Adapting to Variability Before Change

An analysis of preexisting adaptation strategies for climate variability through a socio-ecological resilience framework: The Case of the Republic of the Marshall Islands

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Abstract:

Instead of identifying climate change adaptation strategies that will best fortify against projected impacts, this paper suggests that adapting to climate variability can be used as a strategy to deal with the threat of climate change. Adjustment to climate variability is a longstanding practice for the human species. For as long as the low-lying islands of the Pacific have been inhabited, communities have been exposed to regularly fluctuating sea levels of up to 0.5 meters, patterns which are greatly influenced by the El Niño Southern Oscillation. If anthropogenic climate change acts in addition to natural climate variability, the resultant extremes could be devastating, and the combination threatens to make these islands uninhabitable. With the mounting discourse on adaptation to climate change, a socio-ecological resilience framework can assist stakeholders in deciding which adaptation strategies to choose. As a case study, this paper surveys several adaptation strategies used by the Republic of the Marshall Islands to adapt to natural climate variability. Using a socio-ecological resilience framework, this paper selects certain strategies that can foster adaptation to a variable climate system. It posits that conceptualizing the climate system as intrinsically chaotic rather than equilibrating can reduce the potential for maladaptative fortification projects.

Introduction:

When trying to “adapt” to climate change, it is easy to get swept up in the complexity of accurately assessing or predicting said change. The dominant paradigm advocates using all potential methods to identify climate change impacts with as much certainty as possible, and then identify adaptation strategies that protect against or respond to these impacts. However, it is important to recognize that natural climate variability has historically played, and will continue to play, a large role in the hazards that will require adaption strategies. Even the term ‘climate change’ for many may imply some detectable abrupt shift, when this is not necessarily the case. However, by recognizing that certain communities will be dealing with increased hazards, weather events and overall climate variability, adaptation to a variable climate could be more effective than adaptation strategies that fortify against projected change. Trying to protect against anticipated changes could encourage a system reliant on prevention projects; variability or inaccuracy in those predictions can cause those adaptation strategies to backfire. The increased attention adaptation has received and the resulting flood of ideas reaching the public can make it difficult for stakeholders to discern which strategies are best conducive to their short-term and long-term security. As a method for stakeholders to make decisions, we suggest that conceiving of the environment as continually in flux and inherently dynamic rather than static and equilibrating will point towards these preferred options; this type of thinking is encouraged in a socio-ecological resilience framework.

The socio-ecological resilience framework used in this paper is one that considers the complex interrelationship between social and ecological systems as the fundamental unit of analysis. Under such a framework ecosystems and human systems inform each other's states. Resilience is the relationship of this coupled system with change, and so the framework accounts for the ability of the system to "cope with, adapt to, and shape change" (Folke 2006). The measure of resilience is to what degree the system can absorb changes while producing outcomes that are considered positive for the system, which is a framework for decision making rather than a measure of ability. What characterizes a socio-ecological resilience framework is that the default state of both the social and the ecological systems are dynamic rather than in equilibrium or static optimality (Nelson, Adger, and Brown 2007; Barnett 2001).

The value of this definition is that it recognizes that uncertainty is inherent in the climate change projections, and allows decision-makers to move away from the idea of impacts towards holistic system representation (Barnett 2001). This means identifying the patterns, practices or projects in an area (a neighborhood, a city, a country) that are inflexible, inapplicable, or depleting the natural system, and reconstructing them to be flexible, adaptive and system-strengthening. In the context of climate variability in the Republic of the Marshall Islands, this can mean rainwater harvesting, food and water storage, hazard preparedness training, ecosystem conservation, development away from hazard-prone areas, and networking. To illustrate this method, the paper will address some of the ways the Republic of the Marshall Islands have adapted to climate variability through a socio-ecological resilience framework, illuminating adaptation strategies appropriate to a system that is constantly changing versus fortification strategies against change. The following analysis is intended as an example of this method, which the reader can then apply to another location, yielding adaptive and contextualized strategies.

Variability in the Asia-Pacific Region

Changes in variability in the Asia-Pacific region are likely to have the largest future implications for human sustainability (Reenberg 2008; Barnett and Adger 2003). Coelho and Goddard (2009) have shown that the combination of climate change and El Niño Southern Oscillation (ENSO) variability in the tropical Pacific has the potential to cause an increase in extreme weather events. In other words, even if the magnitude of natural variability such as ENSO doesn't change, the perturbation of the climatic mean from anthropogenic forcing will increase the risk of climate hazards such as drought or heavy rainfall (Goddard and Coelho 2009).

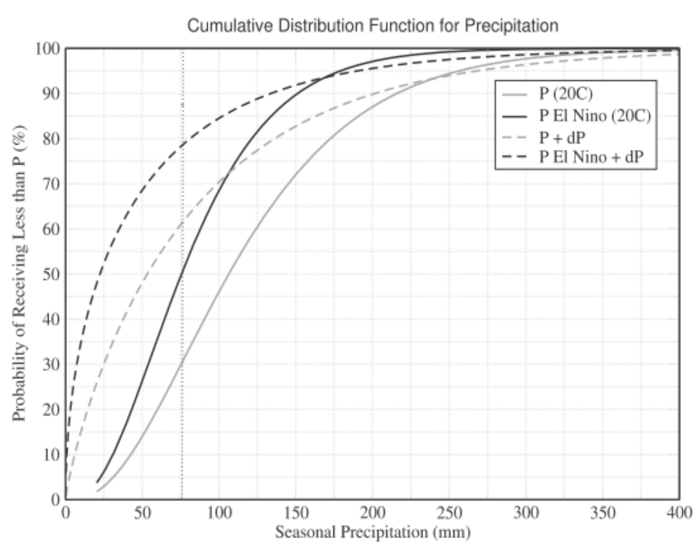

Figure 1: Cumulative distribution functions for precipitation showing the probability (%) of receiving less than a given amount of precipitation (mm) based on fitting a gamma distribution to observed values at a single grid point. The CDFs for twentieth-century precipitation (solid lines) are drawn both for all years (gray: DJF 1959–2001) and El Niño conditions during that period. Similar curves are presented for the twenty-first-century precipitation by adding the CMIP3 multimodel mean precipitation changes at that location to the observed twentieth-century time series and reestimating the parameters. Source: Goddard and Coelho 2009.

Sea level in the Northwest equatorial Pacific drops during El Niño events and rises during La Niña events, on a 3-5 year cycle (Chowdhury, Chu, and Schroeder 2007). In the case of the Republic of the Marshall Islands, this shift in sea level can cause flooding of low-lying areas, such as low-lying islands and atolls, during La Niña events and can statistically contribute to drought and typhoons during El Niño events (Spennemann and Marschner 1994; Birdwell and Daniels 1991; Barnett and Adger 2003) Natural climate variability, extreme weather events, and unpredictable changes are nothing new to Pacific Island cultures (Bridges and McClatchey 2009; Reenberg 2008). The Marshallese have adopted many adaptation strategies, some of which will be explored here. While much adaptation literature has addressed the idea of sea level rise and drowning island states within the context of climate change, we posit that it is more important to focus on climate variability on top of the change rather than isolating the impacts of climate change alone.

Case Study: The Republic of the Marshall Islands

In a study of impacts of sea level rise on small island states, Pernetta (1992) ranked the Republic of the Marshall Islands (RMI) as one of the "first priority" countries in terms of the profundity of the impacts that are expected: many people expect that these islands may soon cease to exist "in the event of worst-case scenarios" (Pernetta 1992). Other dire predictions forecast increases in extreme weather events, such as cyclone activity, intensity, flooding, drought, coral bleaching, changes in fish migration, and contaminated fresh water supply, to name a few (Barnett and Adger 2003; Spennemann and Marschner 1994; Presley 2005; Reenberg 2008; Pernetta 1992; Barnett 2001).

The fact that the Marshallese are islanders contributes to the salience of this analysis. A whole discipline, nissology, has emerged around the study of islands, and it explains how a socio-ecological system with short feedback loops is sensitive to the interactions between water and land on shorter time scales (Baldacchino 2004; Bridges and McClatchey 2009; Berkes 1999). In comparison, the interactions and impacts between land use change and desertification, for example, may not be readily observable. Low-lying islands can also serve as advanced warning for the rest of the world as these communities will likely face changes and challenges earlier than other socio-ecological systems, portending possible changes for other systems to come: "There is no better comparison for an island than another island. There may also be no better comparison for a mainland than an island, since the process and dynamics that occur habitually on a mainland may be enhanced and exacerbated in an island setting" (Baldacchino 2004).

It is true that very few people can identify with atoll living. However, these areas are historically accustomed to variable climate and limited resources, and they have proven resilient to many variables (Barnett and Adger 2003; Adger et al. 2005). In light of current projections of climate change, places like the United States will also see a shift in geography, resource availability and centers of production (Barnett and O'Neill 2010). Like in the RMI, even the most "developed" of countries will need to adapt to variable climate and its associated impacts.

Adaptation vs. Maladaptation

Without aiming to redefine any of these, it is valuable to clarify the use of certain terms, such as *climate change adaptation*, within this paper. Here we engage a broad definition of adaptation as activities taken to reduce actual or expected climate-related impacts that are perceived to be negative, or to exploit positive impacts (*Glossary of Climate Change Acronyms*). *Maladaptation* here refers to actions that imbue safety, or at least a sense of stability, in the short term, but might actually increase vulnerability and fail to enhance adaptive capacity in the long term (Barnett and O'Neill 2010).

Adaptive Co-Management

As has been discussed, Pacific Island communities like the RMI have built up resilience to environmental variability through historical adaptation strategies that are derived over time from local human-environment interaction and ecological knowledge (Bridges and McClatchey 2009). Many scholars interested in adaptation have raised the importance of adaptive management (Tompkins 2004; Plummer and Armitage 2007; Folke et al. 2007; Agrawal 2008; Tompkins 2005). Adaptive management is an iterative, reflexive process wherein decision-making is done under uncertainty, in a "learning-by-doing" fashion (Tompkins 2005). In this way, a social system, and the attendant organizations and institutions, learns to operate with uncertainty and change rather than in protection against a specific outcome. This approach "treats policies as hypotheses and management as experiments from which managers can learn" (Folke et al. 2007). This style of management can be further defined as adaptive co-management, wherein the responsibility and decision-making for allocating resources are discussed and determined amongst many parties rather than one organization or one stakeholder (Plummer and Armitage 2007). Within a socio-ecological resilience framework, this type of decentralized decision making allows for participation on many scales, encouraging projects that are multisectoral. Counter to an assumption that the world is knowable or predictable, an adaptive co-management style leaves room for organizations and institutions to understand and evaluate their adaptation decisions concomitant to, rather than in resistance to, the inherent uncertainty of climate variability and climate change impacts.

Climate variability forecasting is complex, uncertain, and continuously changing. An organization given the task of meeting certain goals based on such information will be more successful in meeting those goals if its dimensions, structure and members can also learn, adapt and improve (Tompkins 2005). In places like the RMI, where adaptation to natural variability is a present and prescient process, we can see adaptive co-management strategies emerging. One such example is the *Reimaanlok Plan* established in 2008 (Reimaanlok: National Conservation Area Plan for the Marshall Islands 2007-2012 2008).

The *Reimaanlok Plan* utilized localized ecosystem assessments to identify areas of conservation and resource management in light of socio-economic needs (Baker et al. 2010). This plan engages multiple parties at the local, the national and the international scales to participate in conserving the natural resources and biodiversity on the RMI. This can reduce duplicating efforts by local and international agencies, which is important for places like the RMI that have limited human resources (Baker et al. 2010). Localized preservation and rehabilitation of reefs and local ecosystems is part of the RMI's portion of an international commitment they made when signing the "Micronesia Challenge" – to "effectively conserve 30% of nearshore marine and 20% of terrestrial resources by 2020" (Baker et al. 2010). The plan integrates very specific local needs within a broader context of climate variability and climate change, allowing for the identification of the most immediately vulnerable areas in light of broader goals to enhance socio-ecological resilience. Incorporating community leadership serves as an exemplar for other organizations and projects in the area because it encourages a learning system wherein the goals of the organization(s) are met through participation at all levels. Through co-management practices, more people are engaged, and thereby empowered, allowing for an iterative process of participation and compliance.

An equally important part of the adaptive co-management process is figuring out how to incorporate local knowledge into a database of scientific information. In the context of adaptive co-management, this is crucial in validating local environmental and social knowledge, which can work to strengthen the ties between local and national or international organizations (Baker et al. 2010). In the same way, effectively communicating scientific information about climate impacts within social networks and organizations themselves can add breadth and depth to local knowledge. The Marshall Islanders, for example, held the common belief that their southern atolls were relatively “safe” from typhoons due to their geographic location and the event of a typhoon in those particular locations were “freak” events (Spennemann 1996). However, through analysis of the association between ENSO and typhoon events, typhoons have been shown to move further to the East during El Niño events (Spennemann 1998; Birdwell and Daniels 1991). In order to address similar knowledge gaps the Reimaanlok team created survey processes to collect, documents, and collate local knowledge with scientific data, “effectively augmenting the relatively sparse scientific data for the area” (Baker et al. 2010). These examples are not to demonstrate that one form of knowledge trumps another, but that they can inform one another on locally specific ways of effectively communicating, and thereby strengthening, climate knowledge. This exemplifies how an adaptive co-management style will honor a variety of approaches to information gathering.

A plan like the Reimaanlok plan addresses climate impacts at the local level, while simultaneously tying their objectives to the broader international goals set forth by the Micronesia Challenge. This model can be extrapolated to the international level given that enhancing local socio-ecological resilience can, in theory, enhance the resilience of globally allocated natural resources. However, as time progresses, nations like the United States who are accustomed to a perceived sense of unlimited resources may need guidance from places like the RMI on how to effectively manage localized resource variability and change.

Human Settlement

Due to its ability to incorporate a dynamic socio-ecological system, the resilience framework is also informative for human settlement patterns and how settlement decisions can be included under “climate change adaptation”. The socio-ecological resilience framework treats the world as continually in flux, and if climate change will create a world that is even more variable than that of today, human settlement patterns can be “adapted” in order to accommodate this variability. In the RMI, variable sea level is attendant with variable tides and ENSO related typhoons (Raymond 1990; Spennemann and Marschner 1994). Instead of encouraging fortified communities that attempt to resist change, the socio-ecological resilience framework can be used to identify the counter-discourse, which in the context of settlement patterns in low-lying areas, means encouraging concomitant objectives, such as facility of movement, conservation of vulnerable ecosystems, and development outside of hazard-prone areas.

There is a body of literature that documents periodic relocation within or between islands as a historical norm for islanders. Christensen and Mertz (2010) state that “migration and human mobility is unambiguously associated with island livelihoods, and is a vital part in making the

Pacific and contouring the island seascapes constantly under change" (Christensen and Mertz 2010). It is valuable to note that these migration patterns were not always preferable, nor will we explore historical resistance to migration within a community. However, they assert that this is often required of local people in order to remain in such a variable system (Christensen and Mertz 2010). As the island grows and moves, the islanders have moved, as a form of climate variability adaptation, from place to place, selecting the highest ground with the least risk of typhoon damage.

In the case of the RMI, for example, Spennemann and Marschner showed that historical settlements avoided areas at most risk for storms (Spennemann and Marschner 1994). These settlement patterns were influenced by environmental variability in wind, wave and storm action; people typically lived along the lagoonal shores and western sections (leeward side) of the islands (Spennemann 1998). However, from 1946 to 1958 the United States carried out atomic bomb testing on certain atolls, relocating several communities and causing many of the islands to be uninhabitable even today (Simon 1998). This international presence propagated development on Majuro Atoll; more specifically, the Delap-Uliga-Dujarrit (D-U-D) area, an eastern section (windward side), was chosen for ease of access for large US military ships. This is now one of the most densely populated areas in the RMI (Spennemann 1998). Sea walls on the D-U-D side, and along many other parts of the atoll, have allowed for people to build right up onto the reef platform, impacting not only the carrying capacity of the land, but the already tenuous coral reef ecosystem. "That the D-U-D area remained a focus of Majuro, and in fact the entire Marshall Islands, is an accident of history, rather than the result of careful planning" (Spennemann 1998).

This example also demonstrates how weather hazards interact with non-climate factors, such as societal changes or economic development. When considered within a socio-ecological resilience framework, settlement patterns, such as increased development on the D-U-D side of the Majuro Atoll that increases exposure to typhoons, can be countered by formally or informally encouraging habitation in what were traditionally high-populated areas. Changes of this nature can be facilitated by adaptive co-management strategies that "learn" from the increased risk and encourage other options.

Climate variability also has implications for the type of homes people are likely to build. One tenet of the resilience framework is to describe the socio-ecological system in terms of an "adaptive cycle" at many scales (See Figure 2) (Holling 2001). Growth and exploitation make up one half of this cycle. When the system has achieved optimization to the point where it becomes

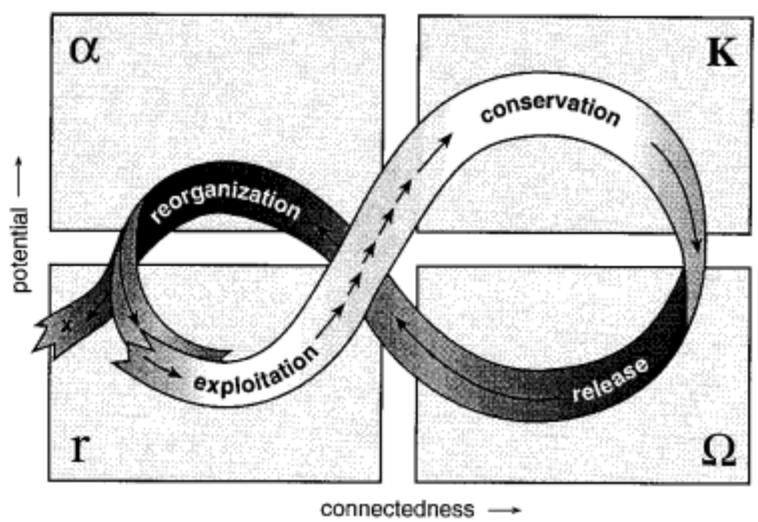

Figure 2: A stylized representation of the four ecosystem functions (r, K, V, a) and the flow of events among them. The arrows show the speed of the flow in the cycle. Short, closely spaced arrows indicate a slowly changing situation; long arrows indicate a rapidly changing situation. The cycle reflects changes in two properties: the y-axis (the potential that is inherent in the accumulated resources of biomass and nutrients) and the x axis (the degree of connectedness among controlling variable). The exit from the cycle indicated at the left of the figure suggests, in a stylized way, the stage where the potential can leak away and where a flip into a less productive and less organized system is most likely. Source: Holling 2001

inflexible, it is followed by the other half of the loop; one of creative destruction and reorganization (Walker 2004). Architectural strategies could integrate a process of continual "destruction" and reorganization where fiscally feasible, by building homes that can be easily reconstructed after disasters. This enables the option of emergency movement, even to nearby locations, without considerable loss of property and infrastructure investment; this is an example of creative reorganization.

The diversification of structures across different social-network scales also holds considerable value for an area like the RMI where resources are scarce but weather hazards are frequent. In order to reduce the risks inherent in this situation, it might be appropriate, for example, to select several high-ground locations that are relatively safe from storms, and construct large community buildings that could serve as refuge for all islanders during extreme weather events. These buildings could incorporate larger infrastructure investments to fortify against strong winds, and serve as a complement to more easily reconstructed buildings at smaller scales. These larger, more expensive structures could serve as community meeting grounds for day-to-day social events and municipal functions, which in the event of a weather hazard can also serve as a shelter and food and water storage facility. These structures can also be elevated or have the ability to float in times of high tide. A crucial component of the socio-ecological resilience framework is *Panarchy*, which recognizes the different spatial and temporal scales inherent in every system, and encourages cross-scale adaptation by diversifying risk amongst various scales (Walker 2004). Thus, a final component of human settlement that must be acknowledged within the climate change context is cross-scale migration.

One of the likely realities of current climate change projections is human *resettlement*. In other low-lying island states, such as Tuvalu, relocation options are already being discussed with Australia (Mortreux and Barnett 2009). Similarly, various communities in the Arctic, such as the Alaska Native coastal village of Kivalina, are relocating due to flooding (Barringer 2008). In the Sahelian strip of Africa, and elsewhere, communities can be internally displaced because of the long-onset hazards of water stress and drought (Leighton 2010). Low-lying areas that are situated near major rivers or deltas, such as Bangladesh, Vietnam and India are also at risk of displacement due sea level rise (Mortreux and Barnett 2009) These are only a few examples of how climate change and extreme weather events could contribute to internal and international displacement of persons. Proposing migration as an adaptation option to climate change does not mean that inhabitants of low-lying islands will necessarily move (Mortreux and Barnett 2009). Despite this, as well as the disruption of central cultural and social values that migration would cause, migration as an adaptation strategy raises questions that currently lack legal frameworks in existing international and national frameworks on migration (Leighton 2010). A term that has appeared in the climate change discourse is "climate refugee", a new phenomenon of the 21st century that is legally unsupported by existing definitions and frameworks set in place for refugees (Lopez 2007). More specifically, the definition of "refugee" does not include those who are displaced due to environmental stressors. Thus, the authors would like to reify that migration can only be considered adaptive within a socio-ecological resilience framework if international frameworks are put in place to cope with portending conflict, disenfranchisement and threats to human rights due to climate change.

The relationship between the RMI and the United States illuminates displacement scenarios deriving from threatened basic human rights. The RMI and the United States have a contractual agreement that, in exchange for the military use of Marshall Island territory, allows citizens of the RMI certain rights afforded to U.S. territories (Armstrong 1980). This *Compact of*

Free Association (1986) recognized the RMI as a self-governing nation, but includes defense and national security provided by the U.S. This relationship arose out of a complex and arguably inequitable agreement made between the United States and the RMI, in light of over twelve years of atomic bomb testing on some of their atolls (Simon 1998). In the same way, the international communities' failure to reduce greenhouse gas emission will leave many people with no choice but to migrate. Determining at what point these low-lying areas become uninhabitable, which will likely occur long before they are completely inundated, and can only be determined by the Marshallese themselves. Climate refugees do not have agreements with developed countries to facilitate their resettlement. While flawed, the *Compact of Free Association* serves as an analogy for international displacement framework.

Geomorphology

Given the "drowning island states" predictions, the *basin of attraction* terminology within the socio-ecological resilience framework can be useful in capitalizing on atoll geomorphology up until the possible time when the Marshallese determine that their land is no longer inhabitable. The socio-ecological resilience framework conceives of the world as dynamic and conceptualizes the socio-ecological system as being at any moment in time characterized as a point in a multidimensional system made up of all the possible combinations of all the possible variables of that system. The *basin of attraction* therefore represents the range of states that the system will tend to assume (Walker 2004). A socio-ecological system will tend to remain in one basin unless some state(s) is perturbed enough that it pushes the system into another basin of attraction, another set of states that the system will remain in until it is pushed out again, if ever. Assuming that the submergence of these atolls is a different basin of attraction than the socio-ecological system is currently located in, it is clear that the new basin is not desirable for the Marshallese.

In order to avoid ending up in such a basin, we first consider the fact that atolls grow and shrink gradually over time; they are not static landforms (Roy and Connell 1991; Yamano 2005; Webb and Kench 2010). Atolls are built of sand that has accumulated on top of coral reef rubble, sitting on the outline of an ancient, submerged volcano. The coral reefs grow over time, making these morphologically very mobile landforms (Solomon and Forbes 1999). In his study of Majuro Atoll, the most populated island within the RMI, Xue determined that there is an ongoing flow of sediment from the east to the west of the island, and that it is common for atolls to erode on the beach facing the ocean while growing on the beach facing the lagoon (Xue 2001). There is an overall sediment "budget", comprised of erosion and reef production adding sediment to the water, while accretion builds more land and exports of sediment to deep water constitute losses to the system (Solomon and Forbes 1999). Yamano et al. have shown that there has likely been a net zero change in the size of Majuro Atoll from 1944 to 2000, although some parts have eroded and some parts have accreted (Yamano 2005).

Acknowledging that the island itself is in dynamic flux is one of the distinctive capabilities of the socio-ecological resilience framework. Imagining atolls as ecosystems that move and change over time, instead of reaching a static equilibrium, can be instrumental in selecting adaptation strategies that are appropriate to the locality and likely to enable the socio-ecological system to remain within the desired basin. In this case, adaptation has often entailed building large-scale sturdy structures, such as seawalls, to prevent the effects of sea level rise and variability in Majuro. This has since been shown to actually have a negative effect on the island through increased erosion (Xue 2001; Pernetta 1992). Groins and vertical seawalls have been constructed without consideration to the dynamical growth of the island, and these have interrupted sediment transport along its original path, causing it to be eroded and lost to sea (Xue 2001). Similar effects have been seen in Tarawa, Kiribati (Solomon and Forbes 1999).

Through the lens of the socio-ecological resilience framework, alternative policies could be explored. Understanding the islands as morphologically variable, sediment transport can be managed and encouraged in a manner that is adaptive to the changing island form. In discussions with Marshall Islanders who were returning to areas from which they had been evacuated during the time of the US nuclear tests in this country, Bridges and McClatchey learned that sediment transport had been traditionally managed (Bridges and McClatchey 2009). People were able to identify areas of the island that had eroded since the time that they had been living there, due to a lack of maintenance. Originally, people had set up a regular set of “land expansion” duties, which trapped sediment as it was washed towards the ocean by piling coral boulders along the edge of the land and planting trees and shrubs. This type of activity created at least one land area that spanned several hundred square meters on Rongelap atoll (Bridges and McClatchey 2009). In this way, the Marshall Islanders were able to implement a solution that used landscape variability to deepen, rather than be pushed out of, their current basin.

As another example of working within environmental variability, planting mangroves along the coast of these atolls is a strategy that can prevent coastal erosion as well as enhance fisheries (Suratman 2008; Badjeck et al. 2010). The RMI have several species of mangroves, which have already been managed by people for their usefulness (Raymond 1990; Ellison 2009; Reimaanlok: National Conservation Area Plan for the Marshall Islands 2007-2012 2008). These plants can live in salt water, and their aerial prop roots act as soil reinforcement during storms and times of high wind, helping to intercept sediments that could get washed into the ocean (Suratman 2008). Plant debris can accumulate on top of the sand, which has happened for 2000 years on some islands of Micronesia. Planting mangroves in atoll setting is fundamentally different from building a sea wall because they work within the sediment transport dynamism of the atoll.

Diversification of Assets: storage and cross-scale connections

Given that the environmental system is inherently dynamic, the socio-ecological resilience framework as a method for adaptation strategy selection discourages strategies that focus only on one project. Instead, having a variety of plans and back-up plans will enable people to avoid crisis situations by drawing on their diversity of assets. The socio-ecological resilience framework calls this *transformability*: the development of a fundamentally new set of options that could be called upon when necessary in a variable climate. For example, diversifying a food source or water source would allow for the second half of the adaptive cycle loop defined earlier, which encourages renewal and change, without losing entire food or water security.

The RMI traditionally had very limited food and water resources that originated directly from the islands and nearby oceans (Spennemann 2000). In terms of water access, most RMI atolls rely on limited groundwater that is held in a “freshwater lens”. This drinkable ground water is recharged from rainfall which seeps into the ground and floats upon the heavier salt water underneath (Spennemann 1998). Traditionally, the Marshallese have relied heavily on the groundwater from the freshwater lens because they have not had the appropriate material to capture and store rainwater (Bridges and McClatchey 2009). They have also traditionally dug pits and lined them with vegetation to serve as water catchment systems for agriculture (Bridges and McClatchey 2009). In 2010, only 36% of households in Majuro had rainwater catchment systems in their homes, and over 57% of households reported that there were some periods of the year when they did not have access to water (Kaiko 2010). From 2008-2010, lack of water for sanitary use caused over 2,000 cases of Pink Eye on Majuro, which has a population of only 28,000 people (Kaiko 2010).

In light of the projected impacts of climate change precipitation patterns and storm tracks, there is a possibility that the RMI will be exposed to variable precipitation and more extreme weather events (Parry et al. 2007; Goddard and Coelho 2009). Attendant tide variability, natural sea level fluctuations associated with ENSO events, and projected overall sea level rise in this area means that the freshwater lenses risk salt water intrusion (Yamano et al. 2007). This implies that a diversification of freshwater sources will need to take place. As previously mentioned, rainwater catchment systems are not universal on these islands due to lack of appropriate material or infrastructural support. A potential localized investment in water catchment systems can include not only rainwater harvesting from the airport but also from the roads and individual housing units. Attendant to this investment, water sanitation units would be necessary to ensure safe drinking water. Local institutions could consider in what ways existing reservoirs can be expanded or adapted to trap rainwater (USAID 2009). In order to diversify water availability, many reservoirs and storage units could be established throughout the island, so that if several become damaged in a typhoon, others will remain. The desalination plants that currently exist in dormancy on Majuro can be maintained, and thus ready should an increase in water supply be required. Any expansion of existing storage capacity would require active monitoring of the storage and sanitation of harvested water, serving to diversify water supplies in times of drought and provide potential expansions in the job market. Within a socio-ecological resilience framework, working with the variable rainfall patterns could mean diversifying sources of fresh water to as to adapt to the variability of freshwater sources.

A parallel issue for places with limited local food resources is ensuring that food supplies are diversified in the event that imports become unreliable. This can stem from conservation, local participation, and a diversification of livelihoods. A huge component of this is reengaging traditional knowledge about resource management (Reimaanlok: National Conservation Area Plan for the Marshall Islands 2007-2012 2008). Traditional knowledge about food storage and fermentation of local root crops can not only provide food security in times of scarcity, but also serve to replenish the nutrient deficient soils for further agriculture (Nunn 2007; Deenik and Yost 2006). Breadfruit, *Pandanus*, coconut, taro and bananas are some examples of local food on the RMI. Breadfruit is capable of semi-anaerobic fermentation and long-term ensilage (Kirch 1982). Fermentation and pit storage of breadfruit was a traditional way of buffering against the risk of food shortage due to drought or other extreme weather events in many parts of Polynesia and Micronesia (Kirch 1982). Furthermore, the cultivation of native food sources can inadvertently address vitamin deficiency (Weisler 1999). While there are physical limits to how much agriculture can actually be supported on the RMI's limited landmasses, a renewed investment in local edible food sources can contribute to biodiversity, reinvigorate and stabilize the soil, provide alternative livelihoods, and even open up access to previously inaccessible international markets (IFAD 2010). Marine resources are also central aspects to atoll life, for survival, food security, and income (Spennemann 2000). Again, the security of these resources is at risk due to acidification of the ocean (Parry et al. 2007). However, these projections can take decades to manifest. On shorter time scales, these resources can be conserved in a sustainable way with an application of the socio-ecological resilience framework, and attendant adaptive co-management participation and compliance.

Conclusion

One of the difficulties inherent in the adaptation to climate change discourse is that follow-up studies and longitudinal interventions are nearly impossible in light of such long time scales. Yet, many people will suffer if they wait for concrete evidence that a given adaptation intervention yields predictable positive results. Thus, a plethora of suggestions abound for how regions can adapt to predicted changes. The method suggested here is to select those proposed strategies that mesh with an understanding of the environment as dynamic rather than static, adapting to variability as a proxy for change.

As illustrated by the Republic of the Marshall Islands, applications of this approach include adaptive co-management, which continually reevaluates locally and temporally relevant management strategies so that they evolve along with the climate; dynamic challenges require dynamic approaches. In terms of housing, mobility is a useful strategy, as is diversification of housing types so that rebuilding one type of housing will not be a crisis because other shelters are available. Similarly, diversification of food and water resources accounts for a variable climate and makes it more likely that as the climate oscillates, some portion of the supplies will be available at any given time. The island itself can be understood as a dynamic entity; this discourages the use of sea walls in favor of mangroves that strengthen sediment retention and accretion strategies. As a cross scale network option within the socio-ecological resilience framework, the paper begins to address the present conflicts with, but potential necessity of, migration as an adaptation strategy. However migration as an adaptive, rather than maladaptive, strategy requires that further policies must be put in place at the national and international level to protect human rights. The resilience framework stresses these concepts in the diagram of the adaptive cycle, where creative destruction, reorganization and renewal are all “normal” aspects of any subset of the world. It is therefore conceivable to generate a diversity of assets, each able to be in a different part of this cycle at the same time. Hopefully the preceding analysis is informative of how this method of adaptation strategy selection can be applied to another location to yield different adaptive and contextualized strategies.

The challenge of adaptation to climate change is often viewed as something that *needs* to be done, but is continually defined by areas that lack it. Yet many of the most useful adaptation strategies can actually be derived from practices that are not necessarily new, but when supported, can enable humans to be comfortable with change as a piece of the variable environmental system. This socio-ecological resilience framework is an acknowledgment that no single type of knowledge can fully grasp or predict the complexity and uncertainty of climate change. However this method of adaptation strategy selection allows for all components of a system to be considered, including all forms of human knowledge. As an alternative to impact or vulnerability analysis, a socio-ecological resilience framework is a method that empowers people to accommodate, rather than resist, change.

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