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VULNERABILITY, IMPACTS, AND ADAPTATION TO SEA LEVEL RISE

TAKING AN ECOSYSTEM-BASED APPROACH

BY KEITH ALVERSON

Last year I traveled to Bangkok, Thailand, for the second Asia Pacific Adaptation Forum, which was called off at the last minute due to the city's worst flooding in the past 50 years. Bangkok, an urban center of great wealth in a relatively rich country, showed itself to be quite vulnerable to climate impacts. The flooding caused 815 deaths, massive displacements of population, and $45 billion in economic damage, including lasting damage to its automobile and electronics supply chains. Similarly, the landfall of Hurricane Katrina in New Orleans, Louisiana, in 2005 caused 1,836 deaths and $81 billion in damage. Thus, while it is certainly true that development can ameliorate some aspects of climate change vulnerability, we surely should not be fooled into thinking that development, sustainable or not, comprises the entire solution to the climate change adaptation challenge. At the very least, developing countries can find, and are finding, new development pathways that avoid some of the maladaptation that has already occurred in the developed world. Additionally, developing and developed countries alike can benefit from improving ecosystem management as an integral part of policies to help reduce vulnerability and increase resilience in the face of climate change.

Human activities have pushed greenhouse gas levels in the atmosphere far outside the envelope of natural variability over the past million years. As one unambiguous consequence, global average temperatures have rapidly risen beyond the natural variability of at least the past thousand years. According to one popular argument (Rockström et al., 2009), the past 10,000 years of climatic stability allowed ecosystems and civilizations to develop and thrive. As we move beyond natural "planetary boundaries" we risk pushing the planet beyond the safe operating space for humanity. Though not without conceptual flaws, this global Earth system boundary approach has shed valuable light on the most dramatic human global-scale impacts on the planet, highlighting where global mitigation efforts make sense. Unfortunately, for the climate change problem, such mitigation efforts have not succeeded: last year, atmospheric greenhouse gas levels rose to a record high, and did so at a record rate of increase. Adaptation to climate change will require a very different paradigm. Instead of global efforts, we need to focus on the local scale to identify impacts and vulnerability, and to develop adaptation strategies.

Reconstructions of local and regional natural climate variability over the past few millennia show that the kind of climate impacts that pose today's largest adaptation challenges—for example, droughts, floods, and sea level rise—have been far more dramatic in the past than during the instrumented period of approximately the last 150 years (Alverson et al., 2003). Although there is no doubt that we live in both unusual and challenging times, at the local level, anthropogenic changes are not happening against a backdrop of 10,000 years of Holocene climatic stability. The dramatic and dynamic history of regional climate variability in the Holocene has enabled ecosystems and societies to develop an inherent resilience that we can now benefit from in the face of dire global anthropogenic changes.

Patterns of climate impacts and societal vulnerability are highly localized. Sea level rise provides one interesting case.

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We have clear observational evidence that global average sea level has been rising at a rate of just over 3 mm yr^{-1} over the past couple of decades (Figure 1). Less well publicized, though equally well established from observations, is that sea level rise is not globally uniform. In the western equatorial Pacific, the average sea level rise over this same period is more than 10 mm yr^{-1}, while sea level in the northeastern Pacific has actually decreased over this same period (Figure 2). Furthermore, local land subsidence is often several orders of magnitude larger than sea level rise.

Looking in more detail at the full range of local changes affecting vulnerability to sea level during the Anthropocene, the climate signal is often relatively small. Consider what has changed in Bangkok over the past 50 years since such massive flooding apparently last occurred. Climatic change has led to a mean sea level rise of a few centimeters. Over the same period, groundwater extraction has caused land subsidence of more than a meter, and the sediment input from the Chao Phraya River that naturally builds up the delta has dramatically decreased due to irrigation, dams, canals, and other changes to the upstream river flow (Syvitski et al., 2009). The population of Bangkok has quadrupled, from just over 2 million in 1960 to over 8 million today. Over the same period, incredible growth of wealth and industry has transformed the city into the economic powerhouse of Thailand, a substantial regional center for the banking, automotive, and semiconductor industries that link Bangkok with the global economy. Clearly, these many nonclimatic developments dominate the likely impacts of sea level rise, as well as the vulnerability and adaptive capacity of the population in and around Bangkok.

Anyone listening uncritically to the political rhetoric in the negotiations of the United Nations Framework Convention on Climate Change (UNFCCC) might be tempted to believe that vulnerability to sea level rise correlates with national boundaries, and is most dire in least developed countries and Small Island Developing States. In this same context, sea level rise is often vastly oversimplified as a uniform, exogenous encroachment on coastal areas, accompanied by woefully simplistic blue coloring on maps of areas that would be inundated given some amount of sea level rise. However, as discussed in the Bankgok example, in scientific terms, the actual patterns of impact and vulnerability are far more difficult to map out. They certainly don't correlate with national boundaries, national development indicators, or height above sea level contours. Vulnerability is usually not the result of the encroachment of the sea directly, but rather of proximate effects such as disease, lack of access to drinking water, and economic losses. There is no reason to expect patterns of vulnerability, impacts, and adaptive capacity to map geographically at all, with large, highly vulnerable, and highly protected populations living side by side, defined not by how high above the flood line their dwelling is, but by their wealth, age, gender, or any number of other socio-economic variables.

As is so often the case, the developed world has numerous adaptation measures already in place, including, for example, the Thames barrier in London, the MOSE (MOdulo Sperimentale Elettromeccanico) gates in Venice, and floating houses in the Netherlands. However, it is not at all clear that such high-tech, expensive projects can be scaled up to less high-profile coastal areas, or that they would be useful at all in the developing world. For the vast majority of the world's coasts, it is simply not economically or technically feasible to engineer our way out of vulnerability to sea level rise. For this reason, concrete

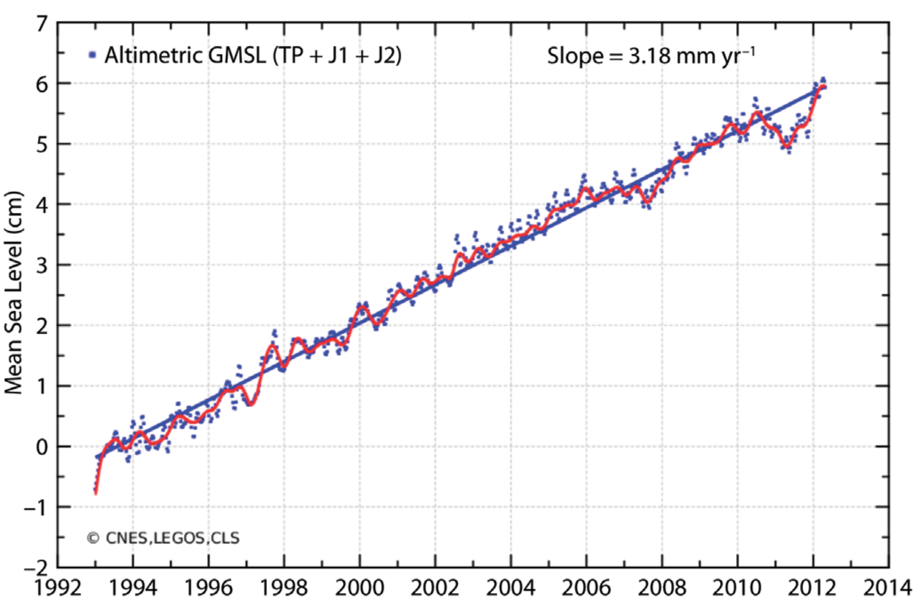

Figure 1. Global average sea level rise over the past 20 years as measured by satellite altimetry. *Source: http://www.aviso.oceanobs.com via Albert Fischer, Executive Director, Global Ocean Observing System*

adaptation actions can rarely be literally about pouring "concrete." Instead, a wide range of ecosystem-based approaches, wherein the natural resilience of a wide range of coastal ecosystems is harnessed to reduce human vulnerability, can be put in place. Three examples follow.

CORALS

Low-lying coral atolls are not, of themselves, vulnerable to sea level rise. They are a perfect example of natural ecosystem resilience that has developed in response to a local climatic variability—in this case sea level rise—over many millennia. It was Charles Darwin, in one of the many, though less well publicized insights derived while aboard HMS *Beagle*, who first discovered that coral atolls are not static, but grow upward to account for either land subsidence or rising seas. In fact, the many small island states now threatened by anthropogenic rises of a few millimeters per year withstood a rise of over 120 meters, at a rate on the order of 100 mm yr^{-1}, at the end of the last glacial period, as coral growth kept pace with sea level rise. Of course, conditions today are very different. Relatively dense human populations now live on the islands, and the coral ecosystems that have protected them in the past are under serious threat from myriad local pressures and ocean acidification. Many of the events commonly attributed to sea level rise impinging on the islands can, in fact, be caused by local human activities, such as land reclamation; mining for building materials, which causes degradation of beaches and reefs; and the construction of causeways between islets (Donner, 2012). Thus, adaptation measures for these islands today must be primarily based on understanding the vulnerability of local populations, including curtailing maladaptive practices to ensure the health and resilience of coral reef ecosystems.

MANGROVES

One of the most well-known ecosystem-based adaptation options in the developing world over the past few years has been the protection, restoration, and/or sustainable management of mangrove forests. These forests protect the shoreline and communities from storm surges, tsunamis, and sea level rise, and they are an excellent example of a no regrets solution providing multiple benefits (Figure 3). They play a key role in securing human livelihoods by providing ecosystem goods such as food, timber, and medicine (Alongi, 2002; Gilmann et al., 2008). Furthermore, mangroves increase fishery and aquaculture yields because many commercial fish species depend on mangrove habitat during their juvenile stages, and shrimp-mangrove integrated farming systems, for example in the Mekong Delta of Vietnam, have increased the productivity of aquaculture facilities.

Cost-benefit analyses of mangrove restoration projects show that rehabilitation can provide net economic benefit even when only direct use by local communities of products, such as timber, fish, and honey, is considered, and shoreline protection also provides significant additional value (Badola and Hussain, 2005). Moreover, mangrove restoration can sometimes be more cost effective than maintaining hard structures, particularly over long relatively undeveloped coastline. In Vietnam, for example, planting 12,000 hectares of mangroves cost $1.1 million but saved an estimated $7.3 million per year in dike maintenance (Reid and Huq, 2005). The value of mangroves is not only apparent in developing countries. The annual economic value to the fisheries industry derived from mangroves in the Gulf of California, for example, has been estimated to be US$37,500 per hectare of mangrove fringe (Arburto-Oropeza et al., 2008).

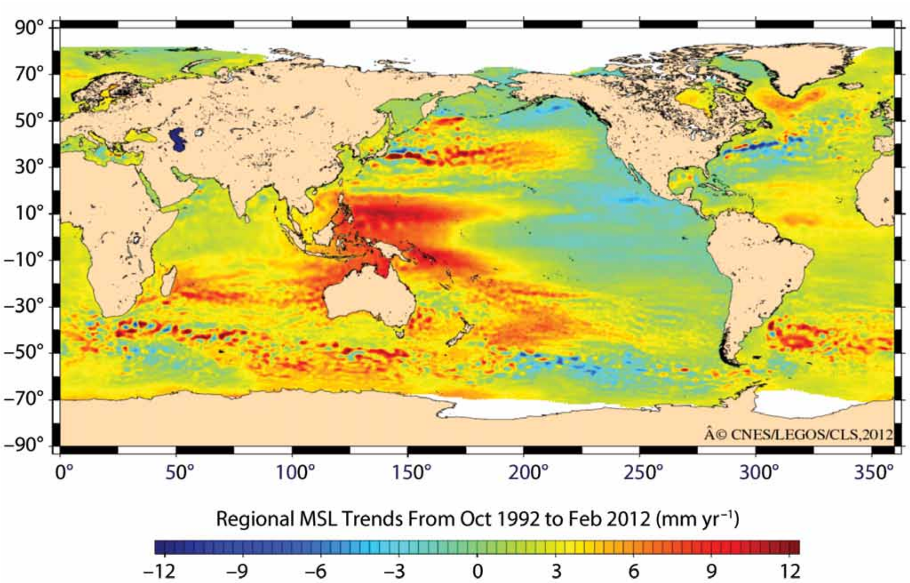

Figure 2. Global pattern of sea level rise trends over the past 20 years as measured by satellite altimetry. MSL = mean sea level. *Source: http://www.aviso.oceanobs.com via Albert Fischer, Executive Director, Global Ocean Observing System*

Finally, and most importantly, mangrove forests are highly resilient, able to recover after extreme events with a high degree of ecological stability. Like corals, mangrove forests can actively raise the forest floor in response to sea level rise, as their presence enables accumulation of sediment above the tidal range (Kumara et al., 2010). Although their ability to do this effectively depends on the rate of sea level rise, studies suggest that mangroves today are keeping pace with sea level rise (Alongi, 2008) and that restoration and management can therefore enable mangrove ecosystem based adaptation to climate change.

COASTAL ZONE MANAGEMENT

As coastal cities have grown in size and number, a wide range of engineering approaches to decreasing their vulnerability to sea level rise has been developed—from dikes and channels in Bangkok, to reservoirs and levees in New Orleans, to sea walls in Japan, to movable barriers in London and Venice. All of these structures clearly reduce vulnerability. However, the unintended consequences of such high-profile and expensive infrastructure projects can be a false sense of security, degradation of natural coastal zone protections, and, ultimately, a lack of resilience. New Orleans provides a good example. As long as the system of levees and reservoirs protected the city, people felt secure even as natural processes of sediment delivery failed to build up the Mississippi delta and barrier islands as they had in the past. When the barriers were eventually breached by an extreme event—Hurricane Katrina—the city and its environment had lost the resilience that integrated coastal zone and river management might have provided had it been an integral component in a more holistic approach. Almost invariably, urban areas can benefit from building up natural resilience in the ecosystems of peri-urban areas. Such ecosystems approaches can include wetland restoration in riparian areas upstream, or dune, sediment, and barrier island restoration and management. Nichols (2011) provides a nice review of land use oriented "soft" defenses.

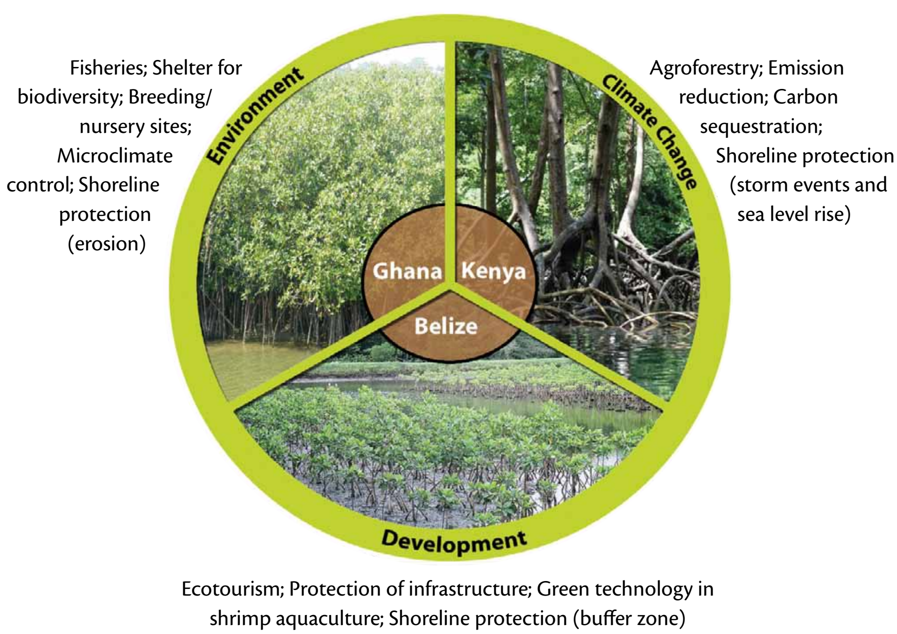

Figure 3. Mangroves occur in a wide variety of coastal habitats, protect against sea level rise, capture carbon, and provide a broad range of multiple benefits to local communities. This diagram was prepared based on activities undertaken as part of a Climate and Development Knowledge Network funded project called "Achieving triple wins: Identifying climate smart investment strategies for the coastal zone." Through case study work in coastal Ghana, Kenya, Belize, and Vietnam, the project aims to present the co-benefits (and damages) from actions that deliver climate change adaptation and mitigation. *Source: Adelina Mensah, University of Ghana*

FALSE PARADIGMS IN ADAPTATION

Having made the case, I hope, for incorporating ecosystem-based resilience as an integral component of plans to reduce human vulnerability to sea level rise, I briefly highlight a few of the more common fallacies that underpin many adaptation projects.

The first fallacy is the concept of "additionality." In order for countries to obtain funding for adaptation work from major multilateral donors, including the Global Environment and Adaptation Funds, they must demonstrate that the planned interventions are distinct from business-as-usual development work. This concept has political support from both developed/donor and developing/recipient countries. Recipients hope that insisting on such a distinction will help ensure they receive "new" funds, additional to traditional development assistance, rather than "relabeled" funds that were in fact already being provided. Donors too are keen to demonstrate that they are indeed providing adaptation support, or at the very least adding some kind of "climate proofing" to their existing development investments. However, scientifically, the concept of additionality is very difficult to justify, primarily because the specific climate drivers that are being adapted to are often either not outside the envelope of natural variability of the recent past and/or not large compared to other drivers. Put another way, human societies are vulnerable to climate-related extreme events irrespective of global anthropogenic change, and local, nonclimatic drivers often dominate the magnitude and extent of this vulnerability. Thus, very often the easiest and most efficient way to decrease vulnerability and/or increase resilience to future climate change is to look at the range of past variations and extreme events, and develop better plans to deal with them in the future. Bangkok, for example, does not require future projections of regional hydrology or sea level rise in order to better prepare for possible future flooding of the extent and magnitude it experienced last year.

These observations lead to a second perplexingly ingrained paradigm in much adaptation work—the perceived need to base adaptation planning on "downscaled" and/or "improved" model forecasts. The hopes that accurate regional climate forecasts can underpin specific adaptation measures are, for the most part, misplaced. In terms of global models, the range of projections, both for global average temperature and regional trends, shows no sign of shrinking, and indeed there are good reasons to think the range may increase as more degrees of freedom, associated with adding new forcing factors, are included in them (Maslin and Austin, 2012). Downscaling such models provides some numbers with variability on horizontal scales that are more compatible with adaptation work. However, there is little evidence that these high-resolution fields actually provide more accurate climate projections. The take-home message is that instead of adapting by implementing tailored additional actions targeting specific climate projections, it is usually easier and more effective to build resilience to a plausible range of variability, including extreme events.

CONCLUSIONS

Adaptation to climate change is one of the defining global environmental, social, and economic challenges of the twenty-first century, recognized by heads of state at the Rio+20 conference on sustainable development in 2012 as "an immediate and urgent global priority." At the root of this challenge is a troubling disparity between the global scale of the anthropogenic causes of change and the local scale of adaptation measures. Additionally, although any one specific trigger may be global climate change related—rising global mean sea level is just one example—the adaptation response will always require much broader interdisciplinary perspectives. Some of the most vexing adaptation challenges are not technical or scientific at their core, but will be dominated by social, economic, and legal considerations. However, one thing is quite clear. Ecosystems have evolved a great resilience to past climatic variability and extreme events. In our efforts to reduce our own vulnerability to these same forces, it behooves us to harness this powerful ecosystem-based resilience as an integral element of our adaptation efforts.

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