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Global values of coastal ecosystem services: A spatial economic analysis of shoreline protection values

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ABSTRACT

A global study to estimate the ecosystem service value of specific coastal ecosystems is developed. Specific variables are identified and used to develop a global multivariate regression function that supports the identification of important drivers of the value of ecosystem service of coastal protection around the world, and the Caribbean is examined in detail. Variables hypothesized to affect the ecosystem service value fall into three categories, and were informed by a meta-analysis of existing economic literature. Site characteristics include ecosystem type and size. Study characteristics include valuation method. Context variables include measures of development, anthropogenic pressures, biodiversity, and population density. Results of the meta-analytic regression show that variables significantly affecting the ecosystem service value included size, level of development, storm frequency, valuation method and gross domestic product per capita. A benefit transfer function is then generated to extrapolate values to other sites around the world where coastal wetlands, mangrove and coral reefs exist. This function is used to derive a global map of the value of a set of coastal ecosystem services worldwide. The Caribbean region is discussed as a case study in this global analysis.

1. Introduction

One third of the world's population lives in coastal communities and coastal zones are twice as densely populated as inland areas (MA, 2005; Barbier et al., 2008). Although coastal communities may interact in very different ways with the natural ecosystems they are located in and surrounded by, it is increasingly well understood that natural ecosystems play a crucial role in determining the well-being of human populations (TEEB, 2010). Thus, preserving the continuous flows of benefits is increasingly recognized as one of the most important catalysts for the conservation and sustainable management of natural ecosystems (Chan et al., 2006; Turner et al., 1998; Fisher et al., 2009).

Coastal wetlands, mangroves and near-shore coral reefs provide crucial benefits to many coastal communities by protecting them from flooding and storm surges, both seasonal and idiosyncratic storm events. The benefits from this ecosystem service may include prevention of loss of life, damages to housing, infrastructure and food sources, as prevention of saltwater intrusion (Brander et al., 2012). This is particularly important in the case of poor, vulnerable communities, which recent research shows to be often the most critically dependent on the provision of ecosystem services (Ghermandi et al., 2013; McGranahan et al., 2007). A widely accepted common ground in most definitions of vulnerability is the identification of the inability to cope with adverse effects, whether these are natural disasters, war, food shortages, or others (McCarthy et al., 2001; Adger, 2009). Vulnerability may be linked to geographical limitations, which constrain market access, for example. Communities which show in general a more strong direct reliance on ecosystem services and the absence of substitutes are more sensitive to impairment in their provision (WRI, 2005; Ghermandi et al., 2013). One important way to investigate vulnerability and dependence on coastal ecosystem services is to examine their estimated values. While coastal ecosystems offer a wide variety of benefits which are difficult to quantify, making estimations of the value can lead to understanding the drivers of the high and low values, and in turn inform policy. While this is a global analysis, it can be used for informing regional policy as well, especially in areas which are data poor.

Capturing the economic value of ecosystem services in a specific monetary unit or welfare measure is a challenging endeavor. Although valuation research is an active area, the lack of a

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standardized methodology and common type of unit makes comparisons difficult. Ideally, the determination of the economic values of services should be preceded by the biophysical assessment of their availability, which in turn should be distinguished from their overall provision or availability, to their actual use, in the form of benefits that humans enjoy from the services. This is however rarely the case, and for a number of reasons. First, some ecosystem services are more easily and directly quantified than others. Second, ecosystem services are inherently spatial and assessments need to rely on modeling of their flow in space and time (TEEB, 2010). As a general rule, biophysical assessments are highly dependent on the status of scientific knowledge and data availability, often relying on proxies to identify service provision, as opposed to benefits. This is particularly true in the case where there is lack of consensus on the best/ideal measurement units for these services. Finding a common metric with which to compare a wide variety of studies and management outcomes is however crucial to inform policy decisions, and hence, monetary valuation, even in the absence of biophysical assessment, can be useful as a common language and framework in which the available information can be analyzed and tradeoffs can be evaluated.

Further compounding the difficulty in quantifying and valuing ecosystem services is the fact that many ecosystem services are public goods and as a result, subject to a failure of the market to reflect their economic value.[1] This is the case, for instance, of the service of shoreline protection, which, in spite of its significance to human lives, is rarely quantified, valued or taken into account in management decisions (de Groot, 1994). Careful quantification and valuation of the services can lead to better informed policy decisions. For that reason, and in an attempt to address different policy questions, researchers have attempted the valuation of services at different spatial scales of assessment, from local (Badola and Hussain, 2005) to global scale (Costanza et al., 1997; TEEB, 2010; de Groot et al., 2012; Ghermandi and Nunes, 2013). These types of studies look at the value of a wide range of ecosystem services, measuring them with a variety of different methods, with the ultimate goal of alleviating the shortcoming associated with the common exclusion of nature's values into policy and decision-making.

This study is the first systematic attempt to examine and map the economic value of shoreline protection as provided by three major coastal ecosystem types – coastal wetlands, mangroves and coral reefs—worldwide. We examine the available information on their economic value and investigate their dependence from a series of study-, site- and context-specific driving factors in a geographically explicit manner by means of meta-analysis. Identifying and understanding the drivers of the ecosystem services values for specific services is a first step towards their eventual integration into governmental policies and accounting. Next, the results of the meta-analytic regression are used to infer an estimate of the value of ecosystem services in other areas for which direct valuation has not been performed and produce a map of the worldwide distribution of shoreline protection values from the considered ecosystems. Finally, we discuss how the results of this study can be interpreted for the Caribbean region, with specific respect to coastal conservation and development policy.

1.1. The services of mangroves, coral reefs and wetlands

One ecosystem service provided by mangroves, coral reefs and coastal marshes in wide coastal areas worldwide devoid of other, artificial defenses, is storm regulation or coastal protection. All three ecosystems mitigate the full effect of the storm surges, slowing or preventing them from reaching coastal human populations.

In general, when reefs and mangroves are damaged or destroyed, the absence of this natural barrier has been shown to increase the damage to coastal communities from normal wave action and violent storms. This storm protection that coastal ecosystems provide prevents both the loss of life and property for communities living in near-shore areas. The roots of mangrove plants help to hold the sediment in place (Orth et al., 2006). Mangrove forests protect inland communities and freshwater resources from saltwater intrusion during storms, and they protect near shore settlements from erosion (Semesi, 1998; Badola and Hussain, 2005). The root systems of mangroves prevent the resuspension of sediment and slow water flow in areas where the protection of shoreline-based activities are important (Spaninks and van Beukering, 1997; Gilbert and Janssen, 1998). Mangroves protect areas from storms, have some recreational and fishing service value, and protect water quality (Aburto-Oropeza et al., 2008). In general, mangroves serve as “natural barriers” to protect life, infrastructure and property of coastal communities (Badola and Hussain, 2005). In addition the protection of property and infrastructure will indirectly benefit the tourism and recreation industries, but this indirect effect is not measured in this study. Valuation of mangroves has primarily focused on their storm protection services, though there is a small growing literature on the direct uses of mangroves. In major storms, research has shown that coastal communities experienced greater damage and higher mortality rates from many types of natural disasters when mangroves had been removed, and the value of these damages ranges widely (Danielsen et al., 2005; Barbier, 2007a, 2007b; Das and Vincent, 2009).

Coral reefs (and mangroves) also minimize the impact of storms by reducing wind action, wave action, and currents and coral reef structures buffer shorelines against waves, storms and floods (Done et al., 1996; Moberg and Folke, 1999; Adger et al., 2005). In general, the structure of coral reefs provides a significant barrier to storm surges (UNEP-WCMC, 2006). They are increasingly under human and climatic threat to due to water pollution, sea temperature rise and ocean acidification (Bruno and Bertness, 2001), and regional studies have shown that the threats that coral reefs are facing affect their ability to provide ecosystem services (Bruno and Selig, 2007). Coral reefs are generally undervalued due to their open-access nature and to the fact that the ecosystem service of storm protection they provide is a (quasi) public good, and as a result, often disregarded in policy and decision-making contexts (Brander et al., 2007). Economic studies on coral reefs have included their diverse uses, which include direct uses such as fishing and diving, as well as indirect uses such as storm protection.

Wetlands found in coastal areas also function as storm buffers distinctly from how open water or land dissipates storm energy (Simpson and Riehl, 1981). This mechanism reduces the area of open water over which wind can form waves and simultaneously decreasing the storm surge, and absorbing the energy of waves (Costanza et al., 2006; Costanza et al., 2008). Moreover, coastal wetlands provide a physical barrier for storm protection. They also serve functions such as water purification, habitat for birds and fish, as well as the prevention of saltwater intrusion from sea water. Wetland ecosystem service studies have been performed more extensively than those from the previous two ecosystems, perhaps due to the wide range of services they provide, as well as possibly because they serve as a link of freshwater—marine systems. Research has been performed on a site scale, and several meta-analyses have been recently published (Brouwer et al., 1999;

[1] The public good nature of certain ecosystem services implies the property of non-exclusivity, in which there is no possibility for one user to preclude another's usage of the service, and the property of non-rivalry, in which use by one does not result in insufficient goods or services for another.