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The protective service of mangrove ecosystems: A review of valuation methods *Marine Pollution Bulletin* special issue: "Turning the tide on mangrove loss"

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ABSTRACT

Concern over the loss of mangrove ecosystems often focuses on their role in protecting coastal communities from storms that damage property and cause deaths and injury. With climate change, mangrove loss may also result in less protection against coastal storms as well as sea-level rise, saline intrusion and erosion. Past valuations of the storm protection benefit of mangroves have relied on the second-best replacement cost method, such as estimating this protective value with the cost of building human-made storm barriers. More reliable methods instead model the production of the protection service of mangroves and estimate its value in terms of reducing the expected damages or deaths avoided by coastal communities. This paper reviews recent methods of valuing the storm protection service of mangroves and their role in protecting coastal areas and communities of tropical developing countries.

1. Introduction

Although approximately 150,000 km^2 of mangroves exist worldwide, over two thirds of the remaining area are located in just eighteen countries — Indonesia, Brazil, Australia, Mexico, Nigeria, Malaysia, Myanmar, Bangladesh, Cuba, India, Papua New Guinea and Colombia (Giri et al., 2011; Spalding et al., 2010). Other major mangrove areas are found in Guinea Bissau, Mozambique, Madagascar, the Philippines, Thailand and Vietnam (Giri et al., 2011). However, around one quarter of the world's mangroves have been lost due to human action, mainly through conversion to aquaculture, agriculture and urban land uses (Barbier and Cox, 2003; Duke et al., 2007; Friess and Webb, 2014; Spalding et al., 2010). With the exception of Australia, which is a high-income economy, these development pressures are mounting in all the major mangrove countries. Finally, the global disappearance of mangroves is having a major impact on the vulnerability of coastal populations and property in developing countries, especially with respect to damaging and life-threatening storms and floods (Alongi, 2008; Barbier, 2014; Cochard et al., 2008; Spalding et al., 2014).

There is mounting evidence that mangroves provide some type of protection against storms and coastal floods, mainly through their ability to attenuate waves or buffer winds (Barbier, 2012b; Barbier et al., 2008, 2011; Gedan et al., 2011; Koch et al., 2009; Marois and Mitsch, 2015; McIvor et al., 2012a, 2012b; Sandilyan and Kathiresan, 2015; Spalding et al., 2014). As this article will discuss, there are now a number of economic studies that have attempted to estimate the value of this benefit. In addition, these studies represent an evolution in methods of valuation of the storm protection service of mangroves. Past valuations of the storm protection benefit of mangroves have relied on the second-best replacement cost method, which employs the cost of building human-made storm barriers to approximate the value of this service. More reliable methods instead model the production of the protection service of mangroves and estimate its value in terms of reducing the expected damages or deaths avoided by coastal communities.

In addition, there is also concern over the increasing vulnerability to climate change of rural populations in the low-elevation coastal zone (LECZ) of developing countries, which is the contiguous area along the coast with less than 10 meters (m) elevation (Barbier, 2015). As mangrove ecosystems disappear or are degraded, there will be less protection against short-lived natural disasters with immediate and often extreme impacts, such as flooding and storm surge, as well as long-term climatic changes with more gradual impacts, such as sea-level rise, saline intrusion and erosion (Barbier, 2014, 2015; Barbier et al., 2011; Gedan et al., 2011; IPCC Working Group II, 2014; Spalding et al., 2014; Temmerman et al., 2013). In addition, the changes in precipitation, temperature and hydrology accompanying climate change are likely to threaten remaining coastal and near-shore ecosystems (Dasgupta et al., 2011, 2014; Doney et al., 2012; Elliott et al., 2014; Erwin, 2009; IPCC Working Group II, 2014; Spalding et al., 2014; Webb et al., 2013). Thus, understanding the value of mangroves for providing protection against storm, flood damages and other coastal hazards is important for the broader policy issue of determining the vulnerability of the rural poor in LECZ of the continual loss of mangroves.

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The paper proceeds as follows. The next section reviews a few representative studies of the economic value of the coastal protection benefit provided by mangroves. These studies indicate an important transformation in valuation methods, which is discussed in a subsequent section. The paper then discusses some of the important issues surrounding valuing the protective benefits of mangroves. The paper concludes by discussing further research priorities with respect to analyzing the protective value of mangrove ecosystems.

2. Economic valuation of mangrove protection benefits

Since the 2004 Indian Ocean tsunami, there has been strong interest globally in both restoring mangrove ecosystems and in their ability to protect coastlines and people from damaging storms. There is also an ongoing debate over whether or not the cost of mangrove restoration is higher than the value of the coastal protection service provided by these ecosystems (Sandilyan and Kathiresan, 2015). Successful mangrove restoration can certainly be expensive and variable, ranging from US$225 to US$216,000 per hectare (ha), excluding the costs of the land (Lewis, 2005). However, most estimates are around US$5000 to US$10,000 per ha; for example, in the Caribbean, restoration site costs are US$5077 per ha (Adame et al., 2015), and in Thailand US$8812 to US$9318 per ha (Barbier, 2007). In addition, mangrove ecosystems provide other important economic benefits other than storm protection, including carbon sequestration, collected wood and non-wood products, and support for off-shore fisheries (Barbier, 2007; Barbier et al., 2011; Huxham et al., 2015).

To date, there are still only a few economic studies that estimate the protective value of mangrove ecosystems, but more estimates have been emerging. Table 1 provides a representative selection of recent studies from tropical developing countries. Although many more studies exist than those listed in Table 1, there are problems of reliability in the estimates of protection benefits produced by some studies because of the arbitrary valuation methods often employed (Barbier, 2007, 2012b).

As Table 1 indicates, the protective value of mangrove ecosystems is directly related to their ability to attenuate, or reduce the height, of the storm surges and waves as they approach shorelines. This wave attenuation function derives from the vegetation and root structure of mangroves, which are an important source of friction to moving water and sediment (Bao, 2011; Gedan et al., 2011; Koch et al., 2009; Massel et al., 1999; Mazda et al., 1997; McIvor et al., 2012b). In addition, mangrove trees also have the capacity to buffer winds (Das and Crépin, 2013; McIvor et al., 2012a). The value of mangroves in providing such protection against high-speed and damaging winds is an often over-looked, but nonetheless very important, benefit. The growing evidence indicating that mangroves have significant wave attenuation and wind buffering functions has led to interest in valuing their storm protection benefit, and also provided better understanding of the underlying ecological structure and functions contributing to this benefit, including how it varies across mangrove landscapes and different tide levels (Barbier, 2012a; Barbier et al., 2008; Koch et al., 2009; McIvor et al., 2012a, 2012b).

Despite the importance of the coastal protection service of mangroves, the geographic coverage of valuation studies remains limited (see Table 1). Moreover, even recent studies (e.g., Huxham et al., 2015) have continued to employ ad hoc valuation methods, such as benefit transfer and replacement cost, which have been criticized for their reliability (see Barbier, 2007; Chong, 2005; and further discussion below). Nevertheless, the studies listed in Table 1 provide an indication of the economic importance of the storm protection benefits of mangrove ecosystems.

For example, mangroves significantly reduced the number of deaths and damages to property, livestock, agriculture, fisheries and other assets during the 1999 cyclone that struck Orissa, India (Badola and Hussain, 2005; Das and Vincent, 2009). Statistical analysis indicates that there would have been 1.72 additional deaths per village within 10 km of the coast if mangroves had been absent (Das and Vincent, 2009). Economic losses incurred per household were greater (US$154) in a village that was protected by a constructed embankment compared to those (US$33) in a village protected by mangrove forests (Badola and Hussain, 2005).

Since the 2004 Indian Ocean tsunami, there has been considerable debate as to whether the presence of mangroves reduced the impacts of the extremely large wave surges associated with this event, thus protecting lives and property (see Cochard, 2011; Marois and Mitsch, 2015 for reviews). As one post-tsunami assessment concluded, "mangroves play a critical role in storm protection, but with the subtle point that this all depends on the quality of the mangrove forest" (Dahdouh-Guebas et al., 2005, p. 446). In a definitive study for one of the worst affected regions, Aceh, Indonesia, Laso Bayas et al. (2011) confirm that not only coastal topography and near-shore bathymetry, but also vegetation including the presence of mangroves, plantations and other coastal forests, were effective in reducing the deaths and damages caused by the tsunami. Mangroves, forests and plantations situated between villages and the coastline may have decreased loss of life by 3% to 8%, as the trees appear to have slowed or diverted the waves. If these natural barriers were located behind the villages, casualties increased by 3% to 6%, because of the debris from the trees that increased the risk of death.

A series of studies for Thailand also indicate a significant protective value of mangroves against the damages caused by frequent storm events (Barbier, 2007; Barbier et al., 2008; Sathirathai and Barbier, 2001). Sathirathai and Barbier (2001) employed the replacement cost method to estimate the value of coastal protection and stabilization provided by mangroves in Surat Thani Province, Thailand. Using the cost of constructing breakwaters to replace protection by mangroves, the authors calculate that the present value over 20 years of mangrove protection and stabilization service is \$12,263 ha^{-1}. The contribution of mangrove deforestation to economic damages of storms was estimated for 39 coastal storm events affecting Southern Thailand from 1975 to 2004 (Barbier, 2007). Over 1979 to 1996, the marginal effect of a one square kilometer loss of mangrove area was an increase in expected storm damages of about US\$585,000 km^{-2}, and from 1996 to 2004, the expected increase in damages from a 1 km^2 loss in mangroves was around US\$187,898 km^{-2} (\$1879 ha^{-1}). Barbier et al. (2008) further show how variation in this protective value of mangroves across a 10 km^2 landscape could lead to substantial change in land use decisions, including the conversion of mangroves to shrimp farms. Barbier (2012a, 2012b) further shows how the type of declining wave attenuation function affects the mangrove conversion decision, including the optimal location of shrimp ponds in the mangrove ecosystem, as well as the risk of ecological collapse.

Table 1
Examples of studies of the protective value of mangrove ecosystems.

Ecosystem structure and function	Ecosystem service	Valuation examples	Valuation method
Attenuates and/or dissipates waves, buffers wind	Protection of coastal communities against property damage, loss of life and/or injuries.	Badola and Hussain (2005), India	Damage cost avoided
		Barbier (2007), Thailand	Expected damage function
		Das and Crépin (2013), India	Expected damage function
		Das and Vincent (2009), India	Storm-related deaths avoided
		Huxham et al. (2015), Kenya	Replacement cost
		Laso Bayas et al. (2011), Indonesia	Deaths and damages avoided
		Sathirathai and Barbier (2001), Thailand	Replacement cost

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