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nature climate change

Harnessing nature to help people adapt to climate change

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Adapting to climate change is among the biggest challenges humanity faces in the next century. An overwhelming focus of adaptation strategies to reduce climate change-related hazards has been on hard-engineering structures such as sea walls, irrigation infrastructure and dams. Closer attention to a broader spectrum of adaptation options is urgently needed. In particular, ecosystem-based adaptation approaches provide flexible, cost-effective and broadly applicable alternatives for buffering the impacts of climate change, while overcoming many drawbacks of hard infrastructure. As such, they are a critical tool at adaptation planners' disposal for tackling the threats that climate change poses to peoples' lives and livelihoods.

As Earth's climate continues to change at an unprecedented rate[1], people face mounting impacts. Ongoing research since the Intergovernmental Panel on Climate Change's 2007 assessment report underscores the urgent need for rapid progress on national and global adaptation efforts[2]. From sea-level rise to heightened hurricane activity, longer and more frequent droughts and floods, and acidification of the world's oceans, lives and livelihoods will be increasingly challenged[3]. Communities that faced the surging waters of the Indus River in Pakistan or the extraordinary heatwave in western Russia in 2011 have probably seen the face of an increasingly common future. The December 2011 United Nations Framework Convention on Climate Change (UNFCCC) seventeenth Conference of the Parties (COP17) in Durban, South Africa saw decision-makers from 194 countries progress with plans to finance global adaptation efforts through the so-called Green Climate Fund, first articulated at COP15 in Copenhagen in 2009. The Durban talks resolved key issues related to the fund's design, readying its coffers to receive the US$100 billion per annum that developed nations have committed to leveraging by 2020 to help developing nations mitigate and adapt to climate change. These prospective funding flows, in combination with rapidly rising levels of multilateral (for example, the World Bank's Pilot Program on Climate Resilience), bilateral (for example, Germany's International Climate Initiative) and national adaptation finance, mean that adaptation efforts are poised to receive unprecedented funding in a bid to meet estimates of global adaptation need, ranging from US$49 billion to US$171 billion per year[4]. Hence, the multibillion-dollar question is: what will this money be spent on?

Adaptation to climate change can incorporate a range of potential actions. Although no single established typology of adaptation actions exists, they can be loosely categorized into 'soft' and 'hard' approaches[5]. Soft approaches generally focus on information, policy, capacity building and institutional function. They include measures that encourage changes in behaviour to reduce potential losses from specific climate hazards (for example, the development of early warning systems for droughts or floods), risk-spreading measures that help people cope with climate-related losses (for example, insurance against extreme weather events for farmers) and measures that enhance people's overall resilience to a range of climate impacts (for example, education and capacity building in at-risk communities)[6]. Hard approaches, in contrast, use specific technologies and actions involving capital goods to reduce potential climate change impacts. These often include engineered, infrastructure-based interventions, such as sea walls and levees to protect vulnerable coastlines, or irrigation infrastructure to help farmers cope with intermittent or reduced water availability[7,8].

A third category of adaptation actions that shares attributes of both soft and hard approaches is now rapidly gaining attention. Ecosystem-based approaches to adaptation (EbA) harness the capacity of nature to buffer human communities against the adverse impacts of climate change through the sustainable delivery of ecosystem services. As such, EbA are generally deployed in the form of targeted management, conservation and restoration activities, and are often focused on specific ecosystem services with the potential to reduce climate change exposures (hereon 'adaptation services'). For example, mangrove forests and coastal marshes can help dissipate the energy of storm surges along exposed coastlines[9–11]. Restoring or conserving mangrove ecosystems can therefore help protect coastal communities from the projected rise in the number of powerful tropical storms under climate change[12]. The potential scope of EbA to help reduce people's vulnerability to a range of climate change impacts is broad. Ecosystems deliver services that can help meet adaptation needs across multiple human development sectors, including disaster risk reduction (through flood regulation and storm-surge protection), food security (from fisheries to agroforestry), sustainable water management (through water purification and flow regulation) and livelihood diversification (through increasing resource-use options or tourism) (Table 1). Hence, EbA have the capacity to both complement some soft approaches (for example, through livelihood diversification) and replace or improve many hard approaches. Although people have used the natural environment to cope with climatic variability for millennia, the potential for natural infrastructure to provide adaptation services is gaining increasing attention at national and international levels because of the urgent need to find tractable, flexible, cost-effective adaptation interventions that reduce vulnerability under rapid anthropogenic climate change.

Many decision-makers in local and national governments, multilateral organizations and businesses focus adaptation planning and funding on hard approaches[5,7,8], particularly where adaptation

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Table 1 | Examples of ecosystem-based approaches to adaptation and broadly comparable hard-engineering options for three human welfare/climate change adaptation outcomes.

	Ecosystem-based approaches for climate change adaptation	Hard infrastructural options for climate change adaptation
Disaster risk reduction (increase in the number of the most powerful tropical storms necessitating enhanced coastal protection)		
	**a**, Coral reefs are natural buffers that provide protection against erosion and wave damage. In the Turks and Caicos Islands this protection is valued at US$16.9 million per year[50].	**b**, The cost of using hard-engineering options (dykes and levees) for coastal protection in the Turks and Caicos Islands has been estimated at 8% of its gross domestic product, or US$223 million (refs 51,52).
	c, Wetlands of the Mississippi Delta are valuable ecosystems providing services worth US$12 billion–47 billion per year[33]. If the wetlands of New Orleans were to be restored and used as part of the coastal defence system, the estimated cost would be: for marshland stabilization US$2 per square metre; for marshland creation US$4.30 per square metre; and for freshwater diversion US$14.3 million (refs 53,54).	**d**, The cost of engineering solutions for coastal defence in New Orleans is high. To heighten a dyke by 1 m costs between US$7 million and US$8 million per kilometre. To heighten concrete floodwalls costs between US$5.3 million and 6.4 million per kilometre length. To heighten closure dams (in water) 1 m costs US$5.3 million per kilometre. To armour levees for each square metre costs between US$21 and US$28 (refs 53,54).
Sustainable water management (increased variability and extremes of precipitation and temperature, necessitating greater water storage and filtration capacity)		
	**e**, About 9 million New York City residents receive 1.3 billion gallons of water per day or 90% of their water from the Catskill–Delaware watershed. Protection of the watershed has cost the city US$150 million per year over the past 10 years[55].	**f**, The cost of a water filtration plant sufficient to filter water for New York City would have been US$6 billion–8 billion up front and would have operating costs of US$300 million per year[55].
	g, The paramo wetland ecosystem above Bogota, Colombia filters out contaminants and traps sediment so efficiently that the water it delivers to the city's treatment plant only needs chlorine treatment for disinfection[55]. This service saves US$19.6 million in avoided water filtration facilities[56].	**h**, The cost of building the water reservoir that will store water until the year 2032 to supply Bucaramanga, Giron and Floridablanca municipalities in Colombia is estimated at US$127 million (ref. 57).
Food security (increased variability and extremes of precipitation and temperature, necessitating actions to enhance resilience of farmers)		
	**i**, The use of sustainable land-management practices such as agroforestry (using trees and shrubs in pastures and croplands) can increase farmers' resilience to climate change through sustaining or increasing food production. By intercropping maize with a nitrogen fixing tree, *Gliricidia sepium*, Malawi farmers increased average yields fourfold, at minimal cost[58].	**j**, To increase average yields fourfold by using nitrogen-based inorganic fertilizers would cost Malawi farmers US$11.6 million annually[58].
	k, In Roslagen, Sweden, smallholder farmers have developed ecosystem-based practices to buffer against climatic variability such as diversifying crops among fields, intercropping and crop rotations, and using multiple sowing dates to maintain a diversity of crops that are more likely to survive in an uncertain climate. They also use crops or trees for shade to conserve moisture, and forest or tree protection to preserve groundwater sources[59], all at negligible direct cost.	**l**, Much of Europe uses forms of micro-irrigation or drip irrigation to cope with drought. Micro-irrigation can increase conventional irrigation water use efficiency from 20–30% to 90%. The average cost for micro-irrigation ranges from US$416 to US$950 per hectare[60,61].

For each human welfare outcome the relevant climate change exposure(s) and adaptation context are given in parentheses. Each example highlights costs and benefits where available, and both developing- and developed-world contexts are illustrated for each outcome. Examples of EbA use ecosystem services that provide a buffer against current climatic variability, with their adaptation benefit increasing under relevant climate change exposures. Image credits: **a**,**c**, © Hemera/Thinkstock; **b**, © Photos.com/Getty Images; **d**,**h**,**l**, © Holly Jones; **e**, © Thomas Northcut/Getty Images; **f**, © Felicia Rein; **g**, © David Hole; **i**,**k**, © IStockphoto/Thinkstock; **j**, © Zoonar/Thinkstock.

is required to reduce current and projected future climate-driven hazards to human life, health, property and livelihoods. Here, we argue for greater consideration of EbA in instances where hard interventions have so far been viewed as the default course of action. We first define the contexts in which EbA will probably be most effective at providing adaptation services and identify the additional co-benefits that EbA can provide in contrast to hard approaches. We then examine the potential for EbA to overcome some of the drawbacks of hard-engineering options and highlight the role of EbA in the context of both the developing and developed world. Finally, we discuss key data gaps and research that is necessary for EbA to achieve the consideration they merit by adaptation decision-makers.

Integrating EbA into adaptation planning

Within a given adaptation situation, natural infrastructure and hard infrastructure are often viewed as competing alternatives. However, we see three contexts for pursuing EbA relative to hard-engineering interventions. First, EbA may complement hard interventions, increasing overall capacity to cope with climate change. For instance, dams and dykes on the Yangtze River in China provide water for agriculture, but also cause major flooding, block animal migrations and degrade water-purifying vegetation, leading to eutrophication and loss of water quality. An increase in extreme flooding and drought events predicted as a result of climate change would further compound these adverse effects[3]. A recent shift to a more holistic management approach that seeks to integrate both hard and natural infrastructure has resulted in the seasonal opening of embankment sluice gates, restoring the connections between the Yangtze, three major lakes and their associated wetlands. This new approach has increased floodwater retention, water purification and agricultural opportunities, and has restored migration routes for spawning fish. Although a secondary system of levees still functions as a failsafe for extremely large floods, the restoration of a more natural flow regime renders the regional hydrological system better able to cope with current climatic variability and more resilient in the face of increased climatic variability projected for the future. At the same time, this integrated approach has increased the incomes of local communities by allowing farmers to diversify their livelihoods[13,14].

Second, in some situations EbA may represent a more cost-effective alternative than hard interventions. In the Maldives, for example, where ~80% of the islands are 1 m or less above sea level, coral reefs and other coastal ecosystems provide critical protection to coastal communities from storms and erosion, substantially reducing storm-related damages and saving lives[15]. In coming decades, climate change is expected to increase the frequency of the most powerful tropical storms[16], making the protective role of the reefs and their conservation even more critical. If they were lost, the cost of building hard infrastructure such as seawalls, breakwaters and other forms of coastal protection to replace the natural reefs has been estimated at US$1.6 billion–2.7 billion (ref. 17). In contrast, conserving the reefs to prevent their on-going degradation as a result of pressures ranging from overfishing to coral mining, through establishment of marine protected areas, would cost ~US$34 million in start-up and ~US$47 million annually (scaled up from calculations for a smaller protected area in the Maldives)[18], would maintain their critical protection service and could generate ~US$10 billion per year in co-benefits through tourism and sustainable fisheries[17].

Third, in some cases EbA may represent the only tractable adaptation option. This may occur where existing hard solutions have already failed or are not feasible to implement. For example, communities in Kimbe Bay, New Britain Island, Papua New Guinea depend heavily on marine resources for their livelihoods[19]. Increasingly, however, coral bleaching events threaten those livelihoods — a risk factor likely to increase substantially under climate change[20]. No hard adaptation options exist to combat bleaching events. Instead, local communities, government and non-governmental organizations have teamed up to establish marine protected areas in an effort to reduce current pressures (for instance, from overfishing) while bolstering the reef's coral diversity and thus its likely resilience to climate change[21].

Benefits beyond climate adaptation

EbA frequently provide economic, social and environmental co-benefits in the form of both marketable (for example, livestock and fish production) and non-marketable (for example, cultural preservation and biodiversity maintenance) ecosystem goods and services[22]. For example, targeted mangrove conservation and restoration, in addition to addressing climate change adaptation needs, typically also provides nursery habitat for aquatic organisms, timber and fuel wood, and opportunities for tourism and commercial fishing[15]. An economic analysis in the Nam Dinh Province of Vietnam suggested that restoring mangroves would cost US$166 per hectare in planting, capital and maintenance, but would provide benefits totalling US$630 per hectare. These benefits included not only the avoided costs of sea dyke upkeep but also the livelihood co-benefits of timber and honey provisioning and fish-stock maintenance[23]. A similar analysis calculated that restoration of the Skjern River floodplain in Denmark would cost US$44.2 million but provide net-present benefits of US$2.3 million in avoided water pumping (at present used to prevent flooding) and US$84.6 million in co-benefits including hunting, fishing, recreational opportunities and biodiversity conservation[24].

In contrast, few hard interventions provide additional benefits beyond the single adaptation function for which they were built. Consequently, as our ability to place monetary values on ecological co-benefits improves and markets for ecosystem services expand, a rapidly growing body of studies[19,22] suggests that increasing numbers of EbA projects will deliver favourable cost/benefit ratios compared with hard interventions. Moreover, by reducing climate change vulnerability while simultaneously providing co-benefits such as carbon storage and sequestration, EbA can help support governments to meet not only their adaptation needs but also their mitigation commitments (for example, through nationally appropriate mitigation actions mandated under the UNFCCC) and broader development goals (for example, the Millennium Development Goals[25]).

There is also substantial scope for synergies with traditional biodiversity conservation and assisted adaptation of ecosystems to climate change. Where ecosystems are protected, managed or restored to harness their adaptation services, they may also provide significant biodiversity conservation opportunities. Moreover, increasing the extent of an ecosystem, enhancing connectivity through restoration or protecting an ecosystem from other stressors can improve ecosystem resilience[20,26], which reduces the risk of ecosystems reaching tipping points[27] and shifting to unmanageable or unrecoverable states[28,29] as climate change proceeds. Hence, EbA could be a significant boost for countries in meeting their obligations under international agreements such as the Convention on Biological Diversity. Conversely, where current or future biodiversity conservation priorities coincide with the adaptation needs of vulnerable people, establishment of a protected area or marine protected area for conservation may also help secure the adaptation service provided by that natural infrastructure. Although some trade-offs surely exist (for example, where a conservation priority conflicts with the management needs of an EbA intervention), proactively identifying and prioritizing win–win opportunities should be a clear goal of both the EbA and biodiversity conservation fields moving forward to maximize benefits for both people and nature.

Flexibility and averted maladaptation

Many hard adaptation approaches are essentially permanent and inflexible — a key drawback in some settings. A hard structure can be mismatched to future climatic conditions, either because it was designed based on an assumption that natural systems such as rivers fluctuate within an unchanging envelope of variability[30] or because projections of future climatic conditions turn out to be inaccurate[31]. For example, levees protect coasts only from finite sea-level rise and are difficult to raise if actual sea-level rise exceeds the projections on which their height was based. Most ecosystems, in contrast, are inherently plastic — for instance, coastal wetlands can migrate inland as sea levels rise, assuming land is available, sea-level rise is not exceptionally rapid and no barriers to migration exist[9]. EbA are thus potentially more flexible in the face of changing needs and uncertainty about the future.

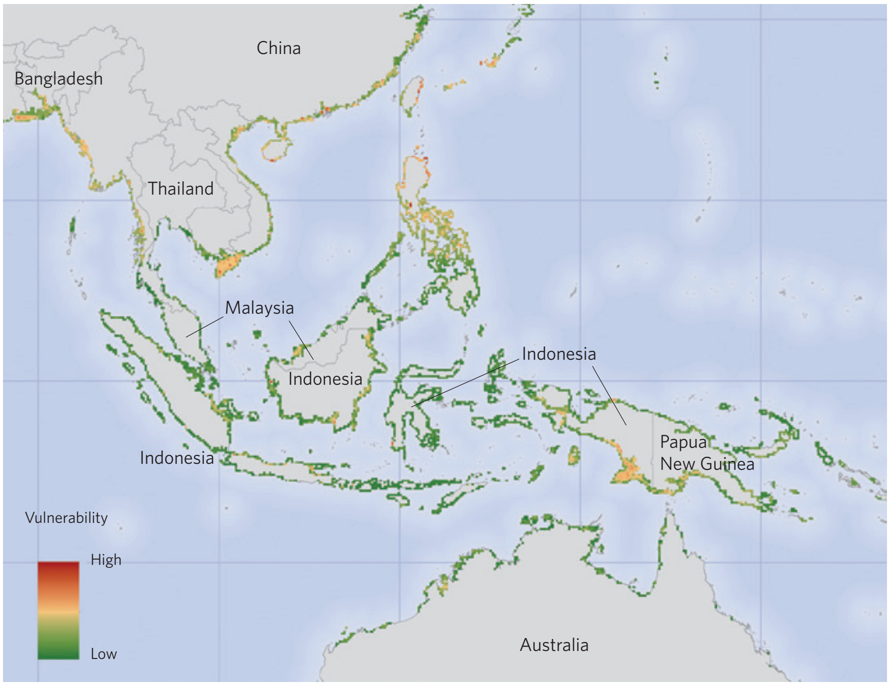

Figure 1 | Coastal regions in Southeast Asia that are particularly vulnerable to climate change. We define vulnerability as the intersection between high exposure (historical storm frequency and 1 m sea-level rise), high sensitivity (high population densities at low elevation and close to the coast) and low adaptive capacity (low scores for governance, access to markets, education indices, infrastructure, health indices and gross domestic product)[3].

Furthermore, hard-engineering interventions can have negative and unforeseen impacts on surrounding human and natural systems[32]. For example, levees channel sediment and fresh water to deeper ocean waters and may fundamentally change coastal ecosystems, degrading the ecosystems' ability to act as natural storm barriers[33]. Engineered structures may even be maladapted to their original purpose. The levees around New Orleans following Hurricane Katrina locked in the flood waters they were built to protect people from, exacerbating the devastating effects of flooding[33,34]. Finally, hard solutions typically require periodic and often costly maintenance[33] and may have short life cycles[35], whereas EbA are more typically self-renewing and often require lower-cost ongoing management. For instance, the annual cost of maintaining mangrove forests in Vietnam is estimated at US$7.50 per hectare[36] and the annual cost of maintaining a sea dyke is US$287.50 per hectare[37].

Developing- and developed-world contexts

The UNFCCC negotiations in Durban were another (albeit small) step towards helping meet the adaptation needs of developing regions such as Southeast Asia, where the impacts of climate change are likely to be greatest, communities and peoples are most vulnerable, and the capacity to adapt is lowest (Fig. 1)[3,38]. Indeed, the livelihoods of the poorest communities are particularly tied to natural resources[39,40], often disproportionately impacted by natural disasters[38] and expected to be most severely impacted by climate change[3]. Hence, there is considerable and largely untapped potential for developing countries to integrate EbA into their national adaptation policies[41]. However, adaptation is much more than a developing-world issue. Of the estimated US$49 billion–171 billion annual costs of global adaptation, ~45–61% of those costs arise in developed countries[4]. The potential for deploying EbA in the industrialized world therefore must not be overlooked; in fact, its use in some sectors is increasing. For example, flood-protection dykes along the Danube River in central Europe have exacerbated past flood peaks, leading to massive flood events that have led to average annual costs of US$164 million (ref. 42). With the threat of larger and more frequent flood events under future climate change, a shift in management to a more integrated approach has been instigated — retaining some hard infrastructure while removing much that was maladapted, and combining with EbA in the form of extensive floodplain restoration. This new climate-resilient system now provides US$700 per hectare in flood control, enhanced fisheries, forestry, nutrient retention and recreational benefits[42].

Building the evidence base

Despite rapidly accumulating evidence highlighting the potential utility of EbA, uncertainties remain. For example, the range of potential future climatic conditions under which particular EbA are effective remains unclear. The complexity of the interactions between ecosystem components that influence ecosystem-service delivery means that EbA generally lack the quantitative estimates of maximum adaptation potential that can be approximated (though often with limited accuracy) for many built structures using engineering-based calculations[43]. Judicious extrapolation from available data and field-testing, together with the collection of new data, are urgently needed to fill this gap.

A related uncertainty is what effect climate change will have on an ecosystem's ability to continue to provide its adaptation services into the future. For example, the coastal protection service provided by many coral reefs could be significantly degraded in the latter half of the century if climate change and ocean acidification continue at current rates, driving those systems past one or more tipping points and towards functional collapse[20]. Efforts to quantify the magnitude of climate-induced change that a particular ecosystem can endure and still provide its adaptation service, combined with a broad range of future climate change projections, will help managers make better-informed decisions about the viability of EbA options. Although significant progress has been made in predicting, for example, the ability of some coastal ecosystems to migrate with changing sea levels[44,45], for many ecosystems such issues have yet to be addressed.

Furthermore, climate change is not the only threat ecosystems face. Specific knowledge of how other drivers of global change (for example, deforestation, invasive species) affect the ability of an ecosystem underpinning EbA to sustainably deliver adaptation services is urgently needed. The rate of ecosystem degradation and destruction in many areas of the world continues to accelerate, effectively removing the adaptation potential of vast areas of natural infrastructure before it can be realized[46]. We also need to better understand and articulate the relative merits of EbA that conserve or manage existing ecosystems and those that require the restoration of degraded or completely transformed systems. For example, further research is required to identify the combinations of social, ecological and economic contexts where restoration-based EbA provide competitive adaptation options even though the principal adaptation service may not be delivered for many years, when the restored ecosystem has reached a certain stage of maturity. Similarly, there is increasing recognition that restoration itself cannot be a business-as-usual intervention under climate change, necessitating consideration of multiple possible future climates when evaluating the optimal species mix, or even ecosystem type, to be restored in any locale[47].

Finally, there is a need for more detailed comparisons between EbA and alternative adaptation strategies, evaluated within a robust cost–benefit framework, to better inform decision-making. Current limitations to accurately valuing ecosystem services, particularly those with intrinsic or intangible values that defy conventional monetization (for example, many cultural services)[48], or that are realized only many years into the future, can increase the risk of undervaluing the adaptation services and co-benefits that specific EbA provide in traditional cost–benefit comparisons with other adaptation options[49]. Conversely, we lack understanding of the maladaptive consequences and costs of many hard adaptation interventions, where incautious implementation risks damaging or destroying both ecological and economic well-being[32]. Although EbA options can also have negative consequences — for example, involving trade-offs in the level of provision of other key ecosystem services — they often will be of lower magnitude than those afflicting many hard interventions.

Harnessing nature

As climate change increasingly threatens lives and livelihoods, maximizing adaptation opportunities will minimize its potentially catastrophic effects. The Durban COP achieved another step towards institutionalizing support for global adaptation needs. Focus now must turn to establishing funding priorities for the Green Climate Fund, which will strongly influence the lending patterns of multilateral agencies and help guide national adaptation policies and planning. Now is the time to learn from the oft-repeated mistake of building first and asking questions later. Hard adaptation approaches will undoubtedly form an integral component of local, regional and national climate change adaptation planning. Nevertheless, cost-effective, robust and flexible strategies that can cope with the magnitude, speed and uncertainty of climate change require a broader mix of approaches. Harnessing the adaptive forces of nature may be one of our most widely applicable, economically viable and effective tools to combat the impacts of climate change. Its potential for synergies with other adaptation options, climate mitigation strategies and development goals warrants EbA having a prominent place in both the national and international funding mechanisms now taking shape to fuel global adaptation efforts and in the adaptation decision-maker's toolbox.

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Additional information
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