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The Long Arm of Climate Change: Societal Teleconnections and the Future of Climate Change Impacts Studies

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Abstract
"Societal teleconnections" – analogous to physical teleconnections such as El Niño – are human-created linkages that link activities, trends, and disruptions across large distances, such that locations spatially separated from the locus of an event can experience a variety of impacts from it nevertheless. In the climate change context, such societal teleconnections add a layer of risk that is currently neither fully appreciated in most impacts or vulnerability assessments nor in on-the-ground adaptation planning. Conceptually, societal teleconnections arise from the interactions among *actors*, and the *institutions* that guide their actions, affecting the movement of various *substances* through different *structures* and *processes*. Empirically, they arise out of societal interactions, including globalization, to create, amplify, and sometimes attenuate climate change vulnerabilities and impacts in regions far from those where a climatic extreme or change occurs. This paper introduces a simple but systematic way to conceptualize societal teleconnections and then highlights and explores eight unique but interrelated types of societal teleconnections with selected examples: (1) trade and economic exchange, (2) insurance and reinsurance, (3) energy systems, (4) food systems; (5) human health, (6) population migration, (7) communication, and (8) strategic alliances and military interactions. The paper encourages further research to better understand the causal chains behind socially teleconnected impacts, and to identify ways to routinely integrate their consideration in impacts/vulnerability assessment and adaptation planning to limit the risk of costly impacts.

1 Teleconnections – An Introduction

Teleconnections are a widely recognized phenomenon in the physical sciences, made most famous by the El Niño-Southern Oscillation (ENSO).[3] The most globally significant

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physical teleconnections are generally those that originate in the ocean or atmosphere (e.g., ENSO). However, teleconnections can occur between and across land, ocean, freshwater and atmosphere. Beyond the direct physical impacts, sometimes extensive and expensive environmental and societal impacts also ensue in their wake. For instance, an El Niño event can have a devastating impact on the Peruvian fisheries. In the western U.S., there is strong evidence that winter and spring snow cover extent over North America impacts monsoonal variables in the desert southwest, such as the total amount and frequency of precipitation, hail, wind and severe weather (Hawkins et al. 2002, see also Supplementary Material #1 for a more extensive discussion on societal impacts from physical teleconnections).

But teleconnections are in no way constrained to the physical world alone. The phrase "teleconnections" has been adopted by some social scientists to help convey the idea that vulnerabilities and climate change impacts do not just originate and unfold in one place but can also result from long-distance relationships (Adger, Eakin and Winkels 2009). The idea of "societal teleconnections" thus is analogous to that of physical teleconnections, but is focused on the human-created linkages via people, structures, institutions and processes.

For instance, floods in Thailand in 2011 (driven by the strongest monsoon in 50 years) killed more than 800 people locally, disrupted local agriculture, and forced some 10,000 computer supply and electronic car and camera part manufacturing factories to close and lay off 350,000 employees (Garside 2012). In addition to the economic impact locally, it also had rebounding impacts globally. Before the floods, one facility owned by Western Digital (a Silicon Valley-based corporation) produced 60% of the company's hard-drive production and 25% of the world's supply of "sliders," a prime component of hard-disk drives. Post-floods the cost of hard drives doubled (Acclimatise 2014). The event not only caused about $45 billion in damages to the Thai economy, and weakened the economic recovery throughout Asia, it also had far-reaching – and expensive – impacts on a leading economic sector in California, USA. This example is now widely cited by the private sector and has spurred several Fortune 500 firms to begin to assess supply chain vulnerability—one possible societal teleconnection—through the lens of climate change (Gledhill et al. 2013).

This example of an economic teleconnection illustrates how local climate vulnerabilities can and do originate in far-away places. This adds a layer of risk that is currently not fully appreciated in most climate change impacts assessments and on-the-ground adaptation planning. Yet being unprepared for these additional risks can cost millions of dollars and, sometimes, lives. In short, teleconnections point to a risky gap in both research, policy and planning.

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[3] Remarkably, however, the recognition of physical teleconnections is not at all new: the Southern Oscillation – the atmospheric component of ENSO – was first characterized by the British mathematician and meteorologist, Sir Gilbert Walker. In 1924 he wrote: "By the Southern Oscillation is implied the tendency of pressure at stations in the Pacific ... to increase, while pressure in the region of the Indian Ocean ... decreases." A few years later, Angstrom (1935) was the first to use the term ''teleconnections'' in reference to the north-south dipole atmospheric anomaly pattern now referred to as the North Atlantic Oscillation.

This paper proposes a systematic, but pragmatic and simple conceptual framework that helps researchers and practitioners identify how what happens afar can affect them. It then highlights and conceptually explores a range of societal teleconnections that have arisen out of societal interactions and the globalization of our world and which create, amplify, and sometimes attenuate climate change vulnerabilities and impacts in regions far from those where a climatic extreme or change occurs. Our goal is to encourage further research to better understand the causal chains behind socially teleconnected impacts, and to identify ways to routinely integrate their consideration in impacts research and adaptation planning. To achieve the latter, the inclusion of long-distance relationships in locally-focused assessments must remain a manageable task for adaptation practitioners in the private and public sectors who neither have easy access to nor the capacity for complex systems modeling, but whose assets are nonetheless at stake.

2 Societal Teleconnections

2.1 Societal Teleconnections: A Simple but Systematic Framework

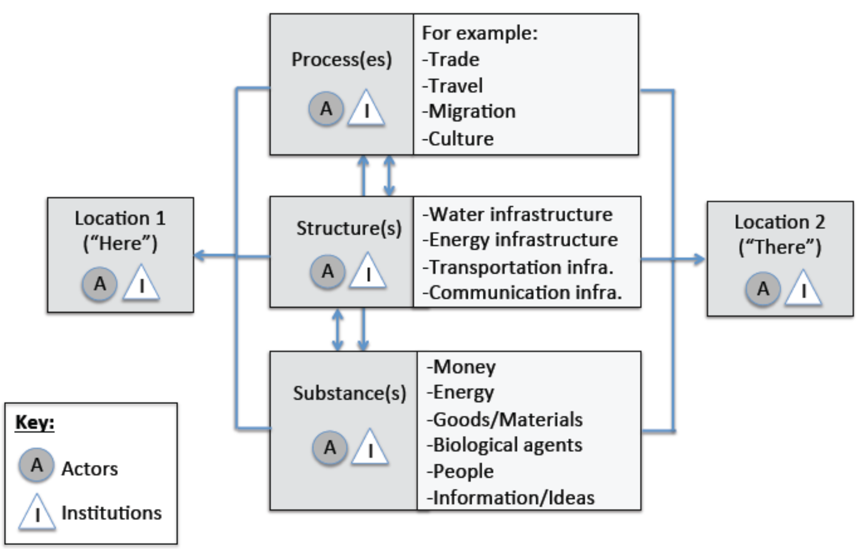
The notion of societal teleconnections applies the idea of long-distance interactions and connectivity to the social realm. While the basic idea of spatial interactions in the physical/natural environment or in societal activities is as old as the discipline of geography, and therefore has a rich theoretical and empirical basis in that field, the idea of societal teleconnections was first explicitly discussed by Adger, Eakin and Winkels (2009). Societal teleconnections link activities, trends, and disruptions across large distances, such that locations spatially separated from the locus of an event can experience a variety of impacts from it nevertheless. The concept of teleconnections broadens place-based discussions of climate change impacts to also include the dynamic, process-based implications of long-distance connections across the globe (Seto et al. 2012, Liu et al. 2013).

There is a broad body of literature on the impacts of globalization and related activities on social, economic, and coupled human-natural systems (e.g., Young et al. 2006, Leichenko and O’Brien 2008). To pick just one example, several studies have examined the impacts of deforestation – due primarily to global demands for increased cropland and local slash and burn agriculture – on communities located near the sites of deforestation (Aide and Grau 2004, Lambin and Meyfroidt 2010). Such studies clearly bring into focus the interconnectivity across space, but these connections have not been fully accounted for to date in climate impacts and vulnerability studies. Moreover, while globalization is one of the main *processes* creating and perpetuating societal teleconnections, it is by far not the only important way in which locations and events get connected across long distances.

Others have developed the related but broader notion of "tele-coupling" as an overarching conceptual framework to link complex, coupled human-environment systems across spatial distances (e.g., Liu et al. 2014; Eakin et al. 2014; Liu et al. 2013). While teleconnections as conceptualized here (and more commonly used in the climate change literature) focuses on the structural and functional connection itself, tele-coupling extends the integrative systems research (particularly in land use and land change science) that emerged over the past two decades on coupled natural-human systems to account for long-distances influences on the functioning of these systems. The influence of biofuels production, such as ethanol from corn, on land clearing and thus carbon emissions is a good example (e.g., Melillo et al. 2009; Youngs and Somerville 2014). Our framework resembles that of tele-coupling, but aims to keep it as simple as possible, yet as complex as necessary, to uncover distal vulnerabilities via a distinct focus on the connection itself.

Societal teleconnections require at minimum three basic components in order to occur. If one or more are missing, the teleconnection is interrupted (Figure 1):

- A natural system or human-built construct that forms the conveying or transmitting physical *structure* (metaphorically, one may think of this as the "hardware"). It does not itself move but stays in place as a teleconnection is made. The finite set of types of physical structures include water, energy, transportation and communication-related infrastructure[4] such as roads, ports, pipes, transmission lines, wires, or satellites.
- The *process* explains the reason, manner or cause for the teleconnection (the "software"). It establishes a functional exchange or relationship between distant entities. Examples of an almost infinitely large set of social processes include the market, travel or migration, human needs and desires, or social and cultural ties. This process is enacted by *actors*, who in turn are enabled and constrained in their actions by applicable *institutions*, i.e., the social norms, cultural customs, laws, rules and regulations that govern the interaction.
- A material *substance* or immaterial element that is moved from one location to another in the course of a teleconnection. It is the only part in a teleconnection that physically moves (the "data"). Again, the finite set of substance types include money, energy, goods or materials, biological agents, people, and information or ideas.



[4] In emergency management these four fundamental types of physical infrastructure are known as "life lines" and are familiar terms to emergency, land use, and adaptation/resilience planners.

Figure 1: Key Components of a Societal Teleconnection between Two Locations (explanation in text)

The combination of *structure*, *process* and *substance* result in connection and movement over long distances, often in complex ways and through combinations of mechanisms. Importantly, there is a finite number of physical structures and of types of substances, but a large number of types of processes, and with them come a wide variety of actors and institutions. The latter are involved in establishing, maintaining and sometimes disrupting the physical structure of a teleconnection. They also enact important services as agents of change and as guardians of the causal interconnectivity (and thus as producers, consumers or movers of the substance being conveyed). Actors are also crucial as those who can increase or decrease a community's vulnerability or resilience in the face of disruption originating elsewhere. This basic way of organizing and thinking of teleconnections helps explain how each component exerts its effects, and how climatic changes and climate-driven disruptions can impact communities and sectors across long distances. In essence, climate change and its impacts can:

- interrupt, modify, reroute or create structural connections;
- alter, establish, disrupt or eliminate (with the help of actors and/or changed institutional arrangements) the causal processes; and
- transport at lower or greater quantity, different quality, or speed certain substances or elements (both familiar, new or unknown).

The resulting wide range of long-distance relationships and interactions can either attenuate or amplify the impacts of far-away events on local circumstances (Pidgeon, Kasperson, and Slovic 2003; Renn 2011). Thus, societal teleconnections should not be understood as inherently good or bad (although the same teleconnection can lead to impacts perceived as positive at one scale, and as negative at another): how exactly they play out will depend on a number of factors, including some that have nothing to do with the teleconnection itself, but with the ability of local communities, sectors, and actors to deal with variable circumstances in their specific context (i.e., preparedness, robustness, and resilience). Of greatest importance, however, may be those far-away events that can exert economic, social, public health or political harm in local contexts.

2.2 Some Important Societal Teleconnections

Using the systematic conceptualization of teleconnections introduced above, we have delineated a few crucial teleconnections (Table 1). Several of these connections and how climate change impacts will "use" them to cause far-reaching impacts (i.e., the "long arm of climate change") are discussed below with their main causal relationships as well as key agents and institutions involved.

The sample of teleconnections listed in Table 1 is incomplete, several are interrelated and some can be nested within or may result in other teleconnections mentioned. We would argue nonetheless that the ones listed are teleconnections that fundamentally affect the resilience of local communities or even larger regions as many current examples of crises attest (weather-related disasters, the Ebola epidemic, social and military unrest in the Middle East). Below, we discuss some of these societal teleconnections through the lens of our conceptual framework and discuss what communities might consider to begin planning for these teleconnections.

[Table 1 is inserted at the end of this document]

Economic Teleconnections: Trade and Insurance

One of the most important long-distance relationships in society results from global economic relationships. A quick look at the labels in clothing or the stickers on food indicates the origin of what we consume locally. While perceived as necessities, these economic ties in a globalized economy make consumers, and intermediaries involved anywhere along the trade chain vulnerable to impacts occurring far from a product's origin. Teleconnections can derive from disruptions to the production process, supply chain, or critical transportation routes and communication channels. Impacts on the perceived desirability of sites or shifts in the labor market due to climate related impacts can ultimately increase production costs and consumer prices.

In the example of the 2011 Thai floods, examining the impacts to one sector specifically, e.g., hard drives sold by a company such as Western Digital, the *structure* that allowed this teleconnection to occur were the transportation routes and communication channels that established the manufacturing linkage between the Silicon Valley and Thailand. The *process* that drives the teleconnection is the desire for cheap labor and the globalization of manufacturing. The *substances* that should have been transported were hard drive components and subsequent financial transactions based on a completed work flow. The key *actors* directly involved include regulators in Thailand allowing the hard drive producing subsidiary to locate in the floodplain and those at Western Digital (and/or their intermediaries) deciding from where – and where alone – to purchase key equipment for their Silicon Valley firm. Land use plans and regulations, building standards, and disaster preparedness policies and measures are the *institutions* most directly affecting the Thai location, but the "law of supply and demand", shareholder agreements, the drive to ever larger profit margins, indirect economic drivers, and organizational policies and norms (or lack thereof) to downplay safety and disaster preparedness across the trade system in question also contributed to the ultimate impact.

The Thai Floods resulted in $15-20 billion in insurance claims (Garside 2012), thus bringing in yet another set of actors, and rippling through the insurance industry with its own set of institutional arrangements. The example highlights the interconnection of trade and economic interests with insurance interests, which is why we integrate them here.

Importantly, this example of supply chain teleconnections should not be confined to the private sector. Local governments also have their own supply chains, both for their normal operations (e.g., materials and equipment needed in water treatment, fire safety, local infrastructure maintenance) and even more so in the case of emergencies (e.g., food and water, heath services, building materials).

Energy Systems and Markets

Another subset of economic activity, singled out because of its importance in all societal and economic activities, is energy production, transmission and use. Pathways are both direct and indirect, and disruptions can have local, regional, national, and sometimes even international ripple effects. Energy production in one location can be disrupted by climate change impacts and thus directly (through immediate interruptions of supply through brown- or black-outs) or indirectly (through increased energy prices for energy purchased from elsewhere) affect consumers in faraway places. The spatial extent depends on the area served by the affected utilities and on supply redundancies in the system. Climate change impacts on supply may result from extreme heat (e.g., affecting nuclear power plant operations), inland or coastal flooding as sea level increases (power plant operations), or drought (availability of and competition among various users for scarce water resources for hydropower generation, nuclear power, fracking, etc.). Similarly, energy transmission can be disrupted by climate change-related extremes (wildfire, heat, storms, ice). Again, the spatial extent depends on the area served by the affected utilities and on supply redundancies in the system.

In September 2011, a transmission line tripped due to high heat in Yuma, Arizona, USA – notably a location already adapted to high heat – which led to a chain of approximately 20 additional events over an 11-minute period culminating in the shutdown of the San Onofre nuclear power plant in California. The power loss impacted Arizona, California and Mexico and resulted not only in long-distant impacts along the interconnected energy system, but also cascading impacts on other sectors, such as sewage spills and water distribution disruptions in the City of San Diego, USA, impacting more than seven million people (Wilbanks et al. 2012b).

Using our teleconnection conceptualization described above, the *structures* that initiated this teleconnected event are the transmission lines, transmitters and power stations that connect power generation and use, in this instance, across multiple states. The *processes* underlying the linkage involved the energy market, driven on one level by supply and demand, yet more directly by the decisions of energy producers and traders, and the energy policies and market regulations that affect utilities' decisions. The primary *substance* moved (or rather: no longer moved) was electricity, but as the event unfolded also sewage. As the cascade of events proceeded, different *actors* come to be involved, such as water treatment plant operators, emergency responders and, of course, the affected consumers and businesses.

With reduced redundancies in the supply system, due to higher electricity demands during heat waves, the most immediate impacts of such a disruption may be only regional or maybe statewide, but energy markets often go beyond state boundaries, thus potentially having far-reaching ripple effects through direct losses and increases in energy pricing (Sathaye et al. 2013). The role of cascading impacts due to interdependencies and a better understanding of the behavioral, ecological, and technological coupling and feedbacks were identified as critical gaps in knowledge in a recent report informing the Third U.S. National Climate Assessment (Wilbanks et al. 2012a). In the case of energy transmission and distribution, feedbacks and impacts will be exacerbated in urban environments due to the higher population and increased number of infrastructural interdependencies; what is necessary for efficiency in large urban centers may in turn contribute to a greater risk of cascading impacts (Wilbanks et al. 2012b).

Population Migration

Migration of people is among the more widely recognized societal teleconnections. Migration always has multiple reasons. People tend to not wish to migrate away from their ancestral or cultural home unless faced with complex and extreme conditions affecting their ability to maintain their security (O'Brien and Barnett 2013; Birkmann et al. 2013; Black, Adger and Arnell 2013). Climate change in this context has been conceptualized as a "threat multiplier" (CNA 2006) that may aggravate already challenging circumstances to the point where people will consider leaving home. Such aggravated threats may come from climate change impacts such as reduced water availability with negative impact on the ability to sustain minimal subsistence requirements or grow food for external markets; sea-level rise and related repeated coastal flooding, progressive coastal erosion, permanent inundation, and saltwater intrusion undermining public safety and the ability to maintain land, communities, economic activities or agriculture in place; or any number of other direct and indirect impacts of a climate-altered environment. Migration in the context of climate change is considered a transformative adaptation (Kates, Travis and Wilbanks 2011).

A 2009 report by the International Organization for Migration (IOM) noted the distinction between migrations due to sudden, extreme events versus slow-onset environmental impacts (Laczko and Aghazarm 2009). For instance, after Hurricanes Katrina and Rita, a large proportion of the city of New Orleans was evacuated and 200,000 homes were either destroyed or severely damaged, resulting in several hundred thousand city residents without a place to return to. By October 2006, ~65% of evacuees had returned to their pre-hurricane addresses and 73% had returned to the counties in which they lived prior to the hurricanes (Groen and Polivka 2008). In contrast to sudden events, migration from slow environmental degradation, which is expected to increase in the future, may have larger and longer lasting impacts and affects more people. Between 1978 and 2008, 78 million people were affected by storms compared to 1.6 billion people affected by gradual environmental changes (EM-DAT 2009).

The *structures* through which the teleconnection is established are the legal or illegal transportation routes, and the *substance* being moved are people, but the reasons for migrating, the causal *processes,* and thus the actors and institutions involved, can vary significantly. In the case of an extreme event, the causal *process* may be the need for temporary safety and shelter, involving evacuees, first responders, and those providing temporary refuge, while people migrating permanently away from an environmentally degraded home region may need relocation/housing assistance, help with finding new permanent work, assistance with socio-cultural integration and so on. Such help can take many forms, and can both help or hinder in maintaining community functioning and ecological integrity, which in turn increase local resilience in the face of other future stresses. For instance, Hecht and Saatchi (2007) describe how in El Salvadore, outmigration remittances allowed relatives who stayed behind to be able to buy food, rather than utilize slash and burn agricultural practices to grow their own food, thus contributing to forest resurgence instead of further deforestation. In both instances of short-term and permanent relocation, migration has immediate and lasting impacts on the affected regions as well as permanent demographic, economic, health, and socio-cultural impacts on the source and destination regions (McIntosh 2008; Hori and Bowman 2008).

Considering the teleconnection of people via migration in local adaptation planning requires that a local jurisdiction develop a better understanding of their community's demographics and socioeconomic conditions to assess who may be mobile, immobile and most at risk of being dislocated (e.g., Black et al. 2013) and their community's capacity to absorb temporary or permanent new residents. For instance, sea-level rise – in combination with other complex, non-environmental processes – is expected to cause outmigration over time from low-elevation island nations (e.g., Piguet 2012; Marino 2012; McLeman and Hunter 2010). Migrants may seek new homes in the U.S., Australia or New Zealand, where there are already established migration pathways, kin or cultural communities. For communities that already have sizable populations of former island residents residing there, it is reasonable to expect additional influx as sea level continues to rise (e.g., Perch-Nielsen et al. 2008). Anticipating this increase in immigration allows the jurisdiction to identify municipal and community needs and resources to adequately prepare. A slow-onset impact, such as sea-level rise, also illustrates that some teleconnections can play out in advance of the actual climate change impact manifesting, i.e., people may decide to abandon a location due to the anticipated impact prior to it actually becoming uninhabitable (Kiribati's "Migration with Dignity" plan, aimed at establishing expatriate communities off-island for i-Kiribati people to join on their own terms instead of waiting for a refuge problem later is one example [Wyett 2013]).

Human Health

Our final example focuses on health. Human health and well-being are the result of complex interactions of social, economic, occupational, lifestyle, psychological, cultural and genetic factors. This is a clear case of individual to global interconnectivity. McMichael (2013) discusses the correlation of climate change and globalization in human health. Among those discussed, climate change can have impacts on human health through the spread of disease vectors; further spread of vectors due to migratory displacement; impacts on fresh- and coastal water quality; impacts on air quality; impacts on food production (Luber et al. 2014).

The SARS epidemic of 2003 highlights how a virus originating in one corner of the world (in this instance, the Guangdong Province in China) can quickly spread globally (with cases reported in Canada), due to international trade and travel (Adger, Eakin and Winkels 2009). In this instance, the *structures* leading to the linkage were the existing ground and international air transportation infrastructure, and – importantly – the global communication infrastructure that carried both the threat and warnings ahead of the threat around the world. The causal *processes* driving the teleconnection were related to trade and travel and the *substance* transported was the SARS virus (and secondarily warnings and information about the health threat). The *actors* involved included those affected by the disease, health care providers and local, national and international health system observers (WHO and national centers for disease control) under the international and intra-national agreements and guides for public health emergency response.

The communication of these sorts of teleconnected, global pandemics is expected to increase with climate change. However, the enhanced flow of information also allows the world to respond quickly to potential outbreaks, epidemics and disasters and there is increased coordination in vaccination programs and systems to respond to infectious disease (McMichael 2013). Thus, human health provides an excellent example of how teleconnections connect the local to the global and can both attenuate and amplify different situations.

3 Identifying and Prioritizing Possible Research Questions

The types of teleconnections introduced above are easily exemplified, but have not yet been assessed systematically, neither globally nor nationally nor locally. While a range of studies have used the broader tele-coupling framework on questions of land use, ecosystem services, and sustainability more broadly (e.g., Challies et al. 2014; Liu et al. 2013; Güneralp et al. 2013; Seto et al. 2012), few studies have attempted to do so in the context of climate change (e.g., Perdinan and Winkler 2013; Adger, Eakin and Winkels 2009). These global connections have been largely neglected in U.S., and other national and global climate assessments to date. The importance of formally assessing such long-distance linkages, however, has been recognized in the Third U.S. National Climate Assessment (NCA) and in Working Group II of the IPCC’s Fifth Assessment (e.g., Oppenheimer et al. 2014; Correll et al. 2014; Wilbanks et al. 2012a) and is an important area for further improvement in future assessments. Below we highlight some key areas ripe for further investigation.

Quantification of Teleconnected Impacts

Quantifying the impacts of teleconnections is actually quite complex. The case of the 2011 Thai floods may be rare in that there was a fairly direct link between economic losses and companies whose manufacturing plants were flooded and ensuing cascading impacts. In many instances, however, societal teleconnections are more difficult to trace and/or are deeply interwoven, thus making analyses difficult. Quantification of these interconnections requires a systems modeling approach that can work at both the local and globally-integrated scale in order to catch the nuance of place-based repercussions of global linkages (Wilbanks et al. 2012b, Perdinan and Winkler 2013). Moreover, when dealing with impacts to trade, it can be difficult to get information since data typically are proprietary or considered trade secrets.

Attributing Impacts to Climate Change Versus Other Driving Forces

For many societal teleconnections, it will be difficult to point to a clear or singular cause and effect. For instance, the Arab Spring cannot be solely attributed to wheat shortages in China or Russia (Sternberg 2013, Werrell and Femia 2013). Similarly, it may never be possible to pin a violent conflict singularly on climate change impacts, yet multiple, complex teleconnections between the threat multiplier of climate change and national security, regional stability and violent conflict are of growing concern to the military (e.g., CNA 2006). In-depth studies of cases such as these can help sort out and better understand the significance of different societal teleconnections, informing the development of systematic assessment models.

Identification of Most Important Linkages

The linkages between and among different societal teleconnections are complex, but ubiquitous. It is therefore critical to identify "the most important" linkages for different types of climate change impacts. Some may dominate regardless of context whereas others may play out differently depending on context. Under what circumstances do which of these linkages matter the most? This may not be a simple question to answer in light of the various components of vulnerability: exposure, sensitivity and adaptive capacity all affect how severely a climatic change or extreme event manifests locally, and each of these components of vulnerability is affected differently by societal teleconnections (e.g., global economic forces, cultural teleconnections via education and knowledge flows co-determine local adaptive capacity; legal and governance structures shape capacities and barriers to adaptation). The answer to these questions, however, will be of critical value to adaptation planners in public offices as well as in private firms who may otherwise be overwhelmed by the universe of potential teleconnections.

Impact of Increased Urbanization

With an increasing number of people choosing, or having no choice but, to live in urban areas, the impacts of societal teleconnections have the potential to be compounded. As in the example of the San Onofre power plant shutdown in 2011, seven million people were impacted by that 11-minute series of events. Identification of urban interdependencies and redundancies, and how those could be impacted with increasing population, is critical for effective disaster preparedness and adaptation.

Impact on Resilience

How is local resilience enhanced or diminished through societal teleconnections and how can communities use this understanding in their efforts to prepare and plan for the long arm of climate change? In the 2011 Thai floods, for instance, production and sales for Silicon Valley companies (and elsewhere) were temporarily crippled because there was no redundancy in their supply chains. Building diversity into business operations may reduce economic efficiency in the short-term but buffer against major disruptions and economic losses over the medium to longer term. How can such diversification strategies be applied to local communities? How do legal, communication, social and cultural teleconnections simplify or complicate adaptation options?

4 Conclusion

In summary, societal teleconnections are important considerations for locally-based climate change vulnerability assessments and adaptation planning in the public and private sector. While not necessarily understood in technical terms ("teleconnections"), the high-profile flooding in Thailand has had a major awareness-raising impact on private firms, which now increasingly assess the impacts of climate change on their supply chains. By contrast, societal teleconnections are not yet included in local vulnerability assessments or adaptation planning, largely because they are not recognized or, if they are, they are considered too complex to assess or manage. Work to date on tele-coupling has highlighted the complex natural-human systems interactions, yet most communities do not have resources or capacity to conduct such computationally-demanding studies. We have therefore proposed a simple and pragmatic but systematic framework for better identifying, understanding, and thus planning for, societal teleconnections. In our examples, we also focused on teleconnections that are crucial to basic community functioning and thus relate most easily to land use planning and resource management, basic service provisions, and emergency preparedness, which is where most adaptation planning currently resides.

The research questions we have identified certainly do not exhaust the research agenda on societal teleconnections, but they delineate key elements of further examination that would significantly improve our understanding of local vulnerabilities to climate change in a deeply interconnected world. Answers to these types of research questions would also support a needed addition in focus to adaptation planning in urban, business or resource management contexts that expands the perspective from the local to the relevant global. Building our understanding of societal teleconnections, in this way, would help counteract some persistent but misleading slogans about vulnerability and adaptation: neither the context of vulnerability nor all adaptation is ever just local. It is glocal.

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References

Acclimatise (2014) Infographic: In 2011 Thailand was under water; but the ripples were felt across the world. Acclimatise http://www.acclimatise.uk.com/network/article/infographic-in-2011-thailand-was-under-water-but-the-ripples-were-felt-across-the-world Accessed March 6, 2014

Adger WN, Eakin H and Winkels A (2009) Nested and teleconnected vulnerabilities to environmental change. Frontiers in Ecology and the Environment 7: 150–157

Aide TM and Grau HR (2004) Globalization, migration, and Latin American ecosystems. Science 305: 1915–1916

Angstrom A (1935) Teleconnections of climatic changes in present time. Geogr. Annal. 17: 243–258

Birkmann J, Chang Seng D and Setiadi N (2013) Enhancing early warning in the light of migration and environmental shocks. Environmental Science & Policy 27(S1): S76–S88

Black R, Adger WN and Arnell NW (2013) Migration and extreme environmental events: New agendas for global change research. Environmental Science & Policy 27(S1): S1–S3

Challies E, Newig J, Lenschow A (2014) What role for social-ecological systems research in governing global teleconnections? Global Environmental Change 27: 32–40

CNA (2006) National Security and the Threat of Climate Change. The Center for Climate and Security. https://www.cna.org/reports/climate. Accessed March 31, 2014

Corell RW, Liverman D, Dow K, Ebi KL, Kunkel K, Mearns LO and Melillo J (2014) Ch. 29: Research Needs for Climate and Global Change Assessments. In: JM Melillo, TC Richmond and GW Yohe (Eds.), Climate Change Impacts in the United States: The Third National Climate Assessment (pp. 707–718), Washington, DC: U.S. Global Change Research Program

Eakin H, DeFries R, Kerr S, Lambin EF, Liu J, Marcotullio PJ, Messerli P, Reenberg A, Rueda X, Swaffield SR, Wicke B and Zimmerer K (2014) Significance of telecoupling for exploration of land-use change. In K. C. Seto & A. Reenberg (Eds.), Rethinking Global Land Use in an Urban Era (Vol. 39, pp. 141–161). Cambridge, MA: The MIT Press

EM-DAT (2009) International Emergencies Disaster Database. http://www.emdat.be/index/database. Accessed March 31, 2014

Garside J (2012, Feb. 14) Thailand flooding costs Lloyd's of London $2.2bn. The Guardian, p. 24. http://www.theguardian.com/business/2012/feb/14/lloyds-thailand-flooding-2bn-dollars. Accessed March 31, 2014

Gledhill R, Hamza-Goodacre D, Ping Low L (2013) Business-not-as-usual: Tackling the impacts of climate change on supply risk. Resilience: A Journal of Strategy and Risk. PWC. www.pwc.com/resilience. Accessed March 31, 2014

Groen JA and Polivka AE (2008) Hurricane Katrina evacuees: Who they are, where they are, and how they are faring. Monthly Labor Review 131(3): 32–51

Güneralp B, Seto KC, Ramachandran M (2013) Evidence of urban land teleconnections and impacts on hinterlands. Current Opinion in Environmental Sustainability 5(5): 445–451

Hawkins, TW, Ellis AW, Skindlov JA, Reigle D (2002) Intra-annual analysis of the North American snow cover-monsoon teleconnection: Seasonal Forecasting Utility. Journal of Climate 15: 1743–1753

Hecht SB and Saatchi SS (2007) Globalization and forest resurgence: Changes in forest cover in El Salvador. BioScience 57(8): 663–671

Hori M and Bowman D (2008) Displacement Dynamics in Southern Louisiana After Hurricanes Katrina and Rita. Paper presented at 2008 Population Association of America Annual Meeting, New Orleans, LA, April 17-19, 2008

Kates RW, Travis WR and Wilbanks TJ (2011) Transformational adaptation when incremental adaptations to climate change are insufficient. PNAS 109: 7156–7161

Laczko F and Aghazarm C (2009) Migration, Environment and Climate Change: Assessing the Evidence. International Organization for Migration (IOM). ISBN 978-92-9068-454-1

Lambin EF and Meyfroidt P (2011) Global land use change, economic globalization, and the looming land scarcity. PNAS 108: 3465–3472

Leichenko, Robin, and Karen O'Brien (2008) Environmental Change and Globalization: Double Exposures. Oxford University Press

Liu J, Hull V, Batistella M, DeFries R, Dietz T, Fu F, Hertel TW, Izaurralde RC, Lambin EF, Li S, Martinelli LA, McConnell WJ, Moran EF, Naylor R, Ouyang Z, Polenske KR, Reenberg A, de Miranda Rocha G, Simmons CS, Verburg PH, Vitousek PM, Zhang F, and Zhu C (2013) Framing sustainability in a telecoupled world. Ecology and Society 18(2): 26. http://dx.doi.org/10.5751/ES-05873-180226

Liu J, Hull V, Moran E, Nagendra H, Swaffield SR, II, B. L. T. (2014) Applications of the telecoupling framework to land-change science. In K. C. Seto & A. Reenberg (Eds.), Rethinking Global Land Use in an Urban Era (pp. 119–139). Cambridge, MA: The MIT Press

Luber G, Knowlton K, Balbus J, Frumkin H, Hayden M, Hess J, McGeehin M, Sheats N, Backer L, Beard CB, Ebi KL, Maibach E, Ostfeld RS, Wiedinmyer C, Zielinski-Gutiérrez E, and Ziska L (2014) Ch. 9: Human Health. Melillo JM, Richmond TC, and Yohe GW (Eds.), Climate Change Impacts in the United States: The Third National Climate Assessment (pp. 220–256). Washington, DC: U.S. Global Change Research Program

Marino E (2012) The long history of environmental migration: Assessing vulnerability construction and obstacles to successful relocation in Shishmaref, Alaska. Global Environmental Change 22(2): 374–381

McIntosh MF (2008) Measuring the labor market impacts of Hurricane Katrina migration: Evidence from Houston, Texas. Papers and Proceedings of the One Hundred Twentieth Annual Meeting of the American Economic Association, The American Economic Review 98(2): 54–57

McLeman RA and Hunter LM (2010) Migration in the context of vulnerability and adaptation to climate change: insights from analogues. WIREs Climate Change 1: 450–461

McMichael AJ (2013) Globalization, climate change, and human health. New England Journal of Medicine 368(14): 1335–1343

Melillo JM, Reilly JM, Kicklighter DW, Gurgel AC, Cronin TW, Paltsev S, et al. (2009). Indirect Emissions from Biofuels: How Important? Science 326: 1397–1399

O'Brien K and Barnett J (2013) Global environmental change and human security. Annual Review of Environment and Resources 38: 373–391

Oppenheimer M, Campos M, Warren R, Birkmann J, Luber G, O'Neill B, Takahashi K (2014) Emergent Risks and Key Vulnerabilities. In: M Brklacich and S Semenov (Eds.), Climate Change 2014: Impacts, Adaptation, Vulnerability, Contribution of Working Group II to the Fifth Assessment Report of the IPCC (pp. 1039-1099), New York: Cambridge University Press

Perch-Nielsen LS, Bättig BM and Imboden D (2008) Exploring the link between climate change and migration. Climatic Change 91: 375–393

Perdinan K and Winkler JA (2013) Changing human landscapes under a changing climate: Considerations for climate assessments. Environmental Management 53(1): 42–54

Pidgeon N, Kasperson RE and Slovic P (2003) The Social Amplification of Risk. Cambridge, UK: Cambridge University Press

Piguet E (2012) Migration: The drivers of human migration. Nature Climate Change 2(6): 400–401

Renn O (2011) The social amplification/attenuation of risk framework: Application to climate change. WIREs Climate Change 2: 154–169

Sathaye J, Dale L, Larsen P, Fitts G, Lewis S, Koy K and Lucena A (2013) Assessing the risk to California energy infrastructure from projected climate change. IEEE Power & Energy Magazine 11(3): 32–45

Seto KC, Reenberg A, Boone CG, Fragkias M, Haase D, Langanke T, Marcotullio P, Munroe DK, Olahand B and Simon D (2012) Urban land teleconnections and sustainability. PNAS 109: 7687–7692

Sternberg T (2013) Chinese drought, wheat and the Egyptian uprising: How a localized hazard became globalized. In: CE Werrell and F Femia (Eds.), The Arab Spring and Climate Change. A Climate and Security Correlations Series. Center for American

Progress. http://climateandsecurity.files.wordpress.com/2012/04/climatechangearabspring-ccs-cap-stimson.pdf. Accessed March 31, 2014

Werrell CW and Femia F (2013) The Arab Spring and Climate Change: A Climate and Security Correlations Series. Center for American Progress. http://www.americanprogress.org/issues/security/report/2013/02/28/54579/the-arab-spring-and-climate-change/. Accessed March 31, 2014

Wyett K (2013) Escaping a rising tide: Sea level rise and migration in Kiribati. Asia & the Pacific Policy Studies 1(1): 171–185.

Wilbanks T, Bilello D, Schmalzer D, and Scott M (2012a) Climate Change and Energy Supply Use. Technical Report by the U.S. Department of Energy in Support of the Third National Climate Assessment, Oak Ridge National Laboratory, Oak Ridge, TN

Wilbanks T, Fernandez S, Backus G, Garcia P, Jonietz K, Kirshen P, Savonis M, Solecki B and Toole L (2012b) Climate Change and Infrastructure, Urban Systems, and Vulnerabilities. Technical Report to the U.S. Department of Energy in Support of the Third National Climate Assessment, Oak Ridge National Laboratory, Oak Ridge, TN

Young OR, Berkhout F, Gallopin GC, Janssen MA, Ostrom E, van der Leeuw S (2006) The globalization of socio-ecological systems: An agenda for scientific research. Global Environmental Change 16: 304–316

Youngs H and Somerville C (2014) Best practices for biofuels. Science 344: 1095–1096

Table 1. List of eight crucial teleconnections, their structures, and causal processes (including the involved actors and institutions) that convey an element or substance.

Teleconnection	Structure/Conveyor	Cause/Process	Element/Substance
Trade and economic exchange	Transportation routes, communication channels	Market exchange, business activity, globalization	Goods, services, raw materials
Insurance & Reinsurance	Insurance Policy	Legal requirements, risk tolerance	Money
Energy Systems	Transmission lines connecting power generation (power plants) and consumption	Supply & demand markets	Electricity, oil, natural gas, etc.
Human Health	Air transportation, trains, roads, ocean- or river-based ship transportation	Trade, human travel (for business or tourism)	Disease carriers (vectors)
Population migration	Legal or illegal migration routes (by land, sea, air)	Seasonal migration, permanent, resettlement, urbanization, conflict etc.	People
Communication systems	Satellite-based, underground, or underwater transmission lines, routers, computers	Exchange via mainstream or social media	(Digital) information, data, knowledge, imagery
Legal obligations	Nations, states, business entities, tribes, etc.	Treaties, laws, regulations, statutory rights	Regulated exchange of goods, raw materials, services, money, information
Strategic & military interests	Nations, ethnic entities, tribes (via communication, population, economic, and transportation routes)	Political, ethnic or religious relationships, tensions or conflicts	People, military personnel, money, military logistical equipment
Cultural ties	Nations, ethnic groups, subgroups (via communication, population, economic, and transportation routes)	Deeply rooted, evolved, inherited or adopted practices, maintenance of identity, sense of belonging	Ideas, habits, ideals, rites, customs, and activities

The Long Arm of Climate Change: Societal Teleconnections and the Future of Climate Change Impacts Studies: Supplementary Material

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Background

To provide more context to the concept of *societal* teleconnections, we offer a brief overview on the more commonly understood, discussed and studied physical teleconnections and their corresponding societal impacts. In the atmospheric sciences, a teleconnection is defined as "a linkage between weather changes occurring in widely separated regions of the globe…the name refers to the fact that such correlations suggest that information is propagating between the distant points through the atmosphere." Jet streams and oceanic currents act as "bridges" and "tunnels," respectively, that carry changes in atmospheric, oceanic, or land patterns along the length of the teleconnection, leading to impacts thousands of miles away (Alexander et al. 2002, Liu and Alexander 2007).

The most globally significant physical teleconnections are generally those that originate in the ocean or atmosphere (e.g., ENSO). Beyond the direct physical impacts, sometimes extensive and expensive environmental and societal impacts can ensue in their wake. The negative impacts of El Niño events on the Peruvian fisheries and on coastal regions of the U.S. West Coast illustrate the point: During an El Niño-event, the southwest of the U.S. experiences cooler and wetter winters, higher sea levels along the West coast, and – as a result of both – typically witnesses severe coastal storms and flooding. El Niño events in the winters of 1982-1983 and 1997 were particularly damaging for Southern California, during which major infrastructure and coastal communities were badly damaged from flooding, increased storm surge, and major coastal erosion (Lajoie and Mathieson 1997; Griggs 1994). Compounding these negative impacts, the increased precipitation across the Southwest during such years can lead to high plant growth and accumulation of fuel that makes forests more vulnerable to fire during subsequent La Niña events (Kitzberger et al. 2001). Moreover, a number of recent studies in Southern California have examined the theoretical connection between El Niño events and the spread of West Nile Virus due to the potentially expanded habitat of the mosquito that carries the disease (Heft and Walton 2008, Cheng2009). Thus, an El-Niño event can have broad implications for local economies, infrastructure extreme events and related disaster management, and for human health.

Beyond oceanic teleconnections, freshwater/atmospheric teleconnections also occur. For instance, it was found that due to hydroclimatological teleconnections, North American river flows in September correlate significantly with Northern European river flows in October (Kingston et al. 2006). In the western U.S., there is strong evidence that winter and spring snow cover extent over North America affects monsoonal variables in the dessert Southwest of the U.S., such as the total amount and frequency of precipitation, hail, wind and severe weather (Hawkins et al. 2002).

Land Use and Environmental Teleconnections

Teleconnections can occur across smaller regions and between the atmosphere and land and, in some instances, land cover changes can alter atmospheric circulation. Several studies have shown a correlation between deforestation in the tropics and precipitation in mid- and high-latitudes winters (Gedney and Valdes 2000; Roni and Werth 2005). This occurs due to reductions in large-scale circulation, which impacts the transfer of moisture throughout the atmosphere. Similarly, irrigated farmlands in the U.S. plains were found to impact the weather for the high Rocky Mountains due to changes in relative humidity in the atmosphere (Chase et al. 1999) and to increase summer precipitation (Moore and Rojstaczer 2002). Similar changes have been observed at the scale of micro-climates (e.g., urban land use changes affecting temperature and wind fields).

Beyond climatic teleconnections, the natural environment features many other long-distance connections. Dispersal of dust, volcanic ash and other particles on the wind, flows of surface or ground water (and associated material flows), and species migration and dispersal are the most important other teleconnection mechanisms (e.g. Bauer and Hoye 2014). For example, rivers transport sediments and nutrients from the source to the end point (generally the sea). While this is a natural process, overloading of nutrients along the flow can lead to detrimental environmental impacts at the river terminus or along the way. For the U.S., the most well-known example of this is agricultural run-off along the Mississippi River, which discharges into the Gulf of Mexico and is a key contributor to the biological dead zone (Turner et al. 2008). Runoff of nutrients and pollutants from streams and rivers into enclosed bays or estuaries is of particular concern (Moser, Williams and Boesch 2012). As another example, in the animal kingdom, animal migrations have exceedingly complex cascading trophic, energetic, and ecological impacts that can even range to global in scale (Bauer and Hove 2014). For instance, many species of old-world songbirds, which breed in northern Europe and then return to sub-Saharan Africa, harbor parasites from both their breeding and wintering ranges and thus potentially transmit these parasites from one to the other locale (Bauer and Hove 2014). The Northern fulmar breeds along the Arctic coastlines and migrates to more southerly regions outside of breeding season; the fulmars accordingly fertilize nutrient-poor terrestrial systems in the Arctic with nutrient-rich excrement derived from their southern habitats.

Relevance to Management

Physical teleconnections, whether global in scale such as ENSO or more localized such as snow cover extent in the U.S. Rocky Mountains, have direct environmental and societal impacts. Understanding this relationship has already lead to better forecasting, which, in turn, supports better preparation for and management of these impacts. NOAA’s Climate Prediction Center routinely monitors several atmospheric/oceanic teleconnections to predict climate and weather patterns for the U.S. and North America. Better understanding the link between snow cover extent and monsoon season, for example, could allow for seasonal forecasting of start and duration of monsoon seasons, allowing managers in the southwestern U.S. to better plan for either intense and damaging flash flooding or drought conditions.

References

Alexander MA, Bladé I, NewmanM, Lanzante JR, Lau N-C and Scott JD (2002) The atmospheric bridge: The influence of ENSO teleconnections on air–sea interaction over the global oceans. Journal of Climate 15(16): 2205–2231

Avissar R and Werth D (2005). Global Hydroclimatological Teleconnections Resulting from Tropical Deforestation. J. Hydrometeorol. 01/2005; 6(2) DOI:10.1175/JHM406.1

Bauer, S. and B.J. Hoye (2014) Migratory animals couple biodiversity and ecosystem functioning worldwide. Science 344 (April 4): 54, doi: 10.1126/science.1242552

Cheng TJ (2009) Effect of the El Niño-Southern Oscillation (ENSO) on Mosquito Vectors of the West Nile Virus in San Diego, CA. San Diego State University Press, 90pp

Griggs GB (1994) California's coastal hazards. Journal of Coastal Research SI(12): 1–15

Gedney N and Valdes PJ (2000) The effect of Amazonian deforestation on the northern hemisphere circulation and climate. Geophys. Res. Lett. 27:3053-3056

Hawkins TW, Ellis AW, Skindlov JA, Reigle D (2002) Intra-annual analysis of the North American snow cover –monsoon teleconnection: seasonal forecasting utility. Journal of Climate 15: 1743 – 1753

Heft DE and Walton WE (2008) Effects of the El Niño-Southern Oscillation (ENSO) cycle on mosquito populations in Southern California. Journal of Vector Ecology 33: 17–29

Kingston DG, Lawler DM, McGregor GR (2006) Linkages between atmospheric circulation, climate and streamflow in the northern North Atlantic: Research prospects. Prog. Phys. Geogr. 30:143-174

Kitzberger T, Swetnam TW and Veblen TT (2001) Inter-hemispheric synchrony of forest fires and the El Niño-Southern Oscillation. Global Ecology & Biogeography 10: 315–326

Lajoie KR and Mathieson SA (1997) 1982-83 El Niño coastal erosion: San Mateo County, California. USGS Circular. USGS. Retrieved March 31, 2014 from http://walrus.wr.usgs.gov/elnino/SMCO-coast-erosion/introtext.html

Liu A and Alexander M (2007) Atmospheric bridge, oceanic tunnel and global climatic teleconnections. Rev. Geophys. 45, RG2005, doi:10.1029/2005RG000172

McMichael AJ and Lindgren E (2011) Climate change: Present and future risks to health, and necessary responses. Journal of Internal Medicine 270: 401–413

Moore N and Rojstaczer S (2002) Irrigation's influence on precipitation: Texas High Plains, U.S.A., Geophysical Research Letters 29: 1755–1780

Moser SC, Williams J.S. and Boesch D (2012) “Wicked” challenges at land’s end: Managing coastal vulnerability under climate change. Annual Review of Environment and Resources 37: 51–78

Sathaye J, Dale L, Larsen P, Fitts G, Lewis S, Koy K and Lucena A (2013) Assessing the risk to California energy infrastructure from projected climate change. IEEE Power & Energy Magazine 11(3): 32–45

Turner RE, Rabalais NN, and Justic D (2008) Gulf of Mexico hypoxia: Alternate states and a legacy. Environmental Science & Technology 42(7): 2323–2327

Supplementary Literature

In the course of our research, we found interesting and relevant articles that we were not able to include in the published text. We include them here for those interested in further reading.

Kasperson RE, Renn O, Slovic P, Brown H, Emel J, Goble R, Kasperson JX and Ratick S (1988) The social amplification of risk: A conceptual framework. Risk Analysis 8: 177–187

Kunkel ML and Flores AN (2011) Non-Stationarity in Atmospheric and Oceanic Teleconnections: Historical Affects on Streamflow and Statistical Models for Forecasting Streamflows. Paper presented at the American Geophysical Union, Fall Meeting 2011, abstract #H42H-02

Leggett J (1994) The emerging response of the insurance industry to the threat of climate change. UNEP Industry and Environment 17: 41–45

Moser SC (2008) Resilience in the Face of Global Environmental Change. CARRI Research Report. Oak Ridge, TN: Community and Regional Resilience Institute

O’Brien K, Sygna L, Leichenko R, Adger WN, Barnett J, Mitchell T, Schipper L, Tanner T, Vogel C and Mortreux C (2008) Disaster Risk Reduction, Climate Change Adaptation and Human Security. A Commissioned Report for the Norwegian Ministry of Foreign Affairs.. Oslo, Norway: University of Oslo

Walker B and Salt D (2006) Resilience Thinking: Sustaining Ecosystems and People in a Changing World. Washington, DC: Island Press