Cost-effectiveness of maintaining and restoring wetlands as an adaptation measure against climate change

Abstract
Reefs, mangrove forests and inland wetlands in arid regions can play a very cost-effective role in attenuating the impacts of extreme weather events such as the impacts of hurricanes and cyclones, extremes in precipitation and increases in evaporation due to higher temperatures. Inland wetlands can reduce extremes in runoff from of rivers. This conclusion is based on the lessons of a range of field projects conducted by the global NGO Wetlands International, combined with several scientific studies.

Efforts to provide the same protection via embankments, dams or breakwaters appear to be much more expensive compared to these wetlands; especially if the additional wetland benefits such as fisheries are taken into account. Calculating all costs and benefits of hard engineering infrastructures compared to wetlands rarely takes place, unfortunately.

Wetlands International asks for attention for the relatively low costs and high benefits of certain wetlands for climate change adaptation. Our organisation also calls for a complete cost and benefit calculation and comparison of ecosystem based adaptation measures if hard infrastructures are considered in the light of climate change adaptation.

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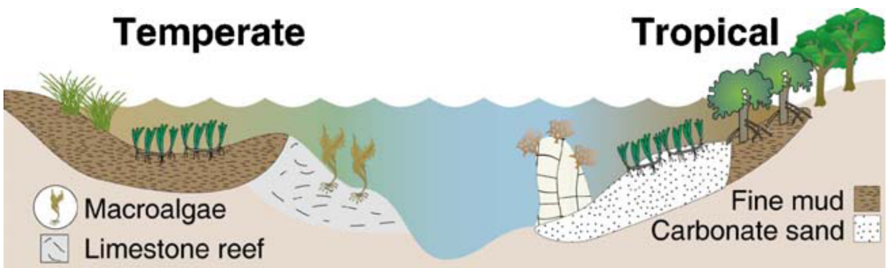
Corals and mangroves are expensive to replace

The 20th century saw a dramatic increase in the utilization of the coasts to the point that now nearly 25% of the world's population – 1.2 billion people - lives within 100 km of the coast, and this proportion is expected to grow to 50% by the year 2030[1]; population densities in coastal regions are about three times higher than the global average, with 70% of the world's mega cities in the coastal zone (i.e., an area up to 200 m above sea level)[2]. The many human activities that take place on the coastal zone have lead to coastal ecosystems being some of the most impacted worldwide, often leading to loss or disruption of ecosystem services as coral reefs, mangrove forests, salt marshes, and seagrass meadows are lost[3] (Figure 1). This loss has come with considerable costs.



Ecosystem	Area (10^6 ha)	Loss (% $year^{-1}$)	Value (US\$ ha^{-1} $year^{-1}$)
Seagrass	18	2–5	19 004
Salt marsh	140	1–2	9 990
Mangrove	15	1–3	9 990
Coral	62	4–9	6 075
Tropical forest	1 900	0.5	2 007

Figure 1. Area of extent, rate of loss, and estimated ecosystem value for key coastal ecosystems in both temperate and tropical regions, compared with tropical forests. (*Duarte CM, Denisson WC, Orth RJW, and Carruthers TJB. 2008. The charisma of coastal ecosystems: addressing the imbalance. Estuaries and Coasts: J CERF 31: 233-238*)

Coral reefs buffer adjacent shorelines from wave action and the impact of storms. At least 500 million people are estimated to live within 100 km of a coral reef and benefit from the production and protection services they provide[4].

[1] Adger WN, Hughes TP, Folke C, Carpenter SR, Rockstroem J. 2005. Social-ecological resilience to coastal disasters. Science 309: 1036-1039.

[2] Duarte CM, Denisson WC, Orth RJW, and Carruthers TJB. 2008. The charisma of coastal ecosystems: addressing the imbalance. Estuaries and Coasts: J CERF 31: 233-238

[3] Nicholls, R.J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden and C.D. Woodroffe, 2007: Coastal systems and low-lying areas. In Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315-356.

[4] Bryant, D. Burke, L., McManus, J., Spalding, M., 1998. Reefs at risk. A map-based indicator of threats to the World's coral reefs. World Resources Institute.

At least nine studies have looked at the role of coral reefs in moderation of extreme weather events in coastal areas and estimated the value of this particular service at between US$25,200 and US$34,408 per hectare per year[5]. It is important to remember that two thirds of the coastal disasters recorded each year are associated with extreme weather events, such as storms and flooding[6].
Alternative hard infrastructures as coastal defenses appear to be very costly: Sri Lanka has spent about US$ 30 million on revetments, groins and breakwaters to curtail coastal erosion where coral reefs had been severely mined. This is estimated to cost US$246,000 to US$836,000 per kilometer[7], and sometimes even more: around US$1 million was spent in Bali, Indonesia, for 500 m of coastal protection[8]. This shows the cost effectiveness of coral reefs as measure for adapting to extreme coastal weather events.

Besides the role in coastal protection, reefs have many other values. The potential net benefits attributable to coral reefs have been estimated to be around US$30,000 million per year, for the global 12658 km (see Table 1); or a total value of US $ 284,000 per hectare.

Table 1. Potential net benefit streams per year of coral reefs per world region (in US$ million)

	SE Asia	**Caribbean (excl. USA)**	**Indian Ocean**	**Pacific (excl. USA)**	**Japan**	**USA**	**Australia**	**World**
Reef Area (sq km)	89000	19000	54000	67000	3000	3000	49000	284000
Fisheries	2281	391	969	1060	89	70	858	5718
Coastal protection	5047	720	1595	579	568	172	629	9310
Tourism/recreation	4872	663	1408	269	779	483	1147	9621
Biodiversity value	458	79	199	172	529	401	3645	5483
Total	12658	1853	4171	2080	1965	1126	6279	30132

Cesar H, Burke L, and Pet-Soede L. 2003. The Economics of worldwide coral reef degradation. Cesar Environmental Economics Consulting and WWF.

Mangroves and sea-grasses help to bind marine and terrestrial sediments, reducing coastal erosion and supporting clear offshore waters that are favourable to corals. For mangroves to be able to have an impact against storm surge it is necessary that they exist as a forest hundreds of meters thick – a narrow strip of coastal forest has minimal effects on the storm surge height and inland flooding[9]. Yet, the ecosystem services provided by mangroves are not always considered in the process of mangrove conversion. For example, villages in Bhitarkanika, India, suffered higher losses if they were not sheltered by mangroves but by embankments, and fared best if they were protected by mangrove forests during a large cyclone in 1999[10]. Sanford estimated the value of coastal protection provided by mangroves to be around US$ 360,000 per kilometer of coast per year[11].

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[5] TEEB 2009. TEEB Climate issues update.
[6] Adger et al 2005. Op. cit.
[7] Berg, H., Ohman, M.C., Troeng, S. and Linden, O. 1998. Environmental economics of coral reef destruction in Sri Lanka. Ambio 27: 627–634.
[8] Cesar H, and Chong, Ch K. 2005. Economic valuation and socioeconomics of coral reefs: methodological issues and three case studies. In Economic Valuation and Policy Priorities for Sustainable Management of Coral Reefs. Second Edition. Ahmed M, Chong ChK, and Cesar H (eds). WorldFish Center, Malaysia
[9] Fritz, H.M., C. Blount (2007). Role of Forests and Trees in Protecting Coastal Areas against Cyclones, Proc. Regional Technical Workshop "Coastal protection in the aftermath of the Indian Ocean tsunami: What role for forests and trees? ", FAO (United Nations), Khao Lak, Thailand, 28-31 August 2006, Food and Agricultural Organization (United Nations), Bangkok, Thailand
[10] Badola R, Hussain SA. 2005. Valuing ecosystem functions: an empirical study on the storm protection function of the Bhitarkanika mangrove ecosystem, India. Environ. Cons. 32: 85-92
Das S and Vincent JR. 2009. Mangroves protected villages and reduced death toll during Indian super cyclone. Proc. Natl. Acad. Sci USA 106:7357-7360
[11] Sanford M. P. 2009. Valuating mangrove ecosystems as coastal protection in post-tsunami South Asia. Natural Areas Journal 29: 91-95

Table 2. Mangrove area, coastal protection values, and loss rates for South Asian countries

	Area (sq. km)	Coastal Protection (US$ million/year)	Direct use	Avg. loss rate (sm. km/yr)	Coastal Protection loss rate (US$ million/year)
Bangladesh	178	65.4	1.5	37.2	13.7
India	3565	1311.5	31.3	112.2	41.3
Indonesia	42550	15654.1	373.7	936.1	344
Malaysia	6424	2363.3	56.4	87.6	32.2
Myanmar	3786	1392.8	33.2	47.5	17.5
Sri Lanka	89	32	0.8	na	na
Thailand	1687	620.6	14.8	63.7	23.4
World	170000	62543	1493.3	2834	1042.6

Sanford M. P. 2009. Valuating mangrove ecosystems as coastal protection in post-tsunami South Asia. Natural Areas Journal 29: 91-95

Restoring mangrove belts: a cost-effective coastal protection

Many mangrove areas have been heavily degraded in the past decades. In these areas, the ability to cope with extreme coastal weather and erosion has largely been lost. It is though possible to restore these ecosystems, as wetlands International has demonstrated in their GreenCoast project (2005-2009). This restoration has proven to be very cost-effective. With only one million euro; we replanted 750,000 mangroves with an average survival rate of 80%, recovering a total area of 415 hectare in Indonesia alone. This protected a coastal strip of roughly 12 kilometer. The project was conducted by involving local communities by providing small loans and grants (the biorights approach). This appears to be much cheaper compared to the conventional coastal defenses as shown earlier in this paper.

Water for arid regions: costs and benefits of wetlands vs. dams

Climate change is expected to lead to on average higher temperatures. These in turn will lead to an extreme increase in evaporation. Of course, this can have very strong impact in arid regions where water is already scarce[12]. Because of this, it is critical that infrastructure development decisions are put in a broader context that considers the impact for an entire area, including the ecosystems and the services they provide to local communities, and not just the particular sector directly affected. Wetlands International is convinced that the wetlands in arid regions like the African Sahel are of increasingly vital importance to sustain the livelihoods of millions.

As an example, we can look at the effect of dams in the Niger River. Intuitively a dam may sound like a good idea – a large reservoir that secures water where this is scarce. In the Sahel, in Africa, most rivers had a natural flow until about 1980, but since then a number of dams have been erected[13]. These have affected river flow, often with strong downstream impacts. All dams provide benefits to some people, but people downstream only lose even in cases where, on average, the country or region benefits as a whole. Wetlands International, together with other partners, pointed out the negative effects that the construction of the Fomi dam (Guinee Conakry) would have on the downstream Inner Niger Delta in Mali and its one million inhabitants. This dam, which would generate electricity (26 GWh/month) in Guinea, would reduce the peak flow level at

[12] Zwarts L, Bijlsma RG, van der Kamp J, and Wymenga E. 2009. Living on the edge. Wetlands and birds in a changing Sahel. KNNV Publishing, Zeist, The Netherlands

[13] Zwarts L, van Beukering P, Kone B, Wymenga E. 2005. The Niger, a lifeline. Effective water management in the Upper Niger Basin. RIZA, the Netherlands.

the Inner Delta that in turn would reduce the inundated area by at least 1400 km^2; this situation would seriously affect 1 million people that depend on the annual floods of the Inner Delta, with an estimated 37% decrease in fish trade, 40% decrease in rice production, and 10-15% reduction in livestock. In addition, it is estimated that more than a third of the ecological values in the Inner Delta would be lost by the construction of Fomi Dam. This example shows that an integral view is needed to make the most cost effective decisions on large infrastructure projects. Impacts in a wide regions should be taken into account and ecosystem based adaptation should be compared with hard infrastructures.

In this particular case, Wetlands International and its partners showed that building new dams is not an efficient way to increase economic growth and reduce poverty in the Inner Niger Delta, and that efforts would be better directed to improve the efficiency of the existing infrastructure and economic activities that already exist in the area.

Table 3. Annual costs and benefits of three dams for several sectors within Mali and Guinea

	Selingue	**Office du Niger**	**Fomi**
Agriculture	152439	36280488	6250000
Livestock	152439	0	-1981707
Fisheries	-4268293	-1219512	-9146341
Biodiversity	-457317	0	-5030488
Transport	304878	-152439	-152439
Electricity	10670732	0	17987805
Total Benefits	6707317	34756098	7621951
Total Costs	3963415	22256098	27743902
Net Value	**2743902**	**12500000**	**-20121951**

Zwarts et al. 2005. The niger, a lifeline. RIZA, the Netherlands

Table X. Impact of Fomi dam on different sectors at the Inner Niger Delta

	Without dams	**With Fomi dam**
Rice (tonnes)	99200	-34000
Fish production (tonnes)	54000 - 133000	-8500
Cattle	1260000	-24000 - -48000
Biodiversity (waterbirds)	3000000-4000000	Loss of 60% of key habitats and extinction of populations

Zwarts et al. 2005. The niger, a lifeline. RIZA, the Netherlands