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# Valuing the storm protection service of estuarine and coastal ecosystems

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ABSTRACT

Recent concern over the loss of estuarine and coastal ecosystems (ECEs) often focuses on an important service provided by these ecosystems, their role in protecting coastal communities from storms that damage property and cause deaths and injury. Past valuations of this benefit have relied on the second-best replacement cost method, estimating the protective value of ECEs with the cost of building human-made storm barriers. A promising alternative methodological approach to incorporate these factors is using the expected damage function (EDF) method, which requires modeling the production of this protection service of ECEs and estimating its value in terms of reducing the expected damages or deaths avoided by coastal communities. This paper illustrates the EDF approach to value the storm protection service of ECEs, using the example of mangroves in Thailand to compare and contrast the EDF with the replacement cost approach to estimate the protective value of ECEs. In addition, the example of marshes in the US Gulf Coast is employed to show how the EDF approach can be combined with hydrodynamic analysis of simulated hurricane storm surges to determine the economic value of expected property damages reduced through the presence of marsh wetlands and their vegetation along a storm surge path.

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## 1. Introduction

Since Hurricanes Katrina and Rita in 2005 and the Indian Ocean tsunami in 2004, attention has focused on how the continuing worldwide loss of estuarine and coastal ecosystems (ECEs) is making coastlines and coastal communities vulnerable to flooding and storm events (Arkema et al., 2013; Braatz et al., 2007; Cochard et al., 2008; Day et al., 2007). There is mounting evidence that a variety of ECEs, including marshes, mangroves, near-shore coral reefs, seagrass beds, and sand beaches and dunes, provide some type of protection against storms and coastal floods, mainly through their ability to attenuate waves or buffer winds (Barbier, 2011; Barbier et al., 2008, 2011; Bouma et al., 2010; Gedan et al., 2011; Koch et al., 2009; Paul and Amos, 2011; Shephard et al., 2012). However, to date, there are few economic studies that estimate the protective value of many systems, although some estimates are beginning to emerge for marsh and mangroves (see Table 1). Although many more studies exist than those indicated in Table 1, there are problems of reliability in the estimates of protection value produced by some of these earlier studies because of the arbitrary valuation methods often employed (Barbier, 2007, 2011).

As Table 1 indicates, the protective value of estuarine and coastal ecosystems (ECEs) 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 contained in some ECEs, such as marsh, seagrass beds and mangroves, which are an important source of friction to moving water (Bouma et al., 2010; Gedan et al., 2011; Koch et al., 2009; Massel et al., 1999; Mazda et al., 1997; Paul and Amos, 2011; Shephard et al., 2012). In the case of coral reefs, beaches and sand dunes, it is their reticulated structure that acts as a natural barrier to storm waves, although the presence of grasses on dunes and beaches enhances wave attenuation (Barbier et al., 2008; Madin and Connolly, 2006; Pompe and Rinehart, 1994; Stockdon et al., 2007).

The growing evidence indicating that a number of estuarine and coastal ecosystems (ECEs) have a significant wave attenuation function has led to interest in valuing their storm protection benefit. But despite the importance of this coastal protection service, very few economic studies have estimated a value for it. Those studies that have been conducted tend to use benefit transfer and replacement cost methods of valuation in an ad hoc manner, which undermine the reliability of the value estimates

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**Table 1**
Examples of studies of the protective value of estuarine and coastal ecosystems.

| Ecosystem structure and function | Ecosystem service | Valuation examples |
|---|---|---|
| Attenuates and/or dissipates waves, buffers wind | Protection of coastal communities against property damage, loss of life and/or injuries | Badola and Hussain (2005), Das and Crépin (2013) and Das and Vincent (2009), mangroves, India<br>Barbier (2007, 2012), Barbier et al. (2008) and Sathirathai and Barbier (2001), mangroves, Thailand<br>Barbier and Enchelmeyer (2014) and Barbier et al. (2013), marsh, SE Louisiana, US<br>Chong (2005), mangroves and coral reefs, various regions<br>Costanza et al. (2008), marsh, US Atlantic and Gulf Coasts<br>Farber (1987), marsh, Louisiana, US<br>King and Lester (1995) and Mangi et al. (2011), marsh, United Kingdom<br>Landry et al. (2011), coastal wetland restoration, US<br>Laso Bayas et al. (2011), mangroves, Aceh, Indonesia<br>Petrolia and Kim (2009), barrier islands, Mississippi, US<br>Petrolia and Kim (2011) and Kim and Petrolia (2013), marsh, Louisiana, US<br>Petrolia et al. (2014), coastal wetland and barrier island restoration, Louisiana, US<br>Pompe and Rinehart (1994), beaches, South Carolina, US<br>Wilkinson et al. (1999), coral reefs, Indian Ocean |

(see Barbier, 2007; Chong, 2005; and further discussion below). For example, for the storm protection valuation studies indicated in Table 1, only a few are considered reliable. Most of these studies of the protective value of ECEs have focused on marshes and mangroves.

Widespread reef destruction caused by catastrophic events and global change, such as hurricanes, typhoons and coral bleaching, gives some indication of the value of the lost storm protection services. For example, as a result of the 1998 bleaching event in the Indian Ocean, the expected loss in property values from declining reef protection is estimated to be \$174 $ha^{-1}$ $year^{-1}$ (Wilkinson et al., 1999). Evidence from the Seychelles documents how rising coral reef mortality and deterioration have increased significantly the wave energy reaching shores that are normally protected from erosion and storm surges by these reefs (Sheppard et al., 2005). However, to date, this effect has not been valued explicitly.

Although field studies indicate that seagrass meadows and sand dunes may have a significant impact on reducing storm waves, no valuation studies currently exist of the resulting protection benefit. For seagrasses, one problem is that coastal protection can vary significantly if damaging storm events occur when plant biomass and/or density are low (Koch et al., 2009; Paul and Amos, 2011). This is particularly important in temperate regions, where seasonal fluctuations of biomass may differ from the seasonal occurrence of storms. For example, along the US Atlantic coast, the biomass of seagrass peaks in the summer (April–June) yet decreases in the fall (July–September) when storm events usually strike (Koch et al., 2009). In tropical areas, seagrass beds have relatively constant biomass throughout the year, so the coastal protection service is relatively unaffected by seasonal or temporal variability.

An analysis of the economic damages associated with 34 major hurricanes striking the US coast since 1980 found that coastal wetlands explained 60% of the variation in relative damages inflicted on coastal communities (Costanza et al., 2008). The additional storm protection value per unit area of coastal wetlands from a specific hurricane ranged from a minimum of US\$23 $ha^{-1}$ for Hurricane Bill to a maximum of US\$463,730 $ha^{-1}$ for Hurricane Opal, with a median value of just under US\$5000 $ha^{-1}$. However, for US Gulf Coast wetlands, the reliability of estimates of the value of wetlands for storm surge protection has been questioned, because the methods used have not taken into account that "the level of storm surge attenuation provided by wetlands depends on many factors including the location, type, extent, and condition of the wetlands and the properties of the storm itself" (Engle, 2011, p. 185).

Recent hydrodynamic storm surge models developed for southern Louisiana also show how the attenuation of surge by wetlands is affected by the bottom friction caused by vegetation, the surrounding coastal landscape, and the strength and duration of the storm forcing (Loder et al., 2009; Resio and Westerink, 2008; Wamsley et al., 2010). By incorporating such features into an economic valuation of simulated hurricane storm surges, Barbier and Enchelmeyer (2014) and Barbier et al. (2013) estimate that a marginal increase in the wetland-to-water ratio along a nearly 6 km storm transect would lower residential property flood damages in Southeast Louisiana by \$592,000–792,100, whereas the marginal increase in bottom friction caused by more wetland vegetation along the transect would reduce flood damages by \$141,000–258,000. Such marginal changes in wetland area and vegetation roughness along a single storm transect are equivalent to saving 3–5 and 1–2 properties/storm, respectively.

Marsh wetlands may also act as a buffer against the wind damages from hurricanes and other storms. Using historical storm frequencies for the Louisiana Gulf Coast, Faber (1987) estimates the expected wind damage to property from the loss of intervening marsh. The present value of the loss of a one-mile strip of wetlands amounts to between US\$1.1 and US\$3.7 million (1980 dollars). The increased cost to property damage amounted to between US\$7 and US\$23 $acre^{-1}$.

A different approach was taken to estimating the protective value of marsh as a sea defense in East Anglia, United Kingdom (King and Lester, 1995). In this region, existing marsh areas in front of constructed sea walls together provide protection against storms, and less marsh means that higher sea walls have to be built. The authors therefore estimate the value of marsh as sea defense by calculating the additional capital and maintenance costs that would be needed to build higher walls as the marsh disappears. Evaluation of an 80 m width of salt marsh in front of a seawall yields a value over the whole area of between £30 and £60 $m^{-2}$.

Mangroves significantly reduced the number of deaths and damages to property, livestock, agriculture, fisheries and other

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