Nested pathways to adaptation

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Abstract

Societies around the world have shown a strong capacity for responding to climatic and other stresses throughout history. Based on the large body of literature on adaptation to both climatic and other stresses, this paper examines the scalar interconnections and nested hierarchical nature of adaptation decision. Drawing on case studies from around the world, we propose three stages of nested adaptation: (a) coping with change, (b) incremental adjustment to manage risk, and (c) system transformation. The effectiveness of coping is often marginal but forms benchmarks against which future adaptation to climate change can be assessed. Incremental adaptations, largely associated with technological fixes, involve more exogenous actors and operate at a greater scale than coping. Transformational adaptation is expected to occur when the rate and magnitude of change threatens to overwhelm the system. Nested with multiple-scale spatial hierarchy, the three pathways to climate adaptation are interconnected; understanding the cross-scale interactions, feedback loops and the spatial and temporal dynamics within the hierarchy is important because it affects planning and policy integration, including allocation of financial resources.

1. Introduction

Until recently, adaptation was viewed as a lesser option in climate change discussions since it was seen as undermining efforts to reduce greenhouse gas emissions (see Easterling et al 2007). In the last decade, however, it has gained mainstream acceptance as an unavoidable response to rapidly changing climate (IPCC 2014, Chhetri et al 2016, IPCC 2018), prompting action within and outside global climate policy negotiations. Climate adaptation needs and response strategies vary across spatial scales (household, local, national, regional, global), temporal scales (addressing current impacts versus preparing for long-term change), and must be undertaken within existing cultural and socio-economic settings. Capacity to respond to changing climate depends on knowledge flow through a broad range of institutions including farmers’ interactions among themselves and with vulnerable communities (Agrawal 2008) and the ability of institutions, operating at multiple scale, to act collectively (Adger et al 2003).

Adaptation has been an ongoing and dynamic process whereby societies across space and time have adjusted to climatic and other stresses, albeit with variable success (Jodha 1978, Adger et al 2003, Klein et al 2007, Butzer 2012). Undertaken voluntarily at the household and/or local level, the traditional approach to coping with changing environmental and other conditions are perceived separately from climate adaptation (e.g. Adger et al 2003, Wisner et al 2004, Tompkins et al 2010, Lavell et al 2012). They can be taken as precursor for adaptation to changing climate, however. Over time, adaptation has also been attained through incremental adjustment to existing systems along with innovation in technology and institutions (Smit et al 2000, Adger et al 2005, Chhetri and Easterling 2010). When such changes do not suffice, adaptive responses must occur on a much larger scale, prompting greater transformational change to the system (Kates et al 2012, Park et al 2012, Agard et al 2014).
It is also important to note that adaptation strategies for climate change may not follow a smooth trajectory. There are several reasons for this. The first reason relates to the nature of climate change itself. The impact of extreme climatic conditions on society will likely be far greater than effects associated with the average change in climatic conditions. Studies continue to reveal a greater potential for accelerating changes in climate with increased intensity of extreme climatic conditions (IPCC 2018). The second point pertains to how accurately society will interpret signals of climate change and respond to them when they are embedded in a set of climate observations punctuated by a high degree of uncertainty (Easterling et al 2007). Third, climate adaptation is inseparable from complex socioeconomic interaction within and between human-environment systems and their linkages across scales (Engle 2011,Dasgupta et al 2014). Finally, the ability of society to effectively adapt to climate change may further worsen if those systems are ‘path-dependent’ on a suite of technologies (or social institutions) that are rendered partially or totally ineffective by the shift in climatic conditions (Chhetri et al 2010).

One of the shortcomings of existing climate adaptation literature is that adaptation initiatives are separated into distinct non-convergent categories. For instance, Tompkins et al (2010) categorized adaptation actions of the UK into three broad categories: capacity building, implementation, and development of an institutional environment. Smit et al (2000), on the other hand, divided adaptation actions as short-term and long-term based on temporal scale. As a way of unifying the literature’s distinct contribution on climate adaptation, this paper proposes a nested conceptualization of adaptation. ‘Nested adaptation’ illustrates how one adaptation type leads to another through cross-scale interaction, strengthening the integrity of system in question. We believe that the scalar and nested hierarchical perspective provides insights on the spatiotemporal dimensions of adaptation actions. Most importantly it aids in the conceptualization of the intricacies and feedback within which adaptation decision making occurs (Adger et al 2005). While introducing the conceptual foundation of nested hierarchical properties of the decision-making environment, in the next section we introduce the characteristics of different adaptation mechanism: coping, incremental and transformative adaptation. This is followed by a discussion of how adaptation action taken today will influence and offer guide to future directions of adaptation. Finally, we conclude by arguing that responding to climate change should be seen as widening opportunities between and within societies to maintain and/or enhance the functionality of system in question.

2. Conceptualizing nested adaptation to climate change

Over the past two decades, various typologies of adaptation have been emerged. Through analysis of 158 distinct adaptation projects, Biagini et al (2014) have revealed ten categories of adaptation types that they refer to as ‘higher-order’ actions. A large body of literature on climate adaptation generally reveals one of six main areas: intent (personal, collective), spatial scope (local, regional, national), timing relative to stimulus (anticipatory, concurrent, reactive, planned), form (technological, behavioral, financial), drivers (private or public), and degree of response (incremental, transformational) (Carter et al 1994, Wilbanks and Kates 1999, Smit et al 2000, Smit and Skinner 2002, Huq et al 2004, Smit and Wandel 2006, Cutter et al 2009, Kates et al 2012, Wing and Fisher-Vanden 2013). While adaptation actions are divided into different types based on key areas or characteristics, combining multiple characteristics in a single typology is crucial for adaptation planning and policy formulation. It is also important to note that adaptation does not occur in the absence of institutions, policy, technology, financial resources and independent of scale. There is a strong need to define what adaptation looks like in practice when scalability is considered (Wing and Fisher-Vanden 2013), especially when adaptation focuses on transboundary resources (e.g. forest, river). Identifying administrative jurisdiction and institutional capacity is important because pathways to climate adaptation demand iterative and inclusive process of negotiation between stakeholders. While addressing adaptation challenges, such iterative and inclusive process can widen the opportunities between countries.

We argue that a scalar and nested hierarchical conceptualization of adaptation types fills three gaps that are not fully addressed by existing typologies. First, the simplicity in nested hierarchy is more applicable for adaptation planning and policy formulation. By partitioning adaptation types into nested hierarchy, a range of influential factors and their interactions across scale can be identified (Lyle 2015), suggesting that there is potential to implement a range of scale specific climate adaptation policies that collectively enhances the adaptive capacity of society. This also provides framework to conceptualize, structure, and measure outcomes of adaptation actions—including how financial resources are allocated (Ford et al 2013). Second, adaptation occurs at multiple scales, with action taken at the local or regional level in an attempt to make adjustments to changes (Klein et al 2013), and can be undertaken by a range of stakeholders including individuals, public institutions, communities, civil society (NGOs), and private sectors. Finally, adaptation does not occur in the absence of institutions, policy, technology, and financial resources. There is a strong need to define what adaptation looks like in practice, when it is punctuated by uncertainty and noise in the system. The pathways to adaptation is also
enabled (or hindered) by governance, institutions, innovation, collective social action, and productive multi-scalar relationships are possible by looking at the roles of regional and local institutions.

The recognition and integration of adaptation types into nested hierarchy serves as structure to guide and facilitate pathways to climate adaptation (Biagini et al 2014). It allows us to identify and implement a range of proactive climate adaptation strategies at specific scale. In addition to representing complexity of adaptation activities and actors, our nesting of three-part typology describes how actors within these scales influence the decision making process within and across the scales. Exploring our understanding of hierarchy helps us identify the nature of decision making environment at each scale so that it can be useful for long-term adaptation strategies. Our intention in this paper is to outline where different approaches to adaptation, some prompted by climate change and some not, can be used to design future adaptation.

Our nested adaptation types are (1) coping with change, (2) incremental adjustment to manage risk, and (3) system transformation. Figure 1 presents how the three types relate to each other while simultaneously reflecting their distinct characteristics. Defined as a reactive and short-term measure, coping strategies are undertaken at the personal, household or community level. It is an endogenous response to minimize risk and vulnerability to climatic and non-climatic stressors. The primary objective here is to reduce risk from changing climatic conditions and current vulnerability of a system in question. Made in response to increasingly unfavorable conditions, incremental adaptation is aimed at improving resiliency of the human environment system. It may entail an extension of activities that are already in place or an introduction of new ones so that the system in question may be able to maintain its functional objectives under changing conditions (Levin et al 2012). Unlike coping strategies, incremental response to climate change involves new tools and techniques. Transformation demands changes in fundamental attributes of a system in response to actual or expected impacts of climate change (Rickards and Howden 2012). This requires a more radical change, involves exogenous drivers and may be pursued as a consequence of national policies, international agreements, or transnational network. It is important to note that both endogenous and exogenous drivers can simultaneously function and mutually engage but exogenous drivers may need to play significant roles as a catalyst to adaptation planning.

Geared toward maintaining the functionality of existing systems through the adjustment of production technologies at the local level, coping has its limitation in responding to large-scale change (Smit et al 2001, Pelling 2011, Noble et al 2014, Pelling et al 2015). The inability of a system to cope and maintain essential function warrants the need for incremental adaptation (Klein et al 2007). By including exogenous actors, incremental adaptation can maintain the functionality of the system to some degree of change but may not deliver expected results if the changes are severe. When incremental adaptation is not enough to reduce social and economic costs, the system requires a transformative and radical change (Kates 2000). The process involves multiple actors and social groups across the nested hierarchy. Therefore, understanding the actors involved, their narratives, policy space they are involved becomes crucial. Transformational adaptation, however, is not
the end product of the adaptation mechanism and has no inherent superiority over other forms of adaptation or resilience building (Matyas and Pelling 2014). It is not a final solution; even a transformed system must continue to evolve across space and time. It is important to recognize the connection between adaptation types, however, so that a system in question is capable of taking advantage of new climate. The black circular arrows added on top of figure 1 represent that movement through the nested hierarchy. Transformational adaptation creates a new system with altered purpose and functionality; to sustain the altered condition, adaptation must be followed by coping and/or incremental adaptation. According to Adger et al (2005), characterization of scalar dimensions nested within a hierarchy aids in the conceptualization and understanding of the intricacies of system of climate change decision making.

There is no strict boundary between different adaptation types, each of them is nested across hierarchical scale (see table 1). The elements that define coping, incremental, and transformative are on continuum whereby multiple pathways to climate adaptation could simultaneously be embarked by different actors. For example, incremental adaptation can be an outcome of technological improvement geared towards maintaining the functional objectives under changing conditions. Therefore, incremental adaptation operates at a relatively larger spatial and temporal scale, with greater resource intensity, more actors, and increased collaboration between actors. In anticipation of the future impacts of climate change, some actors may move from incremental to transformative adaptation as the previous type of adaptation fails to provide the necessary response to climate change. For example, in recognition to the limitation of incremental adaptation farmers can introduce completely new form of agricultural system.

Table 1. Essential elements differentiating each adaptation category (Adapted: Levin et al 2012, Rickards and Howden 2012).

| Spatial Scale | Actor(s) | Temporal Scale | Resource Intensity |
|---------------|----------|----------------|-------------------|
| Individual, Household | Private | Days, Months | Minimal |
| Community | | | Moderate |
| Local | Public | Years | Large |
| Regional | | | Extensive |
| National | | | |
| International | | | |

Coping is nested within incremental adaptation because the foundation of any incremental adaptation is set in motion through an initial reaction to the change. It is entirely possible that a human-environment system is likely to go through coping and incremental adaptation before it is transformed to a new state. For example, in the case of agriculture, pathways to adaptation may begin with managing risk and vulnerability before it is transformed to a new land use practice. So, the coping takes place as a reactionary response to changes, while incremental adaptation can occur to maintain the functioning of the system. Transformative adaptation, operating at a larger scale involving multiple actors, are actions that change the fundamental attributes of a system in response to actual or expected impacts of climate change. In the following sections we discuss the structure of the three climate adaptation types within the framework of nested multi-scale hierarchy.

2.1. Coping (reactive) adaptation
Coping adaptation, also referred to as reactive adaptation, occurs when individuals or communities routinely respond to social and climatic stimuli independent from outside intervention (Soloman et al 2007). As illustrated in figure 1, coping adaptation is an endogenous adjustment to the system in question. It tends to be reactive, short-term, and focused on managing risks and vulnerability to climatic and other stressors (Smit and
of coping strategies in response to large scale climate change may be constrained by the attributes of community and the capacity of household to respond. We present three agricultural cases as illustration of coping. Our first example, of traditional water management in Africa, shows the history of coping adaptation as well as its continued application today. The other two cases provide examples of both the presence and absence of exogenous actors in endogenous coping efforts.

In regions with inadequate precipitation and poor soil, traditional land management techniques form an integral part of many farming systems (Agarwal and Narain 1997). For example, farmers in the Central Plateau of Burkina Faso have developed integrated soil and water management practices (known as zaï) to combat land degradation and improve productivity (Reij et al 2005). The creation of zaï pits is a longstanding tradition in the region and has helped farmers cope in an environment that is less hospitable to agriculture (Ouedraogo and Sawadogo 2001). The zaï method concentrates runoff water and organic matter in small pits (20–40 cm in diameter and 10–15 cm deep) dug manually during the dry season. The pits are combined with contour stone bunds that slow down runoff. Farmers improve the zaï pit through experimentation, increasing the size of the pits to capture more rainfall and adding manure to the pits so that the land can hold moisture for long period of time. Oriented towards survival and prompted by lack of alternative, zaï method may work well enough to improve land when climate remains within the bound of historical experience. It makes coping difficult when it comes to dealing with accelerated climate change.

In the absence of ‘professional’ weather predictions, farmers in Rajasthan, India, have relied on 11 different rainfall prediction methods for making their seasonal cropping decisions (Carter et al 1994). Focused on the timing of the onset of monsoon rainfall and its intensity, these predictions determine the onset of the cropping season, type of crops sown, patterns of cropping, and the variety of crop chosen for pearl millet (bajra)—a dietary staple in the dry region of northwestern India (Birkenholtz 2014). If the summer monsoon is predicted to be delayed, farmers tend to increase the ratio of pearl millet, Kor Dau Bajra, a low yielding but drought resistant local variety. By planting pearl millet, farmers avoid crop failure. While providing broader explanations of coping strategies, this example offers links between local expertise of weather prediction and adaptive agricultural practices by resource-dependent farmers. If local expertise such as this is integrated with technological innovation in agriculture and climate forecasting by regional government entities, it will strengthen the farmers’ abilities to respond to changing climate.

The long dry season and inadequate rainfall in the western hilly region (west of Dhaulagiri mountain range) of Nepal often times causes food shortages. Intermittent drought during the growing season further affects maize production—the region’s most important crop accounting for 78% of the total cultivated area in the hills of Nepal. The Nepal Agricultural Research Council (NARC) has developed a full-season maize variety (matures at 120–150 days) that gives higher yield compared to local ones. To avoid crop failure due to moisture stress, farmers have traditionally grown local varieties of maize that take only 70–75 days to mature, 20 days earlier than one of the high yielding varieties—Arun 2 (90–95 days)—released by NARC. Despite the need to increase production, farmers in Nepal’s western region still opt for lower risks maize cultivars to reduce risk from intermittent drought and inadequate rainfall over the potential profits from higher yielding maize varieties available to them. By growing early maturing traditional landraces, as opposed to full-season improved maize available to them, farmers avoid complete crop failure—a potent example of a local adaptation strategy in response to parched climatic conditions.

Traditional coping mechanisms—practiced by individuals, households and community members—provide benefits under the current climate. These mechanisms can also be called low-regrets measures and may lay the foundation for adaptation to future climate change. Many of the existing mechanism, however, may prove inadequate in response to the rapidly changing climate. Additionally, successful traditional methods applied by the farmers to cope during the period of climatic stresses are disappearing with no concurrent development through public support systems (Kates 2000). For coping mechanism to be effective, users must have the right knowledge, skills, incentive, and resources to adapt efficiently. When coping fails to deliver expected outcomes or it become insufficient to meet needs of the system in question, humans must turn to the next step on the adaptation continuum. The move towards incremental adaptation prompts additional technological and/or institutional innovation.

2.2. Incremental (planned) adaptation
Following Kates et al (2012) and others, we view incremental adaptation as an extension of coping whereby the central aim is to improve efficiency within existing systems while maintaining its fundamental attributes. Oriented towards longer-term livelihoods security, incremental adaptation is largely associated with mobilization of the existing technological and institutional capacity of society (Carter et al 1994, Easterling 1996, Watson et al 1996, Reilly and Schimmelpfennig 2000, Smit et al 2001, Soloman et al 2007). While they are not...
mutually exclusive, the primary distinction between coping and incremental adaptation is the scale and actors involved (see figure 1). Incremental adaptation involves planning and is implemented with the goal of identifying solutions to the consequences of climate change. It is larger in scale and scope than coping adaptation and may involve multiple actors and external agents (see table 1). Our first case is one that clearly demonstrates the steps that make up incremental adaptation; for 2,000 years, people living on the North Sea coastline of what is now Germany have been making stepwise adjustment to protect them from floods and storm surges. Our second case—the city of Chicago’s Climate Action Plan (CCAP)—is an example whereby city planners have developed multi-dimensional approach to adaptation but have done so in an incremental fashion. The final case is from Cedar Falls, Iowa and is an example of how both endogenous (utility commissions) and exogenous (US Army Corps of Engineers) actors play a role in this type of adaptation.

Squeezed between the North Sea and the Baltic Sea, Schleswig-Holstein is the northernmost state of Germany and contains a vulnerable coastal system due to its low elevation. The North Sea coastline is 553 km long and one-fourth of the adjacent coastal lowlands is flood prone. To shield farmlands from salt-water intrusion, early inhabitants built dwelling mounds in the coastal Marshland as well as established ring-dikes along the coast (Goeldner 1999). By the end of 14th century, almost the entire North Sea coastline was protected by a continuous dike-line (Hofstede 2008). These dikes were low in height and subject to be overtopped or breached, yet they could provide defense against tidal inundation and flood. The catastrophic storm surges in 1953 and 1962 demonstrated the inefficiency of the existing dikes to prevent damages. As a consequence, the state government formulated the first master plan—‘Dike-strengthening, dike-shortening, and coastal protection’—in 1963. The main objective of this plan was to construct and repair the existing dike system, shortening the dike length to reduce exposure, and begin rainwater harvesting in the protected coastal lowlands (Kramer 1968). This general plan was later updated in 1977 and 1986; and a new plan was introduced in 2001 by the state government.

Hard infrastructure was the focus in the new plan but tourism, nature conservation, spatial planning, political consensus, and other socio-political issues were also considered (Hofstede 2004). The cost of maintaining sea walls or dikes over the long term (Sterr 2008) prompted the government to introduce salt Marsh management in the latest plan. The salt Marshes in front of the sea walls may reduce the wave energy by transferring it to the edge of the Marsh and thus prevent wave overtopping during storm surges (Hofstede 2003). This case is a quintessential example of incremental adaptation: each change made to protect the population built on top of previous work and was often infrastructure based. Oriented towards livelihood security, this coastal community is strengthening their flood defenses by incrementally building on and improving the efficiency of existing practices, approaches, technologies and governance structures for climate risk reduction and management.

In recent decades, the city of Chicago has encountered extreme heat waves. The summer of 1995 was one of the worst on record, when 800 people died due to heat exposure (Hayhoe et al 2010). Under the changing climate, the city is expecting to face more frequent and intense heat waves that might result in greater heat related deaths, as well as heavy downpours during winter and spring (Meehl & Tebaldi 2004, CCAP 2008). City administrators have proactively engaged in planned adaptation by making adjustment in response to anticipated impacts of climate change, both to reduce potential harm and to take advantage of emerging opportunities.

In 2008, the city government formulated an incremental adaptation plan. Under the Chicago Climate Action Plan (CCAP 2008), the city government introduced green design, restoration of green space, air quality improvement, management of heat response and storm water. In order to manage the urban heat island effect and improve the air quality of the city over 500,000 trees have been planted along with the establishment of 120 green alleys (CoC 2017). The city currently has more than 500 green roofs covering more than 5 million square feet. These green roofs can lower the local temperature by 7°–10° F. About 15 million square feet of municipal buildings have been retrofitted in the last 15 years to make them energy efficient (CCAP 2010). In addition, the city government installed solar panels in city buildings and schools. Now more than 20 percent of these buildings’ energy is supplied from renewable sources. To combat local pollution, the city government is encouraging its residents to use energy efficient products and drive less and walk or bike more. Chicago is also managing storm water via the vacant lands and parking lots. In the first two years of the action plan, permeable surface in the city area has been increased at least 55 acres (CCAP 2010). While city’s climate actions have policymakers from across the city, questions are being raised regarding whether this incremental approach will be sufficient over the long term.

Our final incremental case is in Cedar Falls, a small city in Northern Iowa’s largely agricultural landscape. The city is bisected by Cedar River, which has crested above flood stage around 100 times since 1929 (FEMA 2001). Under the warming climate, the city expected to undergo more intense floods. Twenty years ago, Cedar Falls did not have any flood protection, but between 1998 and 2000, the US Army Corps of Engineers built a mile-long flood control levee. Later, the Cedar Falls Utility (CFU) constructed a ‘flood bladder’ demarcating 100-year flood zone and prohibited any sort of development in that zone. The record-breaking 2008 flood
almost caused the levee to fail, which persuaded the CFU to pass a new flood ordinance (CPCCF 2012). In the new ordinance, the zonal restrictions were increased to 500-year flood protection level. The city limits construction of new structures in the 500-year flood zone. The residents in 500-year flood zone received a flood buyout offer to relocate or leave the flood prone area. The city government facilitate the buyout process with assistance from state and federal government. Also, the CFU reinforced the storm sewer system by improving the old system and creating water retention basins. The city developed the natural storm water drainage network through green infrastructure planning. Lastly, in 2012 the city formulated a comprehensive development plan with attention to floodplain management. Cedar Falls’ adaptation involved the multi-scalar cooperation of actors, endogenous zoning laws, and the exogenous involvement of the Army Corps of Engineers. Incremental adaptation actions include strengthening existing flood defenses, increasing the size of water reservoirs, or improving emergency preparedness systems and this proactive adaptation planning can open up space for new ideas and innovative policies and approaches as well.

The three cases of planned adaptation demonstrate that when the existing technology or infrastructure fails to reduce the risks from climate or other shocks, incremental adaptations can be undertaken in response (Adger et al 2007, Kronlid 2014). As illustrated through the three examples above, incremental adaptations are expert driven, large scale, and tend to be capital intensive (McEvoy et al 2006, Sovacool 2011). It also encompasses extensions of existing structures, plans and/or practices (Noble et al 2014). The most effective incremental adaptations, however, are those that offer co-benefits in the near term, as well as help reduce vulnerability for longer periods (Barnett and O’Neill 2009, Jones et al 2012, Chambwera et al 2014). As the potential for significant changes in climatic conditions becomes more likely, concerns are being raised whether existing approaches will be sufficient to ward off potential large scale consequences. This has given rise to interest in transformational adaptation, which may lead to the implementation of fundamentally different approaches to preparing for and responding to climate risks.

2.3. Transformational adaptation
Within the climate change adaptation research community, the use of term transformational adaptation is on the rise. Defined as ‘adaptation that changes the fundamental attributes of a system in response to climate and its effects’ (Agard et al 2014: 1758), transformational adaptation entails a greater magnitude response to climate change (Tompkins et al 2010, Kates et al 2012, Park et al 2012). Transformational adaptation can also be reactive and can be triggered by a system reaching the limits of its ability to maintain its functionality (Olsson et al 2014). Following Kates et al (2012), transformational adaptation can be distinguished from the adaptation types previously discussed based on its novelty, scale or intensity, and transformative effect on the place. In the case of agriculture, for example, transformational adaptation may entail the introduction of new land use system or complete replacement of past agricultural activities with a new one.

Our transformative adaptation cases accentuate three key things. First, we present the Thames Estuary to show that embedded in every transformational adaptation are coping and incremental adaptations that are often necessary to sustain the transformational change. The second example, vineyard business modifications in Australia, demonstrates how the presence of uncertainties associated with climate change makes it difficult to make decisions on whether the system needs to be transformed. The final case, Cuba’s urban agriculture revolution, provides a non-climatic example of potential triggers to transformational change and the significance of political and economic actors needed to bring it to fruition. While there are some overlaps between incremental and transformative adaptation, the latter demands a more fundamental change within and across the system in question. Depending on the level of interventions and its ‘newness’, transformational adaptation can profoundly alter the capacity of the system.

The Thames Estuary Plan for 2100, a long-range plan to manage flood risk from the Thames River in London (Environment Agency 2009), is transformative because of its novelty to the region and the greater temporal scale of planning and implementation. It is based on a 90-centimeter sea level rise by 2100 and incorporates ten indicators of change that will be evaluated every five years to check for needed modifications which can be made every ten years (Environment Agency 2009). The ten indicators are: (1) sea level rise (2) peak surge levels (3) peak river flows (4) flood defense condition (5) barrier operation (6) development (7) erosion and deposition (8) habitat (9) land use planning and development activities (10) public/institutional attitudes to flood risk. The structure of the long-range plan provides an illustration of how transformational adaptation requires coping and incremental adaptation but also goes beyond what smaller-scale endogenous adaptation can do.

The Thames Estuary Plan for 2100 has moved away from traditional approach, which focused on flood prevention, to a more systems based approach focused on minimizing the damage caused by flooding. It incorporates consideration of climate change risk in its decision-making processes, questioning whether or not current water management approaches and policies will be sufficient to meet their stated objectives under different climate scenarios. Implementing transformational adaption such as the Thames Estuary 2100 is
financially costly and socially taxing compared to marginal or incremental changes (IPCC 2014, Gillard et al 2016). Cost, however, is not the only limitation on implementing transformational adaptation. Rickards and Howden (2012) identify four key issues associated with implementing transformational adaptation: cost, maladaptation, capacity demand, and the role of government. The uncertainty of long-range planning and implementation can easily lead to maladaptation. Likewise, incorporation of the experience from coping and incremental adaptations are also central to successful transformational adaptation.

Climate and market changes are making Australia less hospitable to both large-scale and boutique vineyards. The uncertainty in how climate and other factors will affect their profits is prompting wine growers to transform their business model. Based on the scale of the business venture, vineyard owners are choosing different transformative strategies (Park et al 2012). Large companies with multiple vineyards are buying land in places like Tasmania that have cooler climates. Smaller boutique vineyards are replacing grape production with activities such as tourism. They are not focusing all of their efforts on transformational changes, however, instead incorporating multiple elements to support their livelihoods some of which are incremental adaptations (Park et al 2012). For example, in the vineyards still held in Australia, grapes are being harvested earlier because they are maturing faster, efforts are made to be more water efficient, or to select drought-tolerant root stock.

Our third example illustrates how the collapse of the Soviet Union in 1990/91 transformed the island nation of Cuba from a large-scale, mechanized system subsidized by the USSR (Choy et al 2005) towards low-input, high-yield urban agriculture sponsored by the Cuban government. Prior to 1990/91, Cuban diets were dependent on imports for 90% of fats, 55% of calories and 50% of protein consumed (Koont 2011). After the transformation of the agricultural system, Cuba’s produced approximately 3 million tons of vegetables annually just from its urban gardens (Castro and Ramonet 2007). This top-down approach illustrates the role of governance in transformational adaptation. Although transformational adaptation is a relatively new concept in the context of climate change, innovation that are transformative in nature can be found in other areas. The transformation of the agricultural system in Cuba provides additional impetus for thinking through the role of exogenous actors to respond to sudden and unexpected change.

The push towards low-input high-yield gardens for food production was first made by the military. Growing food in organopónicos (the name given to raised garden beds because they used mostly organic inputs) was implemented on military bases and later—on December 5, 1991—the first civilian plot was planted (Premat 2012). Considerable agricultural education was implemented because the majority of people who became urban farmers were former masons, mechanics, retirees, housewives, and professionals with no previous agricultural experience (Wright 2009, Koont 2011). For example, in 1991, the Ministry of Agriculture partnered with the Havana city government to create agricultural information offices in each municipality (Cruz and Sanchez Medina 2002, Koont 2011). The adaptive strategies employed by Cuban farmers include techniques to improve soil fertility, conserve water, increase cropping diversity, manage trees, and land tenure and land use policy. The adjustments made by the urban residents—the newly minted farmers—to changing political economic conditions transformed the way food is produced in the country to date. The transformation did not happen overnight and the government of Cuba made a significant investment in building human and institutional capacity, in doing so it transformed the entire system of food production in the country.

As illustrated through the three examples above, transformational adaptation often involves exogenous actors to foster climate change adaptation at the local level. The exogenous actors can play significant role as a catalyst for adaptation, including resource appropriation, planning and implementation (Nugraha and Lassa 2018). It seeks changes to institutions—such as legal and regulatory structures underlying resource governance (Craig 2010, Watts 2015)—as well as the cultural rigidity that prevents society from making necessary change (Watts and Bohle 1993, Wisner et al 2004, O’Brien et al 2012). Kingdon (1995) argues that three ‘streams’—problems, solutions, and policy—need to come together at the same time in order to move forward with the process of transformation. For example, as an exogenous actor, the central government in Cuba shaped knowledge-policy interactions and triggered endogenous forces at the local level to foster response to looming food security challenge. So, it is important to understand interactions between exogenous and endogenous actors to planning and carrying out transformational change (Lonsdale et al 2015). To be effective, transformational adaptation may also need to occur at more than one scale—from household, community level to regional, national and, potentially at the international level. An effectively coordinated transformative adaptation could also result shifts in power and greater social justice.

Adaptation to the impacts of climate change is a dynamic process occurring on many scales and undertaken by a variety of stakeholders, ranging from large intergovernmental institutions to local farmers. Table 2 summarizes the extent of scales, actors, and resource intensity across the nine case studies included in this paper. Some adaptation measures are simple operational decisions (e.g. coping), but others take the form of policy intended to build adaptive capacity. Individuals (e.g. farmers) and their groups (e.g. farmers groups) at the local level act as pro-active agents who respond to challenges posed by climate in shorter time scales (e.g. season). Actors operating at the regional, national and international level may create an enabling environment for
adaptation at the local level. A dynamic multi-scalar engagement is important to foster smooth pathways to adaptation. The case studies that we synthesized in this paper indicate that the resource intensity and spatial-temporal scale increase with adaptation type—from coping to transformation.

3. Discussions and conclusions

There is no end-point to which society has to adapt. The three nested hierarchical adaptation types discussed in this paper are generally distinguished by their degree of change and the actors that bring about the change. The disconnect between actors operating at different scales can be problematic in designing robust adaptation strategies at the local level (Fresque-Baxter and Armitage 2012). Inherent to climate adaptation, therefore, are the scalar interconnections and nested hierarchical properties of the decision-making environment (Lyle 2015).

Success of these activities depends on who are the actors, what level the adaptation is undertaken and level of engagement with stakeholders from local to global level. The Chicago case, for example, presented here involved combined actions in multiple levels and sectors with a single goal: building a climate resilient city. Using the existing knowledge and technologies the city government made several efforts to lessen heat stress and to manage storm water. In addition to understanding the potential consequences of climate change, such coordinated effort requires understanding institutional dynamics and constraints.

While the changes made to the agricultural system in Cuba were not motivated by climate change, the technological and institutional innovation executed by the government made the system more resilient which is one of the goals of any adaptation. The fundamental change that ensued in Cuba’s food system after the collapse of Soviet Union has a lasting influence on the Cuban agricultural landscape and its people. The island nation not only transformed its agricultural system but now produces twice as much food with less than half the inputs. To do so the farmers had to learn new method of producing food including developing low-input agriculture. At the crux of this transformation was the coping adaptation of one individual to start a small garden on the military base, which she did in response to the shortage of food in the country (Choy et al 2005). The geographic scope of these garden began to incrementally expand to other military bases across the country with added technological features such as drip irrigation and better seeds. Ultimately the program expanded to civilians and transformed the entire system of food production as the government invested the necessary capital to create organopónicos in many urban areas.

While incremental adaptation enhances the efficiency within existing systems (e.g. technological, governance), transformational adaptation involves the alteration of fundamental attributes of those systems (O’Brien et al 2012). In a normative sense, however, transformational adaptation can be seen as a radical political project of deep-seated institutional change (Feola 2015, Fazey et al 2016), it involves a range of tradeoff that link to other social goals (IPCC 2014). The tradeoff between transformational and other forms of adaption depends on evolving risk profiles and underlying social and ecological conditions (Field et al 2012). Transformational adaptation, however, requires large-scale social discourse and institutional learning (IPCC 2012). Successfully overcoming barriers to enact large-scale social changes is politically and economically costly (IPCC 2014). Given the nature of risks and the scale at which it has to be addressed, transformational adaptation calls for leadership at multiple levels. Most discussions on adaptation thus far have failed to understand the scalar interconnections as they are discussed within the context of local response to change. For this reason, the whole discourse around ‘adaptation as local’ has to be challenged as the scale and magnitude of the impacts of climate change begin to be visible at regional and national level (see table 3). This is not likely to be a failure of intellectual imagination, but

| Adaptation Type | Cases                      | Spatial Scale          | Actor(s)       | Temporal Scale | Resource Intensity |
|-----------------|----------------------------|------------------------|----------------|----------------|-------------------|
| Coping Adaptation | Burkina Faso              | Household, Community   | Private        | Days, Months   | Minimal           |
|                  | Rajasthan, India          | Community, Local       | Private        | Days, Months   | Minimal           |
|                  | Nepal                     | Local                  | Private        | Days, Months   | Minimal           |
| Incremental Adaptation | Schleswig-Holstein, Germany | Regional              | Public         | Years, Decades | Large             |
|                  | Chicago, USA              | Regional               | Public         | Years, Decades | Large             |
|                  | Cedar Falls, USA          | Local                  | Public         | Years, Decades | Moderate          |
|                  | London, England           | Regional               | Public         | Decades        | Extensive         |
| Transformational Adaptation | Australia                | Regional               | Private        | Years, Decades | Large, Extensive  |
|                  | Cuba                      | National               | Public         | Years, Decades | Extensive         |

See Table 3.
Adapting to climate change involves cascading decisions across a landscape made up of agents from individuals, rms and civil society to governments at local, regional and national scales and international agencies. We argue that central to climate adaptation policy is creating options and opportunities for desirable societal innovation-led adaptation which have lessened vulnerability to climatic and other stressors, and allowed humans to flourish in an incredibly diversity of climates. As illustrated in table 2, there is the potential to implement a range of policies targeted to each level in order to unleash the climate adaptation possibilities at scale. Identifying targeted activities at different scales may help in identifying administrative and institutional jurisdictions to devise appropriate policy pathways. For example, adaptation to multiple drivers of coastal change, including sea level rise, include retreat (migration) and/or accommodate and defend by building restrictive infrastructure that may need to be considered over centennial scales (Mander et al 2017, Brown et al 2019).
Likewise, society may have to consider alternative livelihoods and food sources if existing crops are no longer viable due to change if local climate. Ecosystem-based adaptation such as ecosystem restoration, and constructing coastal infrastructure that reduces the impacts of rising seas and intensifying storms may be necessary to manage risk and vulnerability to floods and coastal inundation.

As illustrated in this paper, action on adaptation can range from short-term tactical coping strategies to incremental response and deeper transformations. Each of the adaptation types has its own limitations and understanding those enhances our ability to respond. For example, incremental adaptation occurs at a range of scales and can be an extension of actions that are deemed necessary to reduce the impacts of climate or take advantage of it. A considerable limitation of incremental adaptation is that successes in the short-term or with smaller scale goals—like the improvements made to prevent flooding in Cedar Falls—may hinder processes in long-term solutions by being too short-sighted and using too many resources on short-term solutions. It is important to note that adaptation is not just about technological problems to be managed through engineering solution, it is about engaging with other social actors and their institutions. We argue that, in times of uncertainty, technological solutions will only offer a partial response to climate adaptation.

Transformational adaptation includes actions that change the fundamental attributes of a system. It is pursued in response to actual and expected impacts of climate change. The nested pathways for transformational adaptation, therefore, need to be built on a foundation of constantly evolving knowledge on climatic and other ongoing changes in society. While we acknowledge that some elements of transformational adaptation can be reactive, the pathways to transform the system in question should be proactive requiring imagination and foresight about the scale and magnitude of change. The strategies and action should be such that they allow society to move toward pathways to resilience while helping to improve the social wellbeing. Therefore, policies on transformational adaptation should foster synergies and avoid negative feedbacks or maladaptation. Responding to climate change should be seen as widening opportunities between and within societies to reorganize and rebuild social, ecological, and economic relations so that a greater number of adaptation options are available to a greater number of stakeholders over time.

Local level experience of coping with, and adapting to, are the principal resource for responding to future climate change. The research community and stakeholders can develop adaptive capacity of community and household by combining scientific or factual information with local knowledge and experience of change and responses over time. Not only endogenous, but also exogenous actors are required, because households and communities are often confronted with resource constraints to implement adaptation measures, and it is not sufficient to avoid severe consequences to impending threat from climate change. Key to an effective climate adaptation policy is to be aware of and to overcome those constraints, including the decision-making barriers. By pointing out the limitations of each adaptation type we show the policy dimensions of different adaptation types to climate change. For example, exogenous actors can play significant role as a catalyst for adaptation planning, however, a successful adaptation depend on how receptive and responsive local actors to engage in responding to changing climate.

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