reduced due to siltation, which often turn regular flood events to extreme events. In addition, the capacity of natural irrigation is also declining along with the increasing loss of fish habitat, particularly during the dry season.

Livelihood diversification strategies involve seasonal and occasional migration to urban areas and abroad for better paying jobs. This is a less risky intervention and popular among the communities. However, the adopters of this strategy need to have financial, educational, technical and networking capacities. Thus, this strategy is commonly adopted by relatively richer households. In so doing, one or more household members usually take the opportunity to pursue livelihood opportunities out of the area, and households usually sell land or other valuable assets to accommodate the cost of going abroad. Community members report that this strategy is much better than the other strategies because of the growing cost of cultivation and declining value of agricultural outputs in domestic markets.

The planned interventions of the government of Bangladesh in the study area are distributed in two major streams including climate focused adaptation plans and rural development plans; while the former are more generalized and nationally focused, the latter are more context specific. As a part of the adaptation plans, the government has invested in building embankments along the major rivers of the wetlands for giving protection to rice crops against flashflood events. Although these embankments provide protection services, they significantly contribute to river siltation and watershed destruction. In addition, the government also intends to introduce new crop varieties, although they are external input dependent. In contrast, the development plans intend to offer training and resources for alternative livelihood activities, which contribute to innovations in both natural and non-natural resource dependent activities.

4.3.2. Case study analysis

Planned adaptation can create conditions for maintaining innovation in autonomous adaptation. This situation is usually seen among societies where both development and adaptation plans function together to address climate change impacts. The Bangladesh case study explains such a condition (Ayers et al., 2014).

The case study also suggests that there remains a disjuncture between community autonomous innovations and the government's planned adaptation interventions. The community members are innovating their livelihood strategies using resources available to them and considering their observational knowledge and perceptions about climate change impacts and agricultural market mechanisms. For example, Rahman et al. (2018c) found that seasonal migration abroad and to urban areas gain popularity because of an unstable agricultural market, increasing production cost and repeated production failure due to climate impacts. This livelihood diversification strategy is gaining traction because of its compatibility with community needs, trialability within community networks and high observability.

In contrast, the government of Bangladesh aims to maintain high agricultural productivity by building flood protective infrastructure as a buffer, despite its potential for maladaptive outcomes (Rahman and Hickey, 2019b). The use of this 'shallow', *parameter*-level leverage point disincentivizes communities' intentions to adapt through sustainable strategies, and therefore, a community preference always keeps mounting toward building and maintaining flood protective infrastructure. However, the limitations of the government's adaptation interventions are substituted by its development plans, which mostly aim to enhance communities' capacity to innovate and adopt alternative livelihood activities through human capital development. However, faulty institutional *design* that regulates access to government supports prevents community members from fully utilizing the services provided by the development plans. Moreover, the development plans mainly aim to eradicate poverty without contributing to reshaping norms, values and goals in a changing climate.

4.4. Scenario 4: Autonomous adaptation is not incorporated in planned adaptation nor are conditions for maintaining autonomous adaptation created

4.4.1. Case study: The region of Navarre, Spain

In the traditional irrigation system of the region of Navarre, farmers had to comply with community obligations, such as water infrastructure maintenance and respecting the turns to irrigate so that they could preserve their access to the communal water. Traditional knowledge about flooding irrigation management and the flooding system infrastructure maintenance, as well as which crops support drought periods during the summer season, were some of the traditional strategies attributed to local farmers. This traditional water right and cultivation system took a paradigm shift with the introduction of modern large-scale irrigation, changing the agro-ecological context of the region (Table 3).

In response to the government's large-scale irrigation system, some farmers have adopted an agricultural intensification strategy. Traditional crops such as winter wheat and barley, vineyards, olive and almond trees together with fruit trees and vegetables plots located along the margins of the rivers have now been largely substituted predominantly by corn (*Zea mays*) and forage, as well as some biofuel production. This monocropping-based farming practice has intensified the use of synthetic fertilizers and pesticides. Small-scale farmers, including some old, retired farmers, secondary income farmers (those diversifying their agricultural activity with off-farm activities) and recreational farmers have not invested in the new irrigation technology, and many of them have felt forced to abandon their farming activity due to the reconfiguration of lands and water access (Albizua and Zaga-Mendez, 2020).

In contrast, intensive farmers align with the large-scale irrigation policy and they have a central role in the local knowledge and resource distribution network (Albizua et al., 2020), allowing them to have a better vision of, and access to, important external resources and knowledge through inter-personal networks (Albizua et al., 2020). Although large-scale irrigation has some short-term positive consequences such as higher average yields per year, it may bring undesired environmental, socio-economic and cultural outcomes such as an increased price of irrigation water compared to the traditional system, underground water pollution (nitrates), and river hydraulic alteration from sediment retention in the dams as a consequence of the large-scale infrastructure construction (Albizua and Zaga-Mendez, 2020). Moreover, a higher external control of the natural resources has emerged degrading local traditional knowledge and institutional structure (Albizua and Zaga-Mendez, 2020). Nowadays, an external company oversees the channel irrigation water administration (maintenance and monitoring) whereas in the past, irrigators had more autonomy and capacity to self-organize the irrigation water management. Also, other external inputs like subsidised large-scale machinery cooperatives, as well as technical advice needed for adopting the new irrigation system are provided by the government. For example, the regional government offers a weekly service of a technician visiting the local cooperatives to inform them about agriculture strategies, management and technologies (e.g., new crops suitable for sprinkling irrigation, new irrigation management techniques and pesticides).

4.4.2. Case study analysis

This case study demonstrates that the government's policy of enhancing crop production has brought a paradigm shift in irrigation technology and subsequent management system. In farming practices, the new irrigation system has catalyzed industrial and monocrop farming, and in management practices, the technology has shifted the irrigation management system from traditional knowledge-based community practices to a more expert-driven external management paradigm. This shift in policy and technology has created a new context in the study area where a fraction of farmers have benefited, although the regional government did attempt to help small-scale farmers adopt the new large-scale irrigation system has failed.

Also, the new irrigation system and its management practices have stalled the innovation and diffusion of autonomous adaptation by tarnishing the use of traditional knowledge and dismantling social cohesion and long-enduring community-based institutions (Albizua et al., 2020; Albizua and Zaga-Mendez, 2020). Moreover, the complexity, relative disadvantage and lack of compatibility for small-scale farmers, community members' inadequate capacity to trial the new irrigation system and lack of observability of small-scale farmers' successes discourage them to continue their farming practices, obstructing agricultural alternatives that could be more sustainable in the long-term (Albizua and Zaga-Mendez, 2020).

The new irrigation system for monocrop-based agricultural intensification (Navarra, 2017) has shifted vulnerability from large-scale farmers to small-scale farmers and risked environmental sustainability (Albizua et al., 2019). Overall, the planned adaptation approach has largely intervened on *parameter*-level leverage points and created an institutional *design* that marginalizes small-scale farmers from decision making processes. In addition, the paradigm of intensive agriculture (*intent*-level) incentivizes external input dependent and techno-centric intensive monocropping both nationally and locally to compete in a global market, while mixed-cropping is arguably a more sustainable agricultural practice for small-scale farmers.

5. Discussion

This paper advocates the proposition that the main objective of planned adaptation cannot only be an expert driven and/or externally mediated participatory process of adaptation decision making, rather it should aim at identifying and learning local innovations and to accommodate resources and political supports required for encouraging and maintaining local innovation. As such, the framework presented offers a process of identifying sustainable autonomous adaptation practices, incorporating them in planned adaptation practices and planning interventions for maintaining an environment of innovation. The case studies analyses adopt the framework to demonstrate the importance of the proposition of the paper by representing the different scenarios. In this section, we expand our discussion to explain how the interplay between autonomous and planned adaptation functions under different scenarios.

We observe that the *context* of each case study differs, although they have similarities in terms of resource system and resource use practices. Some of the major differences pertain in the socio-political properties of each case study area. For example, the Canadian case study is characterized with socio-economically homogenous farmers, while the communities in both Bangladesh and Spain are highly dispersed. Group homogeneity propelled a common understanding among community members regarding their climate and market vulnerability (Soubry et al., 2020a; Soubry et al., 2020b). In contrast, high socio-economic discrimination, power differentials, discriminated representation of community members in both formal and informal institutional decision-making practices heterogeneously distribute climate vulnerability among community members in the northeastern floodplain of Bangladesh (Rahman and Hickey, 2019a; Rahman et al., 2018b; Rahman et al., 2018c). We also observe in the Spanish case study that the government's irrigation policy and technique change has transformed local socio-political context, resulting in the displacement of small-scale farmers and a deterioration of social cohesion within the farmers community (Albizua et al., 2020; Albizua et al., 2019; Albizua and Zaga-Mendez, 2020). In both the Bangladesh and Spanish case studies, socio-political properties and government actions have developed an environment of double and multiple exposure – a situation unfavourable for innovation (McDowell and Hess, 2012; O'Brien and Leichenko, 2000).

Ostrom (2015) suggested that group homogeneity is one of the fundamental conditions for developing long enduring collective action-based institutions. We find a strong reflection of this claim in the *innovation* of autonomous adaptation actions in our case studies. In the Canadian case study, community members have developed collective action-based co-operatives for marketing their products, which allow them to share risks and responsibilities to cope with both climate impacts and market uncertainties (Adger, 2003). In contrast, group heterogeneity in terms of socio-economic and power status has instigated more individualistic interventions and adoption of innovation in the Bangladesh case study (Ostrom, 2010; Poteete and Ostrom, 2004). Such interventions may help develop livelihood intensification, extensification and diversification strategies, although equity and justice in resources distribution determine what strategy community members might adopt (Rahman et al., 2018c). The Spanish case study, on the other hand, shows that the government policy change to compete in global food markets has reshuffled resource distribution among farmers resulting in a new form of local political process where one group of farmers has been supported to take advantage of new technology and service for agricultural intensification (O'Brien and Leichenko, 2003). Such planned interventions may inflict uncertainties and mistrust among community members regarding government interventions leading to less innovation for autonomous interventions.

Wider adoption of adaptation strategies as autonomous responses to climate change impacts indicates its successful *diffusion*. We find that the collective action-based market interventions of the Canadian case study community has been adopted widely since diffusion attributes (i.e., *relative advantage, compatibility, complexity, trialability* and *observability*) show overall positiveness in the case study context (Bawakyillenuo et al., 2016). Also, sharing risks and responsibilities allow community members to trial different collective interventions and the *observability* of success enhanced their further actions like hiring pest specialists and communicating with government agencies for maintaining production (Adger, 2003; Kapoor et al., 2014; Wisdom et al., 2014). In contrast, the Bangladesh case study shows that the *diffusion* of autonomous adaptation actions depends on individual capacity of adoption. For example, livelihood intensification strategies depend on the ownership of (or access to) land, while extensification strategies depend on knowledge about different livelihood practices. Also, livelihood diversification depends on access to finance, social network and skill (Adger, 2003; Rahman et al., 2018c). Since the risks and responsibilities associated with these strategies are not shared, their *trialability* seems difficult (; Wisdom et al., 2014). Consequently, the *relative advantages* of these strategies are not conceived by the community members with poor access to resources despite the strategies' higher *observability*. Again, the Spanish case study shows that the relative advantages of the changed irrigation system has been enjoyed by a small group of farmers which is not *compatible* for the other group due to its *complexity* and heavy dependence on external inputs. Rather than trailing the agricultural practices, many of the community members have abandoned their agricultural practices, resulting in low *diffusion* of new practices (Wisdom et al., 2014).

Despite high *diffusion*, an autonomous adaptation practice may bring maladaptive outcomes if it associates with higher negative externality and affects environmental integrity. An autonomous adaptation practice, therefore, needs to be filtered through the principles of sustainable adaptation for being incorporated into planned adaptation practices (Eriksen et al., 2011). Filtration can also contribute to maintaining an environment for innovating autonomous adaptation by regulating what is to be promoted and what is to be deterred. For, example, the case studies suggest that the collective action-based actions are more equitable as it considers multiple stressors and interests, allowing community members to have mutual agreement on distributing roles, responsibilities, risks and resources (Adger, 2003; Soubry et al., 2020b). In contrast, individualistic adaptation interventions usually aim at maximizing individual benefits, while potential negative externalities to society and environment may be high (Rahman and Hickey, 2019a). For example, agricultural intensification and extensification strategies have been deteriorating wetland habitat in the north-eastern floodplain of Bangladesh. Yet, the adaptation policy and practices in Bangladesh have showed inclination towards supporting these strategies, while little attention has been paid to promote non-natural resource dependent livelihood diversification strategies (Rahman and Hickey, 2019a; Rahman et al., 2018c). The Spanish case study also shows how unsustainable livelihood practices gain momentum due to government support. The case study shows that the community members are adopting government's policy of intensifying agricultural production instead of innovating climate related adaptation strategies (Albizua et al., 2019).

Incorporation of autonomous adaptation strategies in planned adaptation activities is not only a matter of learning from local communities, but it also functions as a formal recognition of local innovation to inspire communities for newer innovations. Since both adaptation and development related government policies can contribute to facilitating communities' responses to climate change impacts, attention needs to be given to the policy factors that determine the distribution of resources required for adopting and innovating new adaptation strategies (Wisdom et al., 2014). For example, the government agency described in the Canadian case study has incorporated the community innovation that responds to the collective requirement of the community, which may also create new opportunities for local communities to innovate (Soubry et al., 2020b). In the northeastern floodplain of Bangladesh, the national adaptation and local development plans have contributed to enhance individuals' capacity to adapt, although they have not built any policy mechanism to be informed how community members are adapting using their autonomous responses (Ayers et al., 2014; Rahman and Hickey, 2019a). Despite the policy limitation, the community members of the area are innovating strategies that need thorough scrutiny to avoid maladaptive outcomes and to maintain the process of future innovation (Rahman and Hickey, 2019b). The Spanish case study relies completely on expert driven knowledge, resulting in losing local knowledge and cultural practices that have created a comparatively new agricultural landscape (Albizua and Zaga-Mendez, 2020).

To illustrate how to maintain an environment for continuing innovation, the framework borrows from the concept of 'leverage points' which advocates that investing in local institutional *design* (e.g., institutional innovation) and community *intent* (e.g., acknowledging climate impacts and innovating adaptation actions accordingly) can incentivize innovation (Meadows, 1999). Externally developed adaptation actions that are often short term, engineered and easy fixes, fail to consider local social, economic and political properties, leading to higher maladaptation potential (O'Brien et al., 2007). Our case studies show that the governments' planned interventions pull on different leverage points leading to varying results. The government agencies in the Canadian case study support the community's *intent* of innovation along with *redesigning* institutions by collaborating with community cooperatives. This intervention demonstrates that local innovations and autonomous responses can influence government interventions which presumably have enhanced communities' intention to innovate new autonomous responses to climate change impacts considering diverse interests of local community members and the availability of resources (Soubry et al., 2020b). In contrast, the Bangladesh case study shows that the government agencies pull on shallow leverage points, which give community members short-term protection against different climate impacts for intensifying and extensifying agricultural livelihoods, although sustainable adaptation could be achieved by minimizing resource distribution disparity and redesigning local institutional structure (Rahman and Hickey, 2019b; Rahman et al., 2012). The Spanish case study fully relies on shallow leverage points, and the government's strategy to facilitate large-scale farmers have shifted vulnerability to small-scale farmers (Albizua et al., 2019). The government's intervention has ultimately dissolved any spaces for small-scale farmers' intention and institutional design to generate autonomous responses to climate change impacts.

6. Conclusion

Climate adaptation is a dynamic policy and practice challenge. Although most adaptation decisions are made at a larger scale, they need to be adjusted to local contexts to be effective. Local contexts are characterized by their socio-political properties, production system and climate impacts. However, developing adaptation actions for diverse contexts is difficult unless adaptation policies learn from local innovations. Both planned and autonomous adaptation actions can be effective given the right circumstances, and both lead to maladaptation if they do not take context and broader systems into account. Thus, autonomous adaptation can offer some vital learning for planned adaptation. This paper presents a systematic framework for building congruence between planned and autonomous adaptations, functioning as a mechanism to learn from autonomous adaptation. However, this paper shows that learning from autonomous adaptation is not enough in an ever-changing climate reality, rather an environment for maintaining innovation should be maintained.

We have applied this framework to test its empirical implications. Using case studies from both developed and developing countries and studying diverse social-ecological contexts, this paper draws four important observations. For example, the Spanish case study indicates that investing more in infrastructure-based fixes for irrigation in the face of climate variability and drought may be effective for some of the farmers (if observed at a short-term scale) but at the expense of displacing local small-scale farmers. Moreover, these interventions can deteriorate local environment, cropping practices, and affect adaptation equity and justice. The Bangladesh case study indicates that social equity and justice can be compromised for the benefit of socio-economically empowered community members if autonomous innovations are not filtered through sustainable adaptation principles. Yet, this case study also shows that non-climate related development policies can help minimize the limitations of planned adaptation to maintain conditions for autonomous innovations. When planned adaptation learns from autonomous adaptation and does not maintain conditions for future innovation, a group of winners emerge who can maximize the use of planned adaptation benefits while others lose by being incapable of innovating new adaptation actions. As illustrated in the Canadian case study, a congruence between planned and autonomous adaptation functions best when learning from autonomous adaptation is incorporated into planned adaptation and deep leverage points are identified and utilized to transform, strengthen, and enhance the *design* and *intent* of informal, community-based institutions and systems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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