Ecosystem-based Adaptation in Marine and Coastal Ecosystems

Lynne Zeitlin Hale, Imèn Meliane, Sarah Davidson, Trevor Sandwith, Mike Beck, Jonathan Hoekstra, Mark Spalding, Steven Murawski, Ned Cyr, Kenric Osgood, Marea Hatziolos, Pieter Van Eijk, Nicholas Davidson, William Eichbaum, Carlos Dreus, David Obura, Jerker Tamelander, Dorothée Herr, Caleb McClennen, Paul Marshall

Climate change is already impacting millions of people, particularly vulnerable communities whose survival, livelihoods, and cultural identities are dependent on the integrity of marine and coastal ecosystems. These impacts will continue and increase over the short to medium term, even as the community of nations works to gain consensus on reducing its greenhouse gas emissions. Ecosystem-based adaptation provides an opportunity to reduce the vulnerability of these communities through an improved management of marine and coastal ecosystems so that they continue providing important ecosystem services on which so many depend. There is an urgent need to develop, implement, and fund ecosystem-based adaptation strategies involving coastal communities as a priority response to climate change.

Human Societies Depend on Marine and Coastal Ecosystems

The ocean is a unique, extraordinary, and vital element of our planet, covering more than 70% of its surface. It sustains life by generating oxygen, absorbing carbon dioxide from the atmosphere, and regulating climate and temperature. Billions of people around the world, especially vulnerable communities in tropical areas, depend on ocean and coastal ecosystems for their survival and well-being. Most of these populations live near (or on) coastlines, and wetlands and reefs provide the first line of coastal defense. More than a billion people worldwide rely on fish as their main source of protein. Fisheries and associated industries employ 38 million people directly, and another 162 million indirectly (FAO, 2008). Nature-based tourism on coral reefs is estimated to contribute $30 billion to the global economy each year. In addition, marine and coastal ecosystems provide a wide range of other important services to human society, including medicines, natural shoreline protection against storms and floods, water quality maintenance, and other cultural and spiritual benefits (UNEP, 2006).

Coastal ecosystems produce disproportionately more services related to human well-being compared with other systems, even those covering larger total areas, and at the same time they are experiencing some of the most rapid and intense environmental degradation and over-exploitation (Millennium Ecosystem Assessment, 2005).

Climate Change is Already Impacting Vulnerable Communities That Live Along Coasts

Fifty percent of the human population lives along the coast. Population densities in coastal regions are about three times higher than the global average, with 23% of the world's population living both within 60 miles of the coast AND less than 330 feet above sea level. Sixty percent of the world's cities with a population of over 5 million are located within 60 miles of the coast. Many of the world's poorest communities also live along the coast and rely on mangrove and reef-based fisheries for food security and on tourism for foreign exchange, particularly in small islands and tropical developing countries. A recent study in Indonesia estimates that 60% of the population is dependent on marine and coastal fishing resources for their protein and livelihoods. In the Wakatobi province, 100% of food requirements are met by the sea, and this is complemented

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Hale, Meliane, Davidson, Sandwith, Beck, Hoekstra, and Spalding of The Nature Conservancy; Murawski, Cyr, and Osgood of U.S. National Oceanographic and Atmospheric Administration; Hatziolos of The World Bank; Eijk of Wetlands International; Davidson of The Ramsar Convention Secretariat; Eichbaum and Dreus of World Wide Fund For Nature; Obura of Coastal Oceans Research and Development in the Indian Ocean; Tamelander and Herr of International Union for Conservation of Nature; McClennen of Wildlife Conservation Society; and Marshall of Great Barrier Reef Marine Park Authority. For more information, contact Hale at lhale@tnc.org.

by building materials and cash income derived from marine and coastal natural resources (Emerton, 2009).

Climate change impacts on oceans and coasts are numerous and complex, they are expected to profoundly alter ecosystem functions across polar, temperate, and tropical environments, from the surface to the ocean depths (IPCC, 2007; Griffis et al., 2008).

- Rising seas will erode and inundate coastlines and valuable wetlands and can increase salinity in coastal water sources and lands used to produce food.
- Increased water temperatures make corals more vulnerable to bleaching and change the geographical ranges of many marine species. Already 20% of the world's coral reefs are estimated to be damaged beyond repair and unless emissions are drastically reduced, 80% of the world's reefs could be lost, and their ability to feed people and sustain the livelihoods of millions of people will be severely impaired.
- Increasing acidification of the oceans as a result of CO_2 absorption reduces the ability of key marine organisms like corals, plankton, and shellfish to build shells and skeletons, with consequences for the productivity of marine ecosystems and dependent fisheries.
- Changing weather, wind patterns, and sea temperatures impact various oceanographic processes, including nutrient upwellings and surface currents, which in turn affect ocean productivity by altering population abundance and distribution for many marine species.
- Predicted decline in oxygen concentrations across various depths, reduced ventilation of the mid-water from ocean warming, and local eutrophication will lead to an expansion of oceanic dead zones and fish mortality.

Climate change is also exacerbating other threats to the oceans in a cumulative way. The increased occurrence and distribution of invasive alien species, growing pressure on fisheries resources, altered patterns of coastal development, and shore-based pollution are all exacerbated by climate change leading to increased vulnerability and an unpredictable scale of impact.

The Global Response to Climate Change—Mitigation and Adaptation

There is an immediate need for a significant reduction in greenhouse gas emissions to reduce the rate of climate change and to avoid catastrophic impacts on biodiversity in the long term. In the absence of such strong mitigation action, it is possible that the most vulnerable ecosystems, such as coral reefs, will cease to function in their current forms within a few decades (Hoegh-Guldberg et al., 2007).

Even if mitigation measures are effectively implemented, the earth's climate will continue changing over the short to medium term, due to lag effects of temperature and ocean acidification in response to the build-up of CO_2 already in the atmosphere. This will lead to unavoidable impacts requiring adaptive management responses in the face of change. Management actions can exacerbate or ameliorate the situation. Adaptive measures to reduce impacts and to increase resilience in the face of these changes are a necessary complement to mitigation actions, and will include measures to ensure ecosystem integrity, reduce manageable impacts like pollution, restore habitats, alter use patterns, and most important avoid inadvertent measures that address one problem, like coastal inundation, but cause others, e.g. destruction of coastal ecosystems. Adaptation measures will also increasingly employ the regenerative capacity of natural ecosystems as part of engineered solutions.

There is a Need for Comprehensive Adaptation Strategies to Consider Not Only "Hard Infrastructure" But Also Ecosystem-based Solutions

Coastlines are now more dynamic than ever because of changing storm patterns and sea level rise, placing human and natural communities at greater risk. The costs of these hazards to human and natural communities are increasing as coastal development continues and natural buffers, such as coastal wetlands and dunes, are lost. One of the areas where there are real opportunities for identifying win-win solutions for human and natural communities is in building approaches that combine hazard mitigation and biodiversity conservation in coastal zones to preserve infrastructure, protect human communities and preserve their livelihoods (Kareiva and Marvier, 2007).

Most existing and proposed adaptive responses to climate change in coastal areas have focused on using "hard" engineering solutions to try to address the problem. Over the past century, hard coastal defense structures have become ubiquitous features of coastal landscapes as a response to these threats. The proliferation of defense work affects over half of the shoreline in some regions and results in dramatic changes to the coastal environment. The extent and projected trend of this phenomenon are alarming. For example, 8,500 square miles of the coastal zone in Europe are covered in concrete or asphalt, and urban artificial surfaces increased by nearly 730 sq mi. between 1990-2000 alone (Airoldi and Beck, 2007). Similar examples occur in other parts of the world—e.g. California, Australia, and Japan—where hundreds of miles of coasts are hardened. Worse, the addition of one artificial structure changes erosion and sediment transport and creates the need for yet other adjacent structures in a costly negative feedback loop (Airoldi et al., 2005).

Such expensive infrastructural responses, though in some cases necessary, will not be sufficient to address the full scope of climate change impacts, and can exacerbate the destruction of fragile ecosystems, further reducing their adaptive capacity. For example, shoreline hardening adversely affects wetlands through direct destruction and by preventing sediment transport essential to that ecosystem. This results in increased erosion and further loss of habitat on directly adjacent or downstream shorelines (US EPA, 2009). In addition, such options often come with high maintenance costs.

Ecosystem-based adaptation options often apply directly or indirectly to multiple management goals. For example, allowing wetlands to migrate inland will not only maintain their shoreline protection services, but could also directly address maintaining water quality and preserving habitat for maintaining local fisheries or tourism. Managers need to take into consideration priorities, costs and trade-offs, and consider implementing different options in different areas according to which resources are most in need of protection. In some cases, integrating "soft" and "hard" engineering approaches to adaptation could allow for the development of structural measures targeted at protecting the natural ecosystems themselves, in cases where climate impacts extend beyond their natural resilience. In the Mississippi Delta, for example, plans are being developed for the construction of small dikes that protect salt marshes and coastal peatlands against erosion and allow them to naturally regenerate. Subsequently, the regenerated coastal ecosystems contribute to the resilience of the Delta as a whole and are able to provide their full range of services.

Ecosystem-based Adaptation

Ecosystem-based adaptation aims to:

- Preserve and restore natural ecosystems that can provide cost-effective protection against some of the threats that result from climate change. For example, coastal ecosystems like wetlands, mangroves, coral reefs, oyster reefs, and barrier beaches all provide natural shoreline protection from storms and flooding in addition to their many other services (CBD, 2009).
- Conserve biodiversity and make ecosystems more resistant and resilient in the face of climate change so that they can continue to provide ecological services. This is particularly important for sustaining natural resources (e.g., fish stocks, fuel, clean water, marine biodiversity for tourism attractions) on which vulnerable communities depend for their subsistence and livelihoods.

Ecosystem-based adaptation requires collective action among governments, communities, conservation and development organizations, and other stakeholders to plan and empower action that will enhance environmental and community resilience to climate change impacts. In addition, it can be a major opportunity for community-based adaptation. Vulnerable coastal communities can be engaged, employ local knowledge and participate directly in developing and applying ecosystem-based solutions.

Ecosystem-based Adaptation Benefits in Marine and Coastal Areas

Adaptation strategies that aim to enhance the resilience of ecosystems to enable the continued provision of goods and services can be particularly important for vulnerable communities, that are often directly dependent upon natural resources. A growing body of evidence suggests that ecosystem-based adaptation can be a cost-effective strategy across the major adaptation sectors (Campbell et al., 2009). In addition, ecosystem-based adaptation strategies often address multiple coastal management goals and provide multiple benefits (see Table 1; US EPA, 2009; next page).

Below are some examples of the benefits gained from ecosystem-based adaptation strategies.

Cost-effective shoreline protection. Hard infrastructure like seawalls and levees is expensive, requires ongoing maintenance, and can fail catastrophically under severe storm conditions. Alternatively, an ecosystem-based approach of protecting and restoring "green infrastructure" like healthy coastal wetlands, including mangrove forests and coral reefs, could be a more cost-effective means of protecting large coastal areas, requiring less maintenance (Moberg and Rönnbäck, 2003). Across the globe, there are numerous examples of the important role that coastal ecosystems such as mangroves, wetlands, shellfish reefs, and coral reefs play in coastal protection as they dissipate wave energy. Mangrove restoration in Vietnam has been shown to attenuate wave height and thus reduce wave damage and erosion (Mazda et al., 1997). Sri Lanka's Muthurajawela marsh, a coastal peat bog covering some 7,660 acres, is an important part of local flood control. In Malaysia, the value of intact mangrove swamps for storm protection and flood control has been estimated at US $186,420 per mile, which is the cost of replacing them with rock walls (Ramsar Convention on Wetlands, 2005). Healthy mangroves also provide numerous additional benefits, such as timber and fisheries production, biofiltration, and recreational activities like recreational fishing and bird watching (Spalding et al., in press), services not provided by nonecosystem-based coastal protection alternatives.

Shellfish reefs serve as natural coastal buffers, absorbing wave energy directed at shorelines and reducing erosion from boat wakes, sea level rise, and storms (Meyer 1997, Piazza et al. 2005). In addition, shellfish reefs play an important role as habitat for other species; the fish produced on oyster reefs have significant

TABLE 1. Adaptation options for maintaining and restoring coastal wetlands and shorelines. (Adapted from US EPA, 2009)

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints
Allow coastal wetlands to migrate inland (e.g., through setbacks, density restrictions, land purchases)	Sea level rise	Preserve habitat for vulnerable species; Preserve coastal land/development	Maintains species habitats; maintains protection for inland ecosystems	In highly developed areas, there is often no land available for wetlands to migrate, or it can be costly to landowners
Incorporate wetland protection into infrastructure planning (e.g., transportation planning, sewer utilities)	Sea level rise; Changes in precipitation	Maintain water quality; Preserve habitat for vulnerable species	Protects valuable and important infrastructure	
Preserve and restore the structural complexity and biodiversity of vegetation in tidal marshes, seagrass meadows, and mangroves	Increases in water temperatures; Changes in precipitation	Maintain water quality; Maintain shorelines; Invasive species management	Vegetation protects against erosion, protects mainland shorelines from tidal energy, storm surge, and wave forces, filters pollutants, and absorbs atmospheric CO_2	
Identify and protect ecologically significant ("critical") areas such as nursery grounds, spawning grounds, and areas of high species diversity	Altered timing of seasonal changes; Increases in air and water temperatures	Invasive species management; Preserve habitat for vulnerable species	Protecting critical areas will promote biodiversity and ecosystem services (e.g., producing and adding nutrients to coastal systems, serving as refuges and nurseries for species)	May require federal or state protection
Integrated Coastal Zone Management (ICZM)—using an integrated approach to achieve sustainability	Changes in precipitation; Sea level rise; Increases in air and water temperatures; Changes in storm intensity	Preserve habitat for vulnerable species; Maintain/restore wetlands; Maintain water availability; Maintain water quality; Maintain sediment transport; Maintain shorelines	Considers all stakeholders in planning, balancing objectives; addresses all aspects of climate change	Stakeholders must be willing to compromise; requires much more effort in planning
Incorporate consideration of climate change impacts into planning for new infrastructure (e.g., homes, businesses)	Sea level rise; Changes in precipitation; Changes in storm intensity	Preserve habitat for vulnerable species; Maintain/restore wetlands	Engineering could be modified to account for changes in precipitation or seasonal timing of flows; siting decisions could take into account sea level rise	Land owners will likely resist relocating away from prime coastal locations
Create marsh by planting the appropriate species—typically grasses, sedges, or rushes—in the existing substrate	Sea level rise	Maintain water quality; Maintain/ restore wetlands; Preserve habitat for vulnerable species; Invasive species management	Provides protective barrier; maintains and often increases habitat	Conditions must be right for marsh to survive (e.g., sunlight for grasses, calm water); can be affected by seasonal changes
Use natural breakwaters of oysters (or install other natural breakwaters) to dissipate wave action and protect shorelines	Increases in water temperatures; Sea level rise; Changes in precipitation; Changes in storm intensity	Preserve coastal land/development; Maintain water quality; Invasive species management	Naturally protect shorelines and marshes and inhibit erosion inshore of the reef; will induce sediment deposition	May not be sustainable in the long-term, because breakwaters are not likely to provide reliable protection against erosion in major storms
Replace shoreline armoring with living shorelines—through beach nourishment, planting vegetation, etc.	Sea level rise; Changes in storm intensity	Maintain/restore wetlands; Preserve habitat for vulnerable species; Preserve coastal land/development	Reduces negative effects of armoring (downdrift erosion); maintains beach habitat	Can be costly; requires more planning and materials than armoring
Remove shoreline hardening structures such as bulkheads, dikes, and other engineered structures to allow for shoreline migration	Sea level rise	Maintain sediment transport	Allows for shoreline migration	Costly for, and destructive to, shoreline property
Plant SAV (such as sea grasses) to stabilize sediment and reduce erosion	Changes in precipitation; Sea level rise	Maintain/restore wetlands; Preserve habitat for vulnerable species; Preserve coastal land/development	Stabilizes sediment; does not require costly construction procedures	Seasonality – grasses diminish in winter months, when wave activity is often more severe because of storms; light availability is essential

value to coastal economies (Beck et al., 2009; Grabowski and Peterson, 2007). They also improve water quality through filtration and provide fish habitat, which can enhance tourism and recreation (Freeman, 1995; Lipton 2004).

The analysis of recent disasters, such as the December 2004 Indian Ocean tsunami and the hurricanes that struck North and Central America in September and October 2005, demonstrate the importance of habitat protection and natural resource management in decreasing vulnerability to extreme events (Sudmeier-Rieux et al., 2006). In 2008, Typhoon Nargis struck the Ayayerawady Delta in Myanmar, an area where most mangroves have been cleared, resulting in a humanitarian crisis including deaths of over 100,000 people. FAO and other organizations stated that a broader mangrove belt could have reduced the cyclone's impacts. Prominent insurers and investors are likewise incorporating and advocating risk reduction using the protective value of ecosystems and other natural infrastructure, such as coastal wetlands, barrier islands, trees, mangroves, and other vegetation, as part of development appraisals. This reflects the industry's understanding that natural infrastructure is essential to society's efforts to address climate change, and that these systems must be included as part of any adaptation strategy (Heinz Center and Ceres, 2009).

Mangroves, saltmarshes, and seagrasses are critically important sediment traps while their high productivity enables them to add considerable volume to trapped sediments around their roots. The result is that that their soils can "grow" upwards, enabling them to keep pace with rising sea levels or at least reduce the relative rate of sea level rise compared to unvegetated sites. In some mangrove locations in the Caribbean, mangrove sediments are rising at over 4mm/year (Cahoon and Lynch, 1997; McKee et al., 2007), significantly above the recent global mean sea level rise of 3.1mm/year.

Sustaining local livelihoods and contributing to local economies. The World Bank's Climate Change Framework Strategy (2008) warns that the disproportionate impacts of climate change on the poorest and most vulnerable communities could set back much of the development progress of the past decades and plunge communities back into poverty. Ecosystem-based adaptation helps maintain ecosystem productivity and supports sustainable income-generating activities in the face of climate change. For example, in Kimbe Bay, Papua New Guinea, coral reef resilience principles were applied to design a network of marine protected areas to help the Bay's ecosystems withstand the impacts of a warming ocean and continue to provide food and other resources to local communities (Green et al., 2009). In Samoa, mangroves are being planted as part of a larger restoration project to enhance food security and protect local communities from storm surges, which are expected to increase as a result of climate change (UNDP, 2008). In Myanmar, communities are replanting mangroves in the Ayerwaddy Delta following the destruction from Cyclone Nargis, which devastated life and property in the absence of mangrove forests that had been cleared over time for paddy cultivation (Tripartite Core Group, 2008).

The contribution of marine and coastal ecosystem services to local, regional, and national economies is substantial. For example, a recent study (Emerton, 2009) of the value of Indonesia's coastal ecosystems identified a potential value of sustainable fisheries from coral reef areas alone of more than US $1.2 billion—almost half of the value of national fisheries production. The same study found that marine and coastal ecosystems are responsible for about 49% of the Keladupa sub-district economy, and coral reef fisheries provide the main source of income for almost 80% of the residents in the Raja Ampat Regency. Marketed mangrove products generate 22% of the local economy of Ranong province in Thailand (IUCN, 2008). Estimates of direct tourism revenue generated from the presence and use of medium to good quality coral reefs in the Philippines range from US $23,600 to $39,150 per square mile (White and Trinidad, 1998).

Carbon sequestration and reinforcement of mitigation efforts. Coastal wetlands, including marshes and mangroves, sequester substantial amounts of carbon (Pritchard, 2009), so also play a crucial and incremental role in reducing the pace and scale of climate change itself. Mangroves may play an important role in carbon sequestration and storage in local and ex situ sediments; around 10% of mangrove productivity is incorporated into local sediments (Spalding et al., in press). Other studies have estimated that mangroves contribute about 15% of the organic carbon accumulating in marine sediments globally (Twilley et al. 1992; Jennerjahn and Ittekkot 2002). A conservative estimate is that mangroves sequester an estimated 112 ± 85 teragrams (Tg) of carbon per year, which is still an underestimation due to the lack of information about fine root activities. This amount of carbon sequestration is comparable with that for tropical terrestrial forests (Alongi, 2008; Bouillon et al., 2007). The majority of this captured carbon is likely to remain stable over millennial timescales, making mangroves an important carbon "sink."

Overall, it has recently been estimated that marine angiosperms (including saltmarsh, mangrove and seagrass) contribute some 46% of total organic carbon buried into marine sediments, or some 111 Tg per year (Spalding et al., in press). This contribution by coastal vegetation had been overlooked in earlier mass balance studies and such inputs represent a near-doubling of earlier estimates of the carbon storage function of marine sediments, making them highly significant contributors to global models of carbon flows (Duarte et al. 2005).

Providing refugia—a place to hide. Marine protected areas (MPAs) and other closures can provide refugia, protecting critical areas and functions in the life cycles of important marine species (IUCN-WCPA, 2008). Refugia from multiple threats are important to protect species and larval sources which aid in the recovery of damaged areas. Well-designed MPAs, MPA networks and other closed areas have proven to be effective tools in increasing the resilience and adaptive capacity of coral reefs to bleaching, by protecting them from other disturbances such as increased nutrient loads, pollution, diver and boat damage, sedimentation, and destructive overfishing (Smith et al., 2009). Existing research and management practices have demonstrated that connectivity among sites within a MPA network helps insure against the risk of losing an important habitat or community type following a disturbance such as a bleaching episode or intense storm. Expansion of well-designed MPAs, MPA networks and other closed areas that protect vulnerable species and ecosystems from a range of specific threats potentially provide a foundation for preserving ecosystem function in the face of rapid climate change.

Contributing to social resilience. Communities and local decision-makers still have little access to information on likely changes that will impact their lives and livelihoods and to tools to visualize the potential impacts and identify alternative scenarios. As a consequence, communities are unable to integrate climate-change related impacts and risks into decision-making regarding natural resource protection and land use management. Development of such tools is beginning to occur on pilot scales, [e.g. the Cristal assessment tool (http://www.cristaltool.org), the assessment of livelihood vulnerability and adaptation options for communities dependent on coral reefs (Marshall et al., 2009)], but much more work is needed.

Ecosystem-based adaptation provides a major opportunity for community-based adaptation. By maintaining and restoring healthy ecosystems that are more resilient to climate change impacts, ecosystem-based strategies can help ensure continued availability and access to water and other essential natural resources and ecosystem services so that vulnerable communities can better cope with climate variability and change. These communities can be engaged, employ local knowledge, and participate directly in developing and applying ecosystem-based solutions.

Guiding Principles and Recommendations for Ecosystem-Based Adaptation

Guiding principles for developing effective ecosystem-based adaptation strategies include:

Nature's infrastructure should be used first. Natural ecosystems provide valuable protection and other services, and we should take advantage of them. Maintaining and restoring "nature's infrastructure" should be a priority for reducing vulnerability to climate change impacts. As the effects of climate change become more severe, there will be, however, situations where engineering and hard structures may be necessary. Such structures need be built in sync with nature and its changing patterns.

Healthy ecosystems will be more resilient to climate changes. Ecosystem-based adaptation strategies should include a focus on minimizing other anthropogenic stresses that have degraded the condition of critical ecosystems. It is also important to take into account the full range of impacts, as one environmental change may have cascading effects.

Existing management practices and governance infrastructure should be improved. The most effective ecosystem-based strategies currently available apply established best practices in land, water, and natural resource management to confront the new challenges posed by climate change. Effective management programs that address multiple stressors and that take into consideration priorities, trade-offs, and synergies are central to adaptation planning. Well-designed and effectively managed marine protected area networks can make an enormous contribution to maintaining natural connections across seascapes so that ecosystems can continue to function and to provide services to dependent communities (Smith et al., 2009).

Stakeholders should be involved in strategy development. Ecosystem-based adaptation presents a tangible opportunity to solve climate change problems by aligning conservation, development, and poverty alleviation interests. Such synergies benefit from government collaboration with indigenous and local communities, conservationists, relevant private sector stakeholders, development specialists, and humanitarian aid specialists.

Decision support tools help visualize future scenarios and compare alternative adaptations. One of the major impediments to decision-making is a visceral understanding of potential impacts from climate change to communities and their resources. Tools that can help visualize these futures can be as simple as pictures of coastlines with different flooding scenarios from sea level rise and storms to interactive map servers. They also can provide the basis for examining costs and benefits of alternative approaches to adaptation with either hard or soft solutions with a goal of reducing losses for human and natural communities.

Government and the private sector can provide incentives for "climate smart" development and discourage development in vulnerable and sensitive habitats. The financial and insurance sectors can and need to play a positive role in ecosystem-based adaptation by fully recognizing and accounting for risks associated with development in vulnerable areas and providing incentives for maintaining "nature's infrastructure."

Environmental, ecological, social, and economic changes should be measured and mapped. As climate change impacts increase and our scientific understanding and observation evolve over time, it is important to monitor and report these changes and build on them to improve predictions, and to adapt responses.

Adaptive management is imperative. While the general trends in climate change are well documented, the timing and magnitude of local changes remain difficult to predict accurately. Ecosystem-based adaptation strategies should include monitoring so that management actions can be quickly adjusted in response to changing conditions. Management objectives may need to be revised and geographic priorities may need to be reconsidered to protect natural climate change "refugia," or to triage places suffering severe climate change impacts.

"Mainstreaming" ecosystem-based adaptation into coastal management and development at all levels. Ecosystem-based strategies will be more effective if they are mainstreamed into other development initiatives such as poverty reduction strategies, country development strategies and sector plans, these initiatives should be "owned" by those authorities responsible for preparing and implementing them.

A regional approach is needed. Ecosystems stretch beyond political and geographical boundaries, and this is particularly true for the marine environment. Therefore, efforts need to be made to design adaptation measures that are not limited by these boundaries. Adaptation measures for a resource shared by multiple states can succeed only through integration of a regional or transboundary dimension.

Prepare for the unexpected. In preparing for climate change, we need to keep in mind the possibility of non-linear, abrupt changes or step functions which can alter the state of an ecosystem or biome quickly once a threshold has been reached. These uncertain but high consequence events (such as de-glaciation or alteration of oceanic currents) need to be acknowledged and social resilience to cope with such changes developed.

Currently, a growing number of local, national, and regional initiatives and projects are applying ecosystem based adaptation principles to a variety of marine and coastal areas in various parts of the globe (e.g., see Table 1). There is a need to synthesize the new results as they become available, develop additional management tools, and transfer technology and build capacity for their use.

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