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Valuing the protection services of mangroves at national scale: The Philippines

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ABSTRACT

In this work we pilot a methodology to value the annual coastal protection benefits provided by mangroves in the Philippines and identify where these natural coastal defenses deliver the greatest protection. This is the first rigorous, engineering-based, nationwide evaluation of the effectiveness of mangrove habitats as natural defenses. By comparing flood damages for scenarios with and without mangroves, the study estimates the socio-economic benefits for protecting people and property, to inform conservation and disaster risk reduction policies. Without mangroves, flooding and damages to people, property and infrastructure in the Philippines would increase annually around 25%. These habitats reduce flooding to 613,500 people/year, 23% of whom live below the poverty line. They also avert damages to 1 billion US$/year in residential and industrial property. If mangroves were restored to their 1950 distribution, there would be additional benefits to 267,000 people annually, including 61,500 people below poverty and an additional 453 mill. US$ in avoided damages. Currently, mangroves prevent more than 1.7 billion US$ in damages for extreme events (1-in-50-year). Ultimately, rigorous economic estimates of critical ecosystem services like this will help the national government to integrate the value of mangroves to people, into their national accounting systems.

1. Introduction

Tropical coastal ecosystems such as offshore coral reefs and intertidal mangroves inhabit coastal regions where 23% of the world's population and 50% of the poor people live (Small and Nicholls, 2003). In addition to providing important natural habitats, these ecosystems are also of value to human beings due to the services they provide. Ecosystem services are the contributions of natural ecosystems to human wellbeing, and they result from the interaction of these ecosystems with built, human and social capital (Costanza et al., 2017; Daily, 1997; MEA, 2005). Some of these services have been quantified in terms of their economic value (Christie et al., 2012; de Groot et al., 2012; Norton et al., 1998). But not all services are perceived in the same way or provide the same benefits. Broadly, ecosystem services can be divided into two categories: (a) services with direct benefits that are relatively easy to perceive and measure, such as provisioning services (e.g. food and raw materials) (Barbier, 2007; Breaux et al., 1995) or cultural services (e.g. tourism, cultural heritage and recreation) (Brander et al., 2007); and, (b) services with indirect benefits that are less easy to perceive and quantify, such as regulating services (e.g. flood protection, climate regulation, disease control) and supporting services (e.g. habitat for species livelihood). Such services, particularly flood protection services that rely on keeping ecosystems intact, are rarely valued rigorously (Brander et al., 2012; de Groot et al., 2012; Narayan et al., 2016), have a "hidden value" that may not be perceived until the ecosystem is lost (Sarkis et al., 2010).

This lack of rigorous evaluation of the flood protection services of coastal ecosystems encourages short-term over-exploitation and degradation, reducing the quantity and quality of the goods and services provided. By measuring the value of these services provided by coastal ecosystems, we can inform policies for sustainable development, disaster risk reduction and environmental conservation. This study is oriented to accomplish the requirements of decision-makers (Bagstad et al., 2013), and seeks to fill some of the gaps and deficiencies identified in the last 20 years of natural capital valuation (Costanza et al., 2017).

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One of the challenges in evaluating flood protection services is the nature of the disciplines involved: ecology and economy. Studies from an ecological perspective use sophisticated ecological models but apply rudimentary valuation methodologies, while studies, focused on the economic perspective, tend to use low accurate proxies for the ecosystem effects based on causal relationships or extrapolation of existing data, but more sophisticated valuation methods (Crossman et al., 2013; Philipp et al., 2013). We address these inconsistences between the ecological and economic approaches by improving both the modelling of the ecosystem processes and effects and the methods for economic valuation. For this purpose, we use advanced process-based numerical models to simulate the physical processes involved in hydrodynamics and ecosystem interactions and we rigorously quantify at multiple spatial scales (> 30 m) the value of the flood protection service of mangroves in the Philippines, in human and economic terms.

In the specific case of valuing coastal flood risk protection of mangroves we used the avoided damage method (Samonte-Tan et al., 2007; van Beukering et al., 2006). This method involves measuring the additional people and property affected if existing mangroves were lost. Other approaches, such as the replacement cost method, consider the cost of manmade structures (e.g. submerged breakwaters or seawalls) that would provide an equivalent protection level. However, this method is difficult to apply over large areas. It can overestimate the protection value of ecosystems in areas that are flooded but do not have exposed people or property, and conversely, under-estimate these values in areas of high population density and economic exposure. The appropriate choice of valuation method would make it possible to fulfil the first priority of the Chart of Sendai Framework for disaster Risk Reduction 2015–2030, by improving the current understanding of the disaster risk consequences in case of losing coastal habitats.

Mangrove forests, due to their biophysical characteristics can mitigate the effect of storms, floods, erosion and wind, therefore contributing to disaster risk reduction and climate change adaptation (Duarte et al., 2013). The main parameters affecting flooding and erosion are bottom friction, water depth, mangrove area (in particular the cross-shore width), vegetation density, the vertical structure and shape of each individual tree. The vertical structure of mangroves, including roots, trunk and canopies, plays an important role in reducing wave heights and water levels. The aerial roots of mangroves retain sediments and prevent erosion, while the roots, trunks and canopy reduce the force of incoming wind and waves and reduce flooding (McIvor et al., 2016). For example, a 500-meter wide mangrove forest decreases wave heights by 50–100% (Mcivor et al., 2012a,b; Spalding et al., 2010). In low lying areas, even relatively small reductions in water levels can reduce flooding and prevent property damage. In the long term, mangroves increase sedimentation, decrease erosion and maintain tidal creeks and channels. Mangroves can also support livelihoods and reduce social vulnerability by providing resources such as fish and other.

Among the different coastal habitats, mangrove forests occur in many countries, but they exist in only a small thin but critical band on coastlines. They represent less than 1% of all tropical forests globally yet occur in 118 mostly tropical and developing countries. Asia leads the largest extent of mangroves continents (42%), followed by Africa (20%), North and Central America (15%), Oceania (12%) and South Africa (11%) (Giri et al., 2011). However, mangroves have seen significant decline. For example, these habitats covered 200,000 km^2 in 1997 (Spalding et al., 1997) and 150,000 km^2 in 2010 (Spalding et al., 2010), a loss rate of nearly 2% yearly. Prior work, in particular South Asia, shows that mangrove loss contributes to increasing coastal risk (Giri et al., 2015). As mangroves are degraded and lost, more people and property are directly at risk from the impacts of storms and floods.

Coastal protection is a particularly significant ecosystem service for nearshore habitats, as it is supported by previous studies which have highlighted its relative importance compared with others. For example, mangroves protection service was valued in 15,997 US$/ha in Thailand, representing the 84% of the total ecosystem worth (Barbier, 2007), and the global average value of coral reefs for protection against erosion represents 43% of the total value of its ecosystem services (de Groot et al., 2012). Both contributions to the total value are greater than other measured ecosystem services (de Groot et al., 2012) such as tourist (31%), food and water provisioning (15%), regulating (6%, excluding protection) and habitat (5%).

To halt the loss of the natural capital and ensure the continued provision of ecosystem services, they must be better accounted for in policy and management decisions. However, these ecosystems are rarely considered within coastal development policies, or within wealth accounting systems. Conventional approaches to measuring wealth and economic development focus mostly on built capital and fail to account for the value of all goods and services provided by natural ecosystems. Better valuations of the protection services of coastal habitats can inform decision-makers as they strive to meet risk reduction and environmental management objectives. National economic accounts provide an important pathway for the consideration of these ecosystem services (Polasky et al., 2015).

In this study we quantify the flood reduction capacity of mangroves, following a multistep probabilistic approach, and apply the methodology at national scale in the Philippines, one of the country's most at risk globally from coastal storms and flooding. It is important to know that mangroves not only protect people and property against flooding induced by local extreme events (i.e. tropical cyclones) but also work as daily defense against regular waves from extreme storms far away. Furthermore, the fact that the most practical way for governments to integrate the valuation of natural capital in their decision-making is to do annually results in the necessity of following a probabilistic approach based on Annual Expected functions to provide damages and benefits of coastal ecosystems.

This study shows that flood protection service valuations facilitate further practical applications such as including the monetary value of coastal ecosystems into national systems for wealth accounting and provide critical information to decision-makers allowing them to harness natural defenses for disaster risk management, coastal zone management, and climate change adaptation.

2. Methods and study site

2.1. Analytical framework of risk for the flood protection valuation

To understand how ecosystems, such as mangroves, protect the coast from flooding, risk assessment methods should be used. In the case of coastal flood risk protection by mangroves, we used a global analytical framework similar to others (Pascal et al., 2016; van Zanten et al., 2014). In this, we established the role of ecosystems in reducing the impacts of flooding within a classic risk approach (IPCC, 2014) of hazard, exposure and vulnerability (Fig. 1).

The increase in any one of them would increase the magnitude and probability of the damages. To reduce flood risks, mangroves play an important role in modifying each of the three risk components: Hazard, Exposure and Vulnerability. This study focusses on the contribution of mangroves to reducing Hazard, while they may also be able to modify Exposure (increase or reduce) and reduce Vulnerability, by increasing resilience.

2.2. Multi-step methodology framework overview

In this work we describe and pilot a multistep modeling framework to estimate the economic value of the coastal protection ecosystem services from mangroves in a way that can be readily included into national wealth accounting systems (Table 1). This study follows a multistep approach, and demonstrates a methodology that integrates different fields of knowledge such as engineering, biology, mathematics, physics and socioeconomics, applying a hybrid downscaling of