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Title

Global Values of Shoreline and Coastal Protection: A Spatial Economic Analysis

Authors

Nalini Rao[*1], Andrea Ghermandi[2], Rosimeiry Portela[1], Xuanwen Wang[3]

Abstract

Specific variables associated with the ecosystem service in the coastal areas are identified and used to develop a multivariate regression function that supports the identification of important drivers of ecosystem service values. A benefit transfer function is then generated to extrapolate values to other sites around the world with similar ecosystems, and used to derive a global map of the value of coastal and shoreline protection worldwide. Variables hypothesized to effect the ecosystem service value fall into three categories, and were informed by a meta-analysis. Site characteristics involve ecosystem type, latitude and longitude. Study characteristics include year of the study, ecosystem service and valuation method. Context variables include values of development, anthropogenic pressure, biodiversity, population density, and characteristics of the ecosystem (mangrove, coral reef or wetland). Results of the meta-analytic regression show that variables significantly affecting the ecosystem service value included size, level of development and regional location. The results of the regression and benefit transfer will be used in follow-up research to examine through how ecosystem service values will respond to climate change in various projected scenarios of the future.

***Corresponding author: n.rao@conservation.org**

[1]Science + Knowledge, Conservation International, Arlington, VA, USA

[2]Department of Economics, Ca'Foscari University of Venice, Italy

[3]Center for Construction Research and Training, Silver Spring, MD, USA

Introduction

Natural systems are connected to human systems through different links, one of which is ecosystem services. Specifically, natural ecosystems are linked to human economic systems by ecosystem services, which describe the flow of value to human societies as a result of the state and quantity of natural capital, and are the direct and indirect contribution of ecosystems on human well-being (TEEB, 2010). Preserving this linkage, which contributes to human well-being, is one of the most important reasons to conserve and manage ecosystems carefully. The welfare of many human communities depend on ecosystem services to different degrees, and this varies by income level, geography, level of development and a host of other factors. Examples of ecosystem services provided by natural ecosystems are water purification by wetlands, carbon uptake by forests and pollination. Other examples include the water regulation that natural forests provide to streams or the storm protection that coral reefs provide to near-shore communities.

Some ecosystem services can be quantified easily while others cannot. In addition, quantifying ecosystem services in a specific accounting measure or unit is often challenging. The lack of a common type of unit makes comparisons difficult. Determination of the economic values of services should be precluded by the biophysical assessment of their availability, which must be distinguished from their overall provision or availability, to their actual use, in the form of benefits that humans enjoy from the services. And while some ecosystem services can be more easily and directly quantified than others, depending on the status of scientific knowledge of such services and data availability, quantifying ecosystem services in a specific accounting measure or unit is frequently challenging. Indeed, often proxies are used to determine the services availability, particularly in cases where there is lack of consensus on the best/ideal measurement units for these services. The absence of a common type of unit for services and their equivalent engineering solution, in their absence, makes comparisons difficult. For example, to compare how much an engineering solution to flooding, levees, versus an ecosystem service solution, intact wetlands, is difficult and would likely require a combination of biophysical and economic analysis. For some cultural or spiritual ecosystem services, quantification can be impossible, and does not accurately reflect the importance of that service to communities.

Further compounding the difficulty in quantifying and valuing ecosystem services, is the fact that many services are public goods and as a result, subject to a failure of the market to reflect their economic value. 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. This is the case of a host of ecosystem services, such as pollination, water purification, and of many other services, which, in spite of their significance to human lives, are rarely quantified, valued or taken into account in management decisions (de Groot, 1994).

Since these ecosystems are not quantified or valued, their conservation is rarely included in policy decisions. Further, the services which link ecosystems and economic systems are not described by conservation or economic policies. One main way to link these systems is through the careful quantification and valuation of the services, which could then lead to concrete policy decisions. To this end, different researchers have attempted the valuation of natural capital from the local (Badola and Hussain 2005) to the global (Costanza 1997; TEEB 2010) scales. These types of studies look at the value of a wide range of ecosystem services, and measure them using a variety of different methods.

There are many types of coastal ecosystems, including beaches, rocky shores, mangroves, coastal forests and mudflats, to name a few. Each of these ecosystems provides goods and services to coastal communities. The three major ones which planners often incorporate into integrated coastal ecosystem based management are coastal marshes (wetlands), mangroves and coral reefs (Barbier et al., 2008). These particular ecosystems provide service to coastal communities, which are often vulnerable to the effects of storms. The effects of storms include direct effects such as loss of life, housing and food sources as well as such as destructive storm surges and saltwater intrusion. Coastal communities can be protected from some of these effects by intact ecosystems which provide regulating services to humans from weather and climate related conditions.

This study examines a set of specific coastal ecosystems and a subset of ecosystem services. The goal is to examine, through the means of a meta-analysis and regression techniques, the economic value of these ecosystem services, and what factors drive these values. 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. The baseline values could feed into coupled ecological and economic modeling and/or inform policy makers for decision-making. The pervasive losses of coastal ecosystems and their important contribution to coastal protection, mostly associated with increasing coastal populations, habitat loss, nutrient pollution and invasive species are likely to be compounded by climate related changes, such as those associated with increasing sea temperature and ocean acidification, and the increase in storm frequency and severity. With this baseline, we will be able to adjust the drivers and test for the sensitivity of the values to climate variations or shocks. Indeed the impact of climate change on coastal areas, and their capacity to buffer coastal community from the effects of storms, is an important aspect that policymakers can anticipate in advance, and take measures to protect such ecosystems. The general framework used in this global study could be used to identify tradeoffs in terms of development and conservation, areas for further regional analyses using finer-scale data, and examine the impacts of climate change on the ecosystem service values. To do that, first we discuss the specific services delivered by these particular ecosystems chosen.

Mangroves, Coral Reefs and Wetlands

One important ecosystem service provided by mangroves, coral reefs and coastal marshes worldwide is storm regulation. In major storms, research has shown that coastal communities experienced higher damages and higher mortality rates directly from many types of natural disasters when mangroves were removed (Das et al., 2009; Barbier et al., 2007; Danielsen et al., 2005). Indeed, because one-third of the world's population lives in coastal communities (Barbier et al. 2008) and the coastal zones is twice as densely populated as inland areas (MEA, 2005), the ecosystem services provided in the coastal zone are critical to these communities.

These three ecosystems prevent the full effect of the storm surges to reach coastal human populations, and have the added set of ecosystem services that sustain subsistence livelihoods. In general, when reefs and mangroves are damaged or destroyed, the absence of this natural barrier can 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 (Gilbert and Janssen, 1998; Spaninks & van Beukering 1997). 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 and property of coastal communities (Badola and Hussain, 2005). Valuation of mangroves has primarily focused on their storm protection services, though there is a small growing literature on the direct uses of mangroves.

Coral reefs (and mangroves) minimize the impact of storms by reducing wind action, wave action and currents and coral reef structures buffer shorelines against waves, storms and floods (Moberg and Folke, 1999; Done et al., 1996; Adger et al., 2005). In general, coral reefs themselves provide a significant barrier to storm surges (UNEP-WCMC, 2006), and 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 affects their ability to provide ecosystem services (Bruno and Selig, 2007). 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., 2008; Costanza et al., 2007). In terms of valuation studies, coral reefs are generally undervalued due to their open-access nature and the ecosystem service of storm protection is a (quasi) public good, and this leads to their undervaluation in policy (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 for storm protection.

Coastal wetlands are an important ecosystem which also provides storm protection through the physical barrier. Coastal wetlands 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 the previous two ecosystems, perhaps due to the wide range of services they provide, as well as possibly because they serve as a link in freshwater – marine systems. Research has been performed on a site scale, and several meta-analyses have been recently published (Brander et al., 2006; Woodward and Wui 2001; Brouwer et al. 1999).

Other services provided by these three ecosystems include fuelwood collection and subsistence fishing, which contribute along with the indirect benefits of wetlands to show the larger effect of these ecosystem services (Acharya, 2000). Studies on fuelwood collection vary and are often examined in the context of habitat destruction and deforestation (Kohlin and Parks, 2001), rather than on subsistence livelihoods and sustainable, small-scale extraction (Sood and

Mitchell, 2011; Mamo et al., 2007). Similarly, subsistence fishing studies have examined the activity in the context of destruction of marine protected areas or characterization of the informal economy in an area (Unsworth et al., 2010; Guillemot et al., 2009).

Combining the information on fuelwood collection and subsistence fishing, combined with the information on storm protection, illustrates the vulnerability of coastal communities and their dependence on natural ecosystems for human well-being. These existing studies on ecosystem services have often focused on the range of services provided by a specific type of natural ecosystem. Fewer studies have focused on a specific set of ecosystem services in the coastal zone found over a wide scale, which is the topic of this study. The particular coastal ecosystem services examined in this study have in common the fact that through their direct and indirect uses, they mitigate the vulnerability of coastal communities in the face of natural or economic problems. The contribution of this study will be to examine a small set of ecosystem services provided by coastal habitats, and how their value varies based on certain drivers. This type of study can be useful for both furthering the research on ecosystem service provision to vulnerable coastal communities at a variety of scales, as well as inform regional policies which seek to include the estimated values of selected ecosystem services.

Valuation and Meta-analysis

The valuation of ecosystems is one means to demonstrate the importance of resource conservation and to provide support for policies that seek a more sustainable management and protection of ecosystems. By valuing ecosystem services, it becomes possible to overcome the incompatibility of public and private preferences. An economic (i.e., monetary) valuation can, for instance, balance the marginal private benefits of ecosystem uses against the marginal costs to society of ecosystem losses which are often associated with resources exploitation for individual gain, such as those associated with mangroves destruction for shrimp farming, for example. In that sense, valuation can be extremely relevant in demonstrating the tradeoffs associated with resources allocation, providing insights for public policies. Naturally, a monetary valuation of ecosystem services will not express the intrinsic or inherent value of an intact ecosystem which exists regardless of the perceived human benefit.

Indeed, economists refer to values as instrumental or intrinsic. Instrumental (or utilitarian) refer to values that are useful for some purpose or need, while intrinsic are those whose values which exist in and of itself, irrespective of their utility to something else. From an economic perspective, values are further defined as use and non-use values. Use values can be further divided into direct and indirect values, while non use values can be further classified into existence, bequest and option value.

Common methods for assessment values are revealed preferences and stated preferences. Revealed preferences refer to values inferred from observed behavior, such as market prices, while the stated preference are those normally associated with answers to hypotethical questions, such as with surveys. Types of valuation methods include contingent valuation, hedonic pricing, travel cost, production function, replacement cost and market price, to name a few. Different methods are applicable to different ecosystem services, and it should be noted that results of different valuation techniques will differ depending on the welfare measure used (Freeman, 2003; Kopp and Smith, 1993), and some methods do not have a sound foundation in welfare theory, which may lead to either over- or underestimation (Brander, 2006). However, in this study, the differences in method are accounted for in the meta-regression, though the biases associated with the different methods will indeed affect the results.

For the analysis done in this study, we focused on the economic valuation of selected coastal ecosystem services, as mentioned above. While there are important existence and cultural values of coastal and marine ecosystem services that cannot be easily monetized, the value of the benefits to humans can often be approximated by economic analysis. Many site level studies have examined the value of ecosystem services provided by coral reefs and mangroves around the world. In order to determine what the drivers of value for these ecosystem services are, we performed a meta-analysis. A meta-analysis is a statistical technique used to combine, summarize and review previously performed quantitative analysis, and has been described as the "analysis of analysis" (Glass, 1976). It has been applied to examine issues in environmental sciences including wetlands (Ghermandi et al., 2008; Brower, 1999), toxins (Hites et al. 2004, Lin et al., 2007) and water quality (Van Houvten et al., 2007). The reasons for employing a meta-analysis are several. Firstly, it allows for the assimilation of site based studies and generalized conclusions to be drawn from them regarding the drivers of the ecosystem service values. Secondly, the cost of performing primary studies is high, hence the meta-analysis allows for the results of existing studies to be analyzed at a significantly lower cost. Finally, the results can give insight on areas where the primary study was not performed, or "policy sites," which can be particularly illuminating (Florax et al., 2002). This allows policymakers and/or managers to make decisions on ecosystems based on their values estimated from similar study sites.

Materials and Methods

Literature Review for Meta-analysis

A wide variety of studies were examined during the phase of literature review for this study. The studies were focused on coral reefs, mangroves and wetlands. The studies used are all economic valuation studies which were associated with a specific site. The studies were from a variety of sites, including some marine protected areas. From the 100 studies collected, 58 studies were selected for the meta-analysis. The remainder of the studies was discarded, usually because they were global or regional studies which lacked site specific economic values from which a regression could be created. The studies chosen are shown in Table 1. From these 58 studies, 153 observations were generated. In some cases more than one ecosystem service value was reported based on the type of service or the specific site. The major ecosystem services considered in this study are storm protection, fuel wood collection and subsistence fishing. For shoreline protection, fuel wood collection and subsistence fishing there were 92, 29 and 33 observations, respectively.

In terms of ecosystem types included in the meta-analysis, mangroves comprised 80 of the ecosystems, coral reefs comprised 48 of the ecosystems, and wetlands comprised 25 of the ecosystems. In this study, the definition of wetland is adopted from Ramsar Convention, and specifically those in marine areas.[1]

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[1] *"Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six meters"* and *"may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetlands" (Ramsar Convention, Articles 1.1 and 2.1).*

In total, 29 countries are included. As with similar meta-analyses (see Brander et al. 2006), the distribution of sites is not a reflection of the distribution of these ecosystems on the globe.

Variables

The dependent variable is the economic value of coastal ecosystem measured by US dollar per hectare per year. When the original study did not present the data in such terms, then it was converted to ha/year based on information given in the paper itself.

The independent variables can be described as belonging to one of three categories. The first category is the study variables. The study variables include the valuation method and the specific ecosystem service. Valuation methods used in the studies include replacement cost, damage cost avoided, contingent valuation method, market price and cost-benefit analysis. The specific ecosystem services are storm protection, subsistence fishing and fuel wood collection. The year of the study's publication and the year the study was conducted were also included in the development of the regression.

The second category includes the site variables. These variables include the size of coastal ecosystem, the ecosystem type and the latitude and longitude of the study site. Site variables are recorded from the original study if they were reported. The ecosystem type includes mangroves, coral reefs and wetlands. Latitude and longitude of the study site are collected from the reported coordinates of the study, and from the spatial data source GeoHack if the original study did not provide the coordinates.

The third category of variables is context variables. Context variables include Gross Domestic Product (GDP) per capita in purchasing power parity (PPP) for each study country, population of the study area, a biodiversity index of each study area, a development index and the average monthly temperature in the cell of the study site[2]. The GDP per capita in PPP is collected from CIA World Fact Book and adjusted to 2003 US$ using the Penn World Table (Heston et al. 2006). The index of marine biodiversity was derived from Ocean Biogeographic Information System (OBIS) data sources, and the specific index used was Hurlbert's index, also referred to as the ES(50) index, which estimates the number of species in 50 individuals (Hurlbert, 1971). The human development intensity measures were estimated using the results of the GLOBIO3 model (Alkemade et al. 2009), and used average Mean Species Abundance to categorize the impacts of infrastructure on biodiversity. In this index, biodiversity was defined as "the remaining mean species abundance, MSA, of original species, relative to their abundance in pristine or primary vegetation which are assumed to be not disturbed by human activities for a prolonged period" (Alkemade et al. 2009). The temperature data was sampled from modeled data, from the Community Climate System Model (CCSM) project developed by climatologists at the National Center for Atmospheric Research (NCAR). Population of the study area is either from the original study or from the United Nations population information from online publications. Regional variables are introduced in the model to capture the fixed effect of region, such as historical, cultural, demographic, geographic characteristics. All 29 countries are divided into five regions, Africa, Asia, North America, Caribbean, and Oceania.

The description of both dependent variable and independent variables are summarized in Table 2 and Table 3, respectively. Since the studies range from different year, the US dollar

[2] The cell size was 0.5 degree by 0.5 degree.

values are standardized to 2003 US$ and were determined for a per one-hectare area. All independent variables are categorized into four categories, study variables, site variables, socio-economic context variables, and regional dummies.

Meta-analytic regression

Single variable analysis

Single variable regressions are conducted to test whether the economic value of the coastal ecosystem is correlated with the size of ecosystem, population of the study area and the GDP per capita of the study area.

Multivariable Analysis

A multivariable analysis is also conducted to test the benefit function of economic value of coastal ecosystem. An Ordinary Least Square (OLS) model is applied in this study. Various functional forms were tested. According to the BOX-COX test, the LOG-LOG functional form is the best fit for this study.

The OLS model for meta-analytic regression is defined in Equation 1 below.

$$\ln Y_i = \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 X_{4i} + \varepsilon_i \qquad (1)$$

In Equation 1, Y_i represents the economic value of coastal ecosystem measured by dollar per hectare per year (2003 US$), ln Y_i denotes the natural log of Y_i, X_{1i}, X_{2i}, X_{3i} and X_{4i} stand for a vector of study variables, a vector of site characteristics, a vector of socio-economic context variables, and a vector of regional dummies, respectively. The coefficients to be estimated are β_1, β_2, β_3 and β_4. The error term is denoted by ε_i and is assumed to be independent, identically, and normally distributed. For the value transfer, we used a value transfer function rather than a direct value transfer.

Results

General Results

In terms of characteristics of the studies used in the meta-analysis, observations from Indonesia, the USA, and Thailand occur the most frequently, at 31, 19 and 15 times, respectively. Ninety-six observations come from Asia, nineteen observations from North America, nineteen observations from Caribbean, fourteen observations from Oceania, three from Africa and two from Europe. On average, 2.6 observations are obtained from each study. The maximum number of observations from a single study is nine while the minimum number of observations from a single study is one. Twenty-one out of 58 studies come from peer reviewed journals, and 37 are from "grey literature," working papers or final reports (Table 1). It was determined that whether or not the research was published did not have a significant effect on the outcome of the regression.

The size of ecosystem has a negative and significant correlation with while the GDP per capita has a positive and significant correlation with the economic value of coastal ecosystem. The population of the study area does not significantly correlate with the economic value of coastal ecosystem. The functional form, R-squared and results are summarized in Figure 2, 3, and 4.

Econometric Results

Econometric results of the OLS regressions are reported in Table 4. Also included are the number of observations in each model, R-squared values, adjusted R-squared values and F-tests. For the robustness test, three different models are presented. Based on the tests, the results are stable and robust across different models. Model 1 is the preferred model, with and adjusted R^2 of 0.43 (R^2=0.50). The statistical result of the F-test rejects the null hypothesis and suggests that all the coefficients are jointly significantly different from zero. The model was examined for heteroskedasticity (Breush-Pagan), and multicollinearity, which were not found to affect it.

Given the LOG-LOG functional form, the coefficients of each continuous independent variable refer to the elasticity, the percentage by which the dependent variable changes with respect to a one percent change in the independent variable.

Regression results of study variables

The coefficients for the valuation method variables are insignificant, which indicates using either replacement cost method or damage cost avoided approach does not bring a different impact on the economic value of coastal ecosystem, comparing other methods such as actual market price of output, contingent valuation method and so on. Storm protection and subsistence fishing dummies are positive and significant, which imply that the economic value of storm protection or subsistence fishing is higher than the economic value of fuel wood collection. With a positive coefficient of 1.87, the economic value of storm protection is the highest among three service provided by coastal ecosystems: storm protection, subsistence fishing, and fuelwood collection.

Regression results of site characteristics

The size of ecosystem has a negative and significant impact on the economic value of coastal ecosystem. Since the functional form is a log-log function, the coefficient is elasticity. Therefore, the economic value of coastal ecosystem is expected to decrease by 0.289% with respect to a one percent increase in the size of ecosystem.

Regression results of context variables

There is no significant relationship between the GDP per capita in PPP with the economic value of coastal ecosystem when the multivariable regression is applied, although the single variable regression does show a positive relationship. Similarly, the biodiversity index has a no significant relationship with the economic value of coastal ecosystem. Two human development indexes are put in the model, medium impact and low impact, using the high impact as the base. The regression results show that the study sites having medium impact or low impact tend to have lower economic value than the study sites having high impact.

Regression results of regional indicator variables

For the analysis of regions, Oceania and Europe are used for the base. The negative and significant coefficient for Africa suggests that the economic value reported in Africa is lower than the value reported in Oceania and Europe. There is no significant difference between the economic value reported in Asia is different from the value reported in Oceania and Europe. The positive and significant coefficient for the Caribbean suggests the economic value reported in the Caribbean sites is higher than the value reported in Oceania and Europe.

Discussion

The negative and significant correlation between the economic value of coastal ecosystem and the size of ecosystem, suggests the bigger the size of ecosystem the lower estimated value. This was true in both the single variable correlation calculations and in the regression results. The explanation may be that the larger the resource is, the lower its estimated economic value, and the smaller the ecosystem is, the higher the estimated value. This is also an issue of scarcity of the ecosystem resource—the smaller the resource, then the more it is valued in terms of providing critical ecosystem benefits. It might be important then to consider the population of the area served by the ecosystem rather than the population or log of the population. Other studies, primarily of wetlands, have shown that the size of the ecosystem has a negative correlation with the value (see Brander et al. 2006), but some studies have shown the opposite or constant result (Woodward and Wui, 2001).

In the single variable correlation calculation, the GDP per capita has a positive and significant correlation with the economic value of coastal ecosystem, suggesting the higher the GDP per capita the higher the per hectare per year dollar value of the coastal ecosystem. Countries with a higher per capita GDP might value the resources at a higher level over and above the PPP adjusted levels for a variety of reasons, including the quality of infrastructure, development and livelihoods which are protected from storms in these areas. However, this result was not mirrored in the regression results. Perhaps a more spatially explicit, finer-scale dataset of GDP should be used, such as the spatially explicit GCAP, developed by Nordhaus (2006). It is likely that the GDP of the entire country per capita might not reflect accurately those areas which depend on ecosystem services and not engineering solutions, to storm protection.

The regression results imply that the economic value of storm protection is higher than the economic value of fuel wood collection. This might be because the value of the storm protection function is estimated by the value of property, infrastructure, livestock and humans in the coastal area, and the value of fuelwood collection is calculated by the real market price. Subsistence fishing is not significant, which implies there is no significant difference between the economic value of fuel wood collection and subsistence fishing. This may be because the economic value of subsistence fishing is also calculated by the market price of fish. Additionally, these are two subsistence activities, for which the benefit of the ecosystem service accrues to a poorer general population, and it is possible that storm protection benefits will accrue to a higher number and more economically diverse population. It has indeed been found that the ecosystem service values determined for ecosystems that provide use values have generally lower values (Brander et al., 2006). Additionally, the magnitude of the damages and damages avoided in the event of a storm may be much larger than that of the direct values, and the regression results may reflect this result.

The ES(50) biodiversity index no significant relationship with the economic value of coastal ecosystem. Biodiversity being a key supporting ecosystem service, the result was surprising in that our *a priori* expectation was that biodiversity would have a positive and significant effect on the ecosystem service value. Coral reefs require oligotrophic (nutrient-poor) conditions for good ecosystem health, higher nutrient levels or organic matter can increase internal erosion of the reef (McClanahan et al. 2002). This nutrient poor requirement might cause there to be a lower number of species as measured by the biodiversity index. As the ES(50) biodiversity indicator puts emphasis on the number of species per 50 individuals, this may have had an effect. The exact nature of the connection between biodiversity and ecosystem service value requires further exploration, which will include examining interaction issues between size and biodiversity, as well as regional location and biodiversity.

When compared to sites with high impact, sites with low and medium levels of development impact tend to have lower average dollar value estimates for the ecosystem service value. It is likely due to the fact that he bigger the size, the lower the average economic value of ecosystem. Compared to high development sites, low or medium development sites have lower values. High development sites are well developed with hotels, houses and facilities. Therefore, the dollar value of storm protection of ecosystem is higher because the calculation is based on the replacement cost or damage avoided approach. Again here it might be important to examine interaction terms, perhaps between GDP and development, to understand the nature of the effect more precisely.

The natural log of the temperature was not significant. This result could be due to the fact that the temperatures in the pan-tropical belt, where the majority of the studies were found, does not vary that much. In the model development, the natural logs of the minimum and maximum temperature were included, but with similar, non-significant results. It was hypothesized that temperature might be a factor in the integrity of the ecosystem, and might thus have an effect on the ecosystem service value. However, this view is not justified by our results.

Regarding the inclusion of a biodiversity index, development pressure index and temperature information into the regression, these were original components of this study. The inclusion of these context variables was notable and added dimensions to this exploratory analysis, namely ecological, demographic and physical parameter which are often not examined in purely econometric studies. The results of their inclusion were mixed, with only the demographic pressure variable showing a significant result. In future, and for finer-scale analysis, it might be important to examine other demographic features, as well as physical or ecological data found at the border between the land and marine ecosystems, where these ecosystems occur. Possible variables for examination include the sea level rise, ocean acidity levels, biodiversity indices not based on number of species but perhaps some iconic species, and perhaps monthly temperature averages.

The general regional conclusions show that in Africa, when compared to sites in Oceania and Europe, the economic values tend to be low. On the contrary, the economic values in Caribbean are likely to have higher values than the Oceania and European values. This may be because of the actual area protected by the reef or mangrove system, frequency of storms and other physical factors. One main issue is that the number of observations in Africa is very low. This is due to a variety of issues, two of which are that the number of studies performed in Africa is quite low, and the number of published or “grey” literature results publicized is low as well.

In terms of the results of the value transfer, in this study we performed a preliminary analysis using a value transfer function based on the meta-analytic regression function presented above. To test the bias in the model and determine the accuracy of the benefit transfer on the ecosystem service value, we used a *jackknife* technique (n-1 data splitting). This technique systematically removes one observation for the sample and yields an estimate for the bias and variance. Using this technique we generate 153 separate predictions, and benefit transfer results are significant at the 20% level ($t=1.41; p=0.16$). The spatial results can be seen in Figure 5.

It is important to note that this result is affected by several value transfer errors. Firstly, the use of dummy variables decreases the accuracy of the value transfer, because the variation is lost in the analysis. Secondly, the sites were concentrated in Asia, and so the value transfer function assigns values to areas where there is insufficient primary data or original sites. These are the main issues in the value transfer presented here. Further analysis will attempt to refine the meta-analytic regression framework which will then lead to a more accurate value transfer result.

Though a higher number of observations is often desired, meta-analytic regression analyses have been published using a smaller number of observations than has been presented here (e.g. Brander et al. 2007). Accompanying this study was an exploratory analysis in which a regression was developed for each of the ecosystem services separately. This was performed to determine if improved results could be possible by separating the direct and indirect coastal ecosystem services examined in this study. The predictions of these accompanying studies were not explained as well by the model, and hence are not presented in this paper.[3]

Policy Implications

While the predictions of the benefit transfer are adequate, this may not be at a scale that is needed by policymakers who generally work at regional and local scales, where higher accuracy is desirable. The reasons for the model predictions outside the study site are outlined above. On a larger scale, different spatial trends are apparent. In figure 5 we can see the general trends of high and low values, where the highest value is approximately $3.3 million/ha/yr (US $, 2003). High values are visible around Central America, India and West Africa, whereas lower values are predicted around the Pacific, Southeast Asia and the Caribbean. Data availability issues affected

[3] The results of the separate meta-analytic regressions performed for each of the three ecosystem services separately are available to the reader upon request.

these results, as described above, as well as the existence of studies on these particular ecosystems for the specific services. Nevertheless, the studies have implications for policy in terms of vulnerability of coastal populations. In Southeast Asia, coral reefs and mangroves are extensive, yet the model predicted low ecosystem service values, adjusted for 2003 levels. In future studies, it might be important to examine how the property in at these study sites were accounted for; vulnerable populations might not construct high value homes in developing countries, and this will affect the damage costs, for example. Climate vulnerability is a next step of this baseline study, and further research will include examining key climatic variables which affect each of the three ecosystems. As different climatic variables will affect the ecosystems differently, different models will be parameterized, using specific, detailed ecological and physical parameter. To the extent possible, projections of demographic variables will also be included. In addition, finer scale analysis at a regional level will likely have implications for policymakers from a practical standpoint.

Conclusions

After performing a meta-analytic regression of the economic value of coastal and shoreline protection, the results show that size, level of development and whether the sites are in Africa are all negatively correlated with the economic value of the ecosystem service. Important issues to consider for future analysis include improving the biodiversity index, determining the exact area for which the ecosystem provides the service, and improving the population estimates (from population to population per capita or population per capita in a certain radius of the site).

Additionally, finer scale GDP will be used to determine how it may affect results. The value transfer function was tested, and found to be significant, though at a level that is likely not useful for regional planning. Original contributions of this study were the inclusion of temperature, biodiversity and development intensity spatial data, which had some degree of significance on the model predictions. Inclusion of different types of such context data will lead to better model prediction. Future model specification might include an instrumental variable regression model, which may increase the accuracy of the meta-analytic regression, as well as the benefit transfer results.

Climate change is an important issue that will affect ecosystem service value. This will occur because climate change will, among other effects, increase sea surface temperature and cause ocean acidification. Both of these physical changes will affect coastal ecosystem health, which will in turn decrease the capacity of the ecosystem to buffer against storms, and/or provide sufficient subsistence fishing or trees for fuelwood collection. Follow-up research is underway to examine how climate change scenarios—including temperature, acidity, biodiversity and various data sets involving demography and population—might be used in a similar regression fashion, based on this current research above, to determine what the drivers of ecosystem service value might be. The implications, when combined with other coastal ecosystem service valuation, including those of recreation, tourism, and larger-scale fisheries research, will contribute to the understanding of how ecosystem service values will change. In this preliminary research presented above, one component is examined and the results presented. In the near future, collaborative research between physical scientists, biologists and economists will be necessary to understand and determine the true values of the ecosystem services of the marine and coastal zone. The policy implications, in light of climate change already happening, will be important on many scales.

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Appendix

Table 1: List of studies used in meta-analysis.

Num.	AUTHORS	YR_PUB
1	Badola, R. and Hussain, S. A.	2005
2	Bann, C.	1997
3	Bann, C.	1997
4	Bann, C.	1999
5	Barbier, E.B.	2007
6	Barbier, E.B., Strand, I, and Sathirathai, S.	2002
7	Bennet, E. L. and Reynolds, C.J.	1993
8	Berg, H., Öhman, M. C., Troeng, S., and Lindén, O.	1998
9	Burke, L. and Maidens, J.	2004
10	Burke, L., Greenhalgh, S., Prager, D., and Cooper, E.	2008
11	Burke, L., Selig, E., and Spalding, M.	2002
12	Carleton, C. and Lawrence, K.S.	2005
13	Cesar, H.J. S.	2002
14	Cesar, H.J. S.	1996
15	Cesar, H.J.S. and Van Beukering, P.J.H.	2004
16	Cesar, H.J.S., Burke, L., and Pet-Soede, L.	2003
17	Cesar, H.J.S., Öhman, M.C., Espeut, P. and Honkanen, M.	2000
18	Christensen, B.	1982
19	Cooper,E., Burke, L., and Bood, N.	2009
20	Costanza, R., Farber, S.C., and Maxwell, J.	1989
21	De Lopez, T. T.	2003
22	Emerton, L. and Kekulandala, L.D.C.B.	2003
23	Farber, S.C.	1987
24	Farber, S.C.	1996
25	Farber, S.C. and Costanza, R.	1987
26	Gammage,S.	1997
27	Gunawardena, M. and Rowan, J.S.	2005
28	Gustavson, K. R.	1998
29	Hargreaves-Allen, V.	2004
30	Howarth, R.	1983
31	IUCN	2003
32	IUCN	2006
33	JacobsGIBB Ltd.	2004
34	Janssen, R. and Padilla, J.E.	1996
35	Janssen, R. and Padilla, J.E.	1999
36	King, S.E. and Lester, J.	1995
37	Lal, P.N.	1990
38	Ledoux, L.	2003

39	Nam Do T. and Bennett J.	2005
40	Naylor, R. and Drew, M.	1998
41	Öhman, M.C. and Cesar, H.	2000
42	Pet-Soede, C., Cesar, H.J.S., and Pet, J.S.	1999
43	Ranasinghe T. and Kallesoe M.	2006
44	Ruitenbeek, H. J.	1992
45	Ruitenbeek, H. J. and Cartier, C.	1999
46	Samonte-Tan, G., White, A.T., Tercero, M.A., Diviva, J., Tabara, E. and Caballes, C.	2007
47	Sathirathai, S.	1998
48	Sathirathai, S. and Barbier, E.B.	2001
49	Seenprachawong, U.	2002
50	Shabman, L.A. and Batie, S.S.	1987
51	Spurgeon, J.	2002
52	Tuan, T.H., Xuan, M.V., Nam, D., and Navrud, S.	2009
53	Tri, N. H., Adger, N., Kelly, M., Granich, S., and Ninh, N. H.	1996
54	Van Beukering, P.J.H. et al	2006
55	Van Beukering, P.J.H. et al	2007
56	Van Beukering, P.J.H., Cesar, H.J.S. and Janssen, M.A.	2003
57	White, A.T., Vogt, H. P., and Arin, T.	2000
58	White,A.T., Ross,M., and Flores M.	2000

Table 2: Description of independent variables. *The natural log of economic value was adjusted to account for zero values.

Independent Variable ($/ha/yr)	Observations	Mean	Std. Dev.	Min	Max
Natural log of economic value*	153	5.40	2.29	0.00	15.08

Table 3: Categories of variables in valuation, ecosystem service, site and context categories, with the associated mean, standard deviation, minimum and maximum values (n=153).

Category	Variables	Mean	Std. Dev.	Min	Max
Valuation Method	Replacement Cost	0.12	0.33	0.00	1.00
	DCAA	0.24	0.43	0.00	1.00
Ecosystem Service	Storm Protection	0.60	0.49	0.00	1.00
	Subsistence Fishing	0.22	0.41	0.00	1.00
Site Characteristics	Size (log)	9.27	3.67	1.10	15.83
	Population (log)	12.03	4.10	3.93	20.97
	Mangroves	0.46	0.50	0.00	1.00
	Coral Reefs	0.31	0.47	0.00	1.00
Context	GDP/capita (PPP) (log)	8.58	0.97	6.73	10.53
	Average Temperature (log)	2.89	1.15	0.00	3.42
	Minimum Temperature (log)	3.21	0.42	0	3.39
	Maximum Temperature (log)	3.40	0.30	0	3.48
	Biodiversity Index (log)	2.60	1.74	0.00	3.92
	Low Impact Development	0.04	0.19	0.00	1.00
	Medium Impact Development	0.52	0.50	0.00	1.00
	Africa	0.02	0.14	0.00	1.00
	Asia	0.63	0.49	0.00	1.00
	North and Central America	0.25	0.43	0.00	1.00

Table 4: Meta-analysis regression results. Note: *,**,***, represents significant at 10%, 5%, and 1%, respectively.

		Model 1		**Model 2**		**Model 3**	
Category	**Variable**	**Coef.**	**P>t**	**Coef.**	**P>t**	**Coef.**	**P>t**
Constant		6.213**	0.074	1.766	0.895	4.742**	0.061
Valuation Method	Replacement Cost	0.611	0.253	0.645	0.239	0.590	0.267
	Damage Cost Avoided Approach	0.234	0.638	0.286	0.587	0.294	0.547
Ecosystem Service	Storm Protection	1.874***	0.000	1.848***	0.001	1.869***	0.000
	Subsistence Fishing	0.955**	0.037	0.961**	0.037	0.952**	0.037
Site Characteristics	Size (log)	-0.289***	0.000	-0.293***	0.000	-0.294***	0.000
	Population (log)	0.014	0.837	0.015	0.839	0.020	0.775
	Mangroves	-0.759	0.183	-0.782	0.175	-0.827	0.139
	Coral Reefs	-0.187	0.726	-0.187	0.738	-0.275	0.593
Context Variables	GDP/capita (log)	0.230	0.426	0.265	0.408	0.258	0.364
	Average Temperature (log)	-0.419	0.534				
	Minimum Temperature (log)			-0.609	0.788		
	Maximum Temperature (log)			1.426	0.801		
	Biodiversity Index (log)	0.075	0.529	0.063	0.615	0.055	0.632
	Medium Impact Development	-0.859*	0.061	-0.870*	0.060	-0.865*	0.058
	Low Impact Development	-0.795*	0.057	-0.806*	0.062	-0.850**	0.037
	African	-3.800***	0.009	-4.016***	0.012	-3.310***	0.006
	Asian	-0.020	0.970	-0.074	0.895	-0.094	0.858
	North/Central America	0.980	0.309	0.822	0.436	0.873	0.356
	Caribbean	2.390***	0.001	2.425***	0.001	2.336***	0.001
Observations		**151**		**150**		**151**	
R^2		**0.50**		**0.50**		**0.50**	
Adjust R^2		**0.43**		**0.43**		**0.44**	
F Value		**7.78**		**7.18**		**8.27**	

Figures

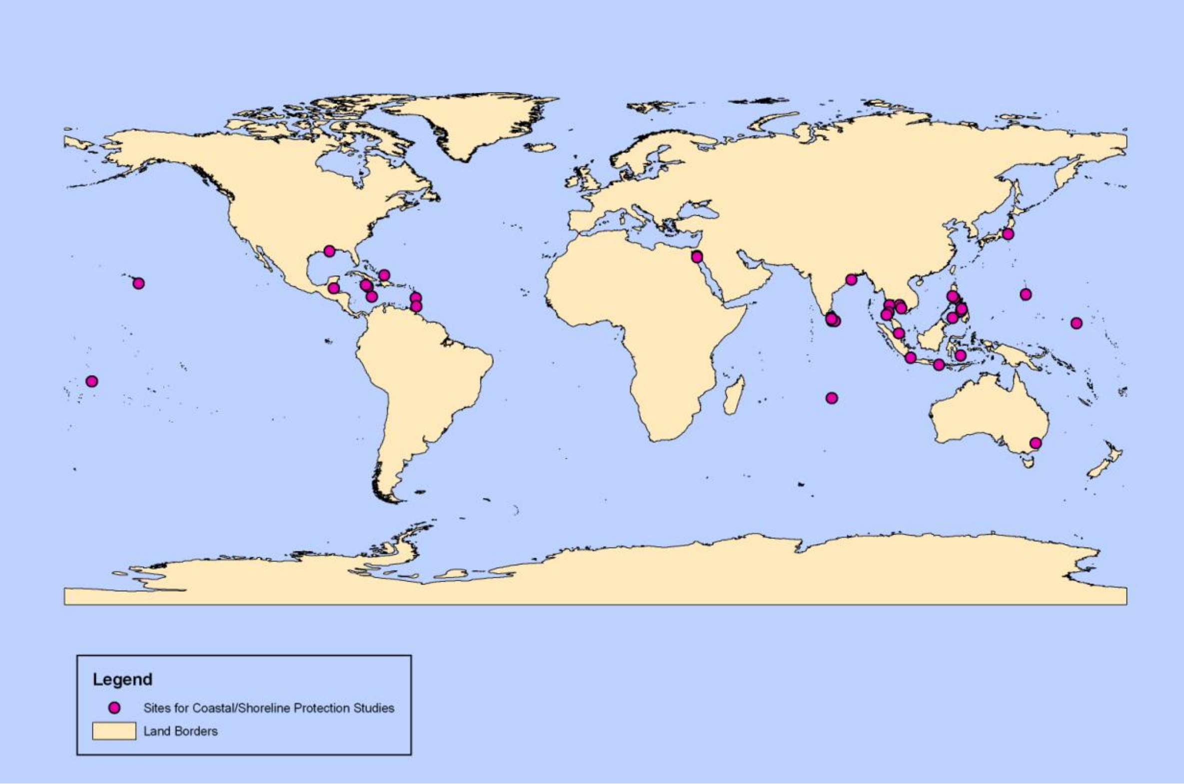

Figure 1: Location of studies used in the meta-analysis.

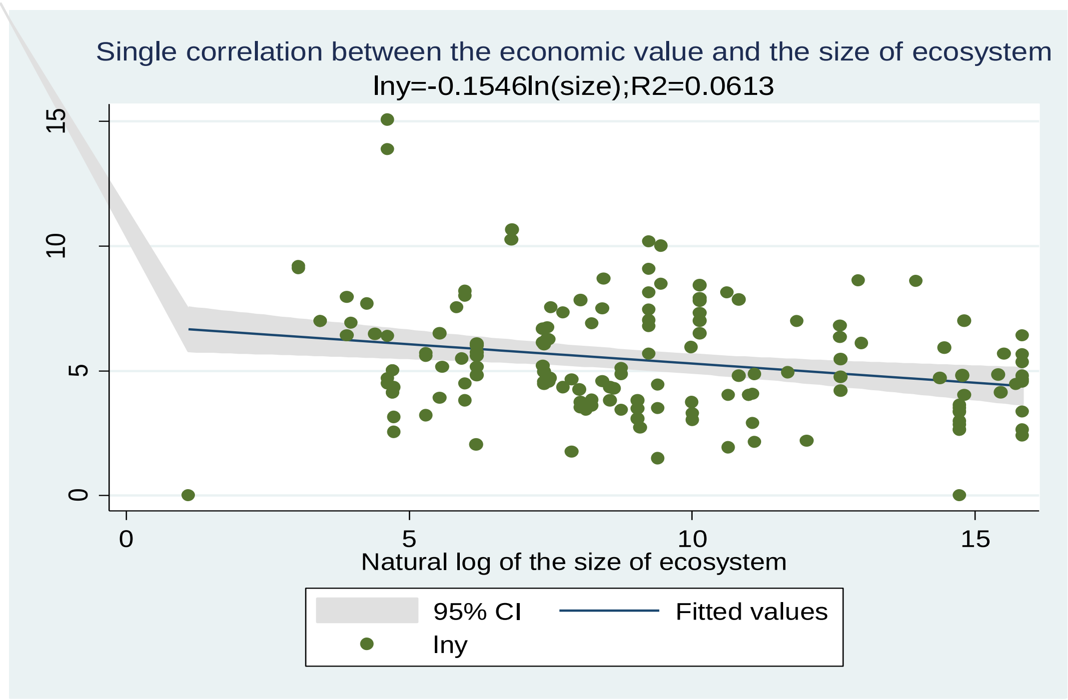

Figure 2: Single correlation between the economic value and the size of the ecosystem.

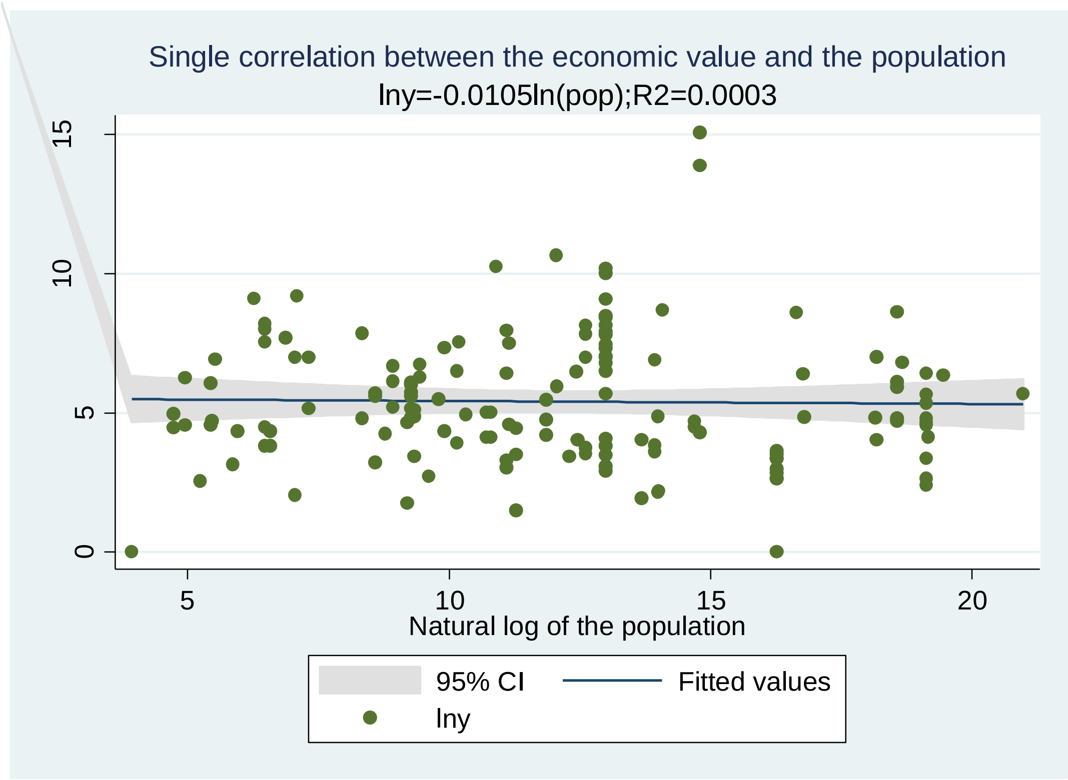

Figure 3: Single correlation between the economic value and the population

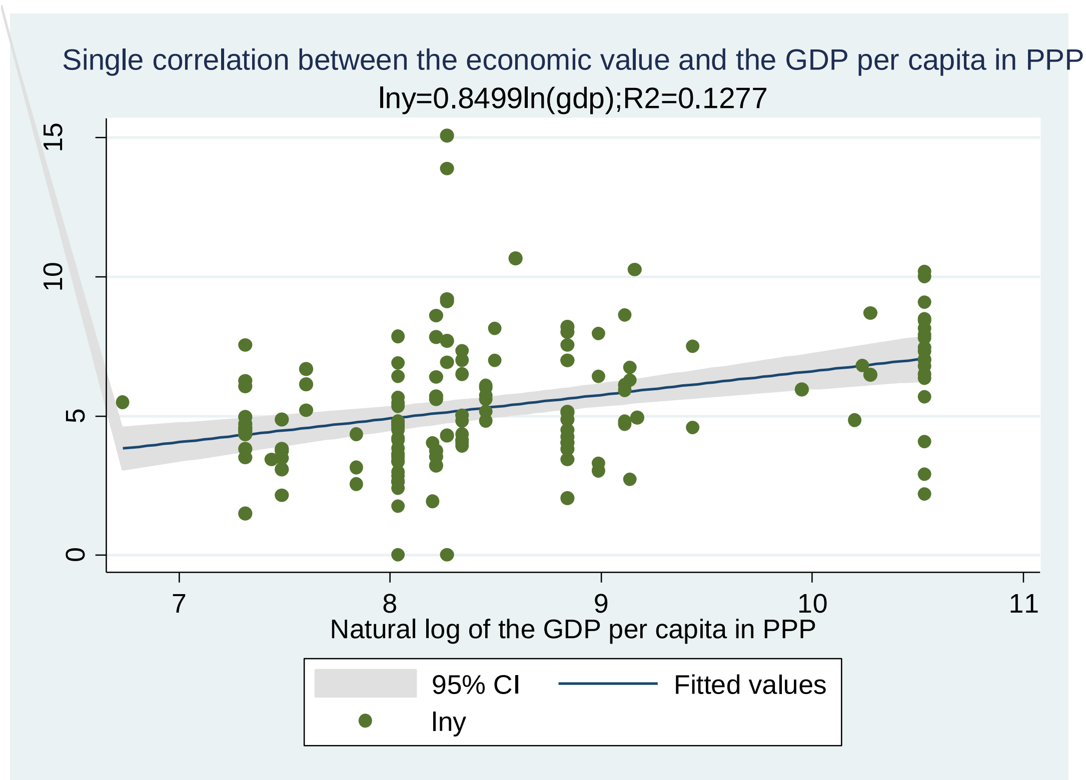

Figure 4: Single correlation between the economic value and the GDP per capita in GDP.

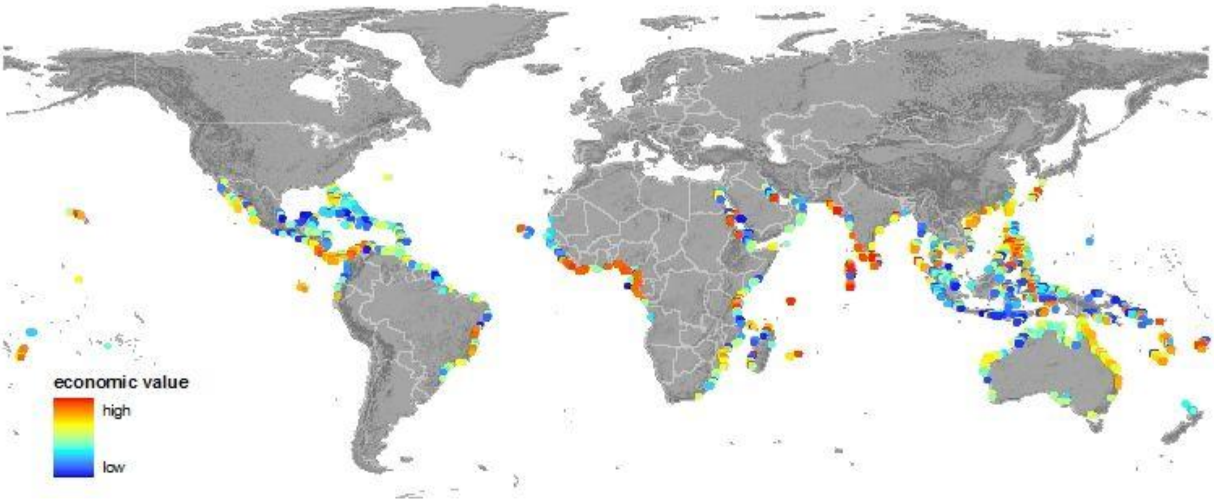

Figure 5: Values determined using the benefit transfer function, ranging from \$0 to \$3.3 million (US \$, 2003).