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Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application

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ABSTRACT

This paper examines the value of ecosystem services provided by mangroves. It presents a meta-analysis of the economic valuation literature and applies the estimated value function to assess the value of mangroves in Southeast Asia. We construct a database containing 130 value estimates, largely for mangroves in Southeast Asia. Values are standardised to US$ per hectare per year in 2007 prices. The mean and median values are found to be 4185 and 239 US$/ha/year respectively. The values of mangrove ecosystem services are highly variable across study sites due to, amongst other factors, the bio-physical characteristics of the site and the socio-economic characteristics of the beneficiaries of ecosystem services. We include explanatory variables in the meta-analysis to account for these influences on estimated mangrove values. A geographic information system (GIS) is used to quantify potentially important spatial variables, including the abundance of mangroves, the population of beneficiaries, and the density of roads in the vicinity of each study site. The meta-analytic value function is used to estimate the change in value of mangrove ecosystem services in Southeast Asia under a baseline scenario of mangrove loss for the period 2000–2050. The estimated foregone annual benefits in 2050 are US$ 2.2 billion, with a prediction interval of US$ 1.6–2.8 billion.

1. Introduction

Mangroves[1] provide a number valuable ecosystem services that contribute to human wellbeing, including provisioning (e.g., timber, fuel wood, and charcoal), regulating (e.g., flood, storm and erosion control; prevention of salt water intrusion), habitat (e.g., breeding, spawning and nursery habitat for commercial fish species; biodiversity), and cultural services (e.g., recreation, aesthetic, non-use) (Spaninks and van Beukering, 1997; UNEP, 2006; TEEB, 2010). Many of these ecosystem services have the characteristics of 'public goods' such that the people who benefit cannot be excluded from receiving the service provided (e.g., habitat and nursery service supporting fisheries); and that the level of consumption by one beneficiary does not reduce the level of service received by another (e.g., coastal protection and storm buffering). Due to these characteristics, the potential for private incentives to sustainably manage mangrove ecosystem services is limited and markets for such services do not exist. In other words, there is a 'market failure' and by their inherent nature, mangrove ecosystem services are under supplied by the market system.

As a result, mangroves are generally undervalued in both private and public decision-making relating to their use, conservation and restoration. The lack of understanding of, and information on, the values of mangrove ecosystem services has generally led to their omission in public decision making. Without information on the economic value of mangrove ecosystem services that can be compared directly against the economic value of alternative public investments, the importance of mangroves as natural capital tends to be ignored. A number of studies have developed and applied methods to calculate the monetary value of mangroves (Ramdial, 1975; Ahmad, 1984; Barbier, 1994; Bann, 1998). Although these studies provide some insight in the range

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[1] The term mangrove is loosely used to describe a wide variety of trees and shrubs (around 80 species), that share characteristics of being adapted to conditions of high salinity, low oxygen and changing water levels (Saenger et al., 1983). The mangrove biome dominates tropical and sub-tropical coastlines between latitudes 32°N and 38°S and covers approximately 22 million hectares. Around 28% of global mangroves are located in Southeast Asia with Indonesia alone accounting for 25%.

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of values that may be assigned to the ecosystem services provided by mangroves, they are all context specific and do not provide a more generic insight in the values of mangroves.

Mangroves throughout the world face a number of threats, including pollution, deforestation, fragmentation, and sea-level rise (Giri et al., 2011). The main drivers underlying these threats are increasing populations and development in coastal areas and climate change. Mangroves are being converted to other land uses such as aquaculture ponds, urban developments, agriculture and infrastructure. In Asia there has been large scale conversion of mangrove forests to shrimp farms (Barbier et al., 2011).

The aim of this paper is to provide an estimate of the value of the change in ecosystem services provision due to the loss of mangrove area in Southeast Asia under a business as usual scenario for the period 2000–2050. This estimate represents the benefits foregone by not maintaining the stock of mangroves or equivalently the cost of policy inaction to conserve this stock of natural capital.

The paper is organised as follows, Section 2 sets out the selected methodology for estimating the value of ecosystem services from mangroves in Southeast Asia; Section 3 describes the collection and preparation of value data; Section 4 presents a meta-analysis of mangrove values; Section 5 applies the obtained value function to estimate site specific values and presents the aggregated results; finally Section 6 provides a discussion and conclusions.

2. Methodology

The selected methodology for estimating the foregone value of ecosystem services due to change in the extent of mangroves in Southeast Asia over the period 2000–2050 is to apply a value transfer approach using a meta-analytic value function combined with spatial data on changes in mangrove area. This approach allows the estimation of spatially variable site or patch specific values that reflect the characteristics and context of each mangrove patch.

Value transfer is the procedure of estimating the value of an ecosystem (or goods and services from an ecosystem) by applying an existing valuation estimate for a similar ecosystem (Navrud and Ready, 2007). The ecosystem of current policy interest is often called the ‘policy site’ and the ecosystem from which the value estimate is transferred is called the ‘study site’. This procedure is also known as benefit transfer but since the values being transferred may also be estimates of costs or damages, the term value transfer is arguably more appropriate (Brouwer, 2000).

The use of value transfer to provide information for decision making has a number of advantages over conducting primary research to estimate ecosystem values. From a practical point of view it is generally less expensive and time consuming than conducting primary research. Value transfer can also be applied on a scale that would be unfeasible for primary research in terms of valuing large numbers of sites across multiple countries. Value transfer also has the methodological attraction of providing consistency in the estimation of values across policy sites (Rosenberger and Stanley, 2006).

The transfer of values using a meta-analytic value function, in which policy site characteristics are plugged into a value function estimated from the results of multiple primary studies, appears to offer the most promising means to explicitly control for the specific characteristics of each policy site in the transfer process. By utilising information from multiple studies, a meta-analytic value function includes greater variation in both site characteristics (e.g. size, service provision) and context characteristics (e.g. abundance of other mangrove sites, number and income of beneficiaries) that cannot be generated from a single primary valuation study.

Meta-analysis is a method of synthesising the results of multiple studies that examine the same phenomenon, through the identification of a common effect, which is then ‘explained’ using regression techniques in a meta-regression model (Stanley, 2001). Meta-analysis was first proposed as a research synthesis method by Glass (1976) and has since been developed and applied in many fields of research, not least in the area of environmental economics (Nelson and Kennedy, 2009). It is widely recognised that the large and expanding literature on the economic value of ecosystem services has become difficult to interpret and that there is a need for research synthesis techniques, and in particular statistical meta-analysis, to aggregate results and insights (Stanley, 2001; Smith and Pattanayak, 2002; Bateman and Jones, 2003). In addition to identifying consensus across studies, meta-analysis also provides a basis for transferring values from studied sites to new policy sites (Rosenberger and Phipps, 2007). It is for this purpose that we develop the meta-analysis presented in this paper.

An important consideration in estimating the value of changes to a biome across a large geographic area, such as we propose to do in this paper, is that changes in the stock of the resource may affect the unit values of each individual patch. Localised changes in the extent of an individual ecosystem may be adequately valued in isolation from the rest of the stock of the resource, which is implicitly assumed to be constant. When valuing simultaneous changes in multiple ecosystem sites within a region (e.g., changes in mangrove extent in Southeast Asia for the period 2000–2050), it is arguably not sufficient to estimate the value of individual ecosystem sites and aggregate without accounting for the changes that are occurring across the stock of the resource. We therefore follow the method proposed by Brander et al. (2012) to include spatial information in the meta-analytic value function on the abundance of mangrove ecosystems in the broader surroundings of each study site. This variable is intended to capture the effect of changes in the availability of substitute or complementary mangrove sites in the vicinity of each mangrove patch. In addition, a number of other characteristics of each case study location derived from spatial data are included in the analysis as potential determinants of ecosystem value.

3. Data description

For the purposes of conducting a meta-analysis of mangrove ecosystem service values, we collected mangrove valuation studies through online journal databases, libraries, online valuation reference inventories and contact with authors. The collected literature includes journal articles, working papers and professional reports. In total 41 studies were collected that contain sufficient information to be included in a statistical meta-analysis, i.e. report values that can be standardised to an annual monetary value per unit of area and contain data on the explanatory variables included in the meta-regression function. Table 1 lists the studies included in the meta-analysis together with information on the ecosystem services that they examine, the valuation methods used and the number of value estimates that enter the meta-data. Although the focus of the value transfer analysis presented in this paper is on Southeast Asia, the meta-data contains estimates for mangrove study sites around the world. This enables us to construct a larger database with which to estimate the factors that determine variation in mangrove ecosystem values. The locations of the study sites covered in the literature are presented in Fig. 1, illustrating that some regions are better represented in the data than others. Southeast Asian

Table 1
List of studies included in the meta-analysis.

References	Country	Ecosystem services	Valuation method[a]	Number of estimates
Ahmad 1984	Bangladesh	Fisheries	NFI	1
Bann 1997	Cambodia	Fuel wood, materials, fish	GR	13
Bann 1999	Malaysia	Coastal protection, fish	CV	4
Barbier and Strand, 1998	Mexico	Fish	PF	1
Barbier 1997	Thailand	Coastal protection, fish	PF	2
Bell 1989	US	Fish	PF	4
Bennett and Reynolds 1993	Malaysia	Fish, materials	GR	2
Bergstrom et al., 1990	US	Fish	CV	1
Burbridge and Dixon 1884	Indonesia	Fish, materials	GR	2
Christensen, 1982	Thailand	Fish, materials	GR	6
Cooper, et al,. 2009	Belize	Coastal protection, fish	RC, GR	3
Dharmaratne and Strand, 2002	Trinidad and Tobago	Fish	NFI	1
Do and Bennett, 2005	Vietnam	Fuel wood, materials, fish	GR	3
Dugan, 1990	Malaysia	Fuel wood, materials, fish	GR	1
Emerton 2002	Sri Lanka	Coastal protection, fuel wood, materials, fish, water quality	GR, RC	13
Emerton and Kekuaandala, 2002	Cambodia	Fish, fuel wood, materials	GR	4
Farber, 1996	US	Coastal protection	CV, RC, GR	4
Gammage, 1997	El Salvador	Fuel wood, materials, fish	GR	2
Guanawardena and Rowen, 2005	Sri Lanka	Coastal protection, fuel wood, fish	RC, GR	5
Hamilton and Snedaker,1984	Trinidad and Tobago	Fuel wood, materials, fish	GR	3
Hammit, et al., 2001	Taiwan	Coastal protection, fuel wood, materials, fish, water quality	CV	1
Kairo, et al., 2009	Costa Rica	Fish	NFI	1
Khalil, 1999	Kenya	Flood control, Fish	GR, RC	6
La,l 1990	Pakistan	Fuel wood, materials	GR	2
Levine, and Mindedal,1998	Fiji	Fish, materials	NFI	2
MENR, 2002	Vietnam	Fish	PF	1
Milon and Scrogin, 2006	El Salvador	Coastal protection, fuel wood, materials, fish, water quality	CV	3
Morton 1990	US	Coastal protection, Fish	CE	1
Naylor Drew, 1998	Australia	Fish	GR	1
Nickerson 1999	Federal States of Micronesia	Coastal protection, fuel wood, materials, fish, water quality	CV, NFI	2
OAS, 2002	Philippines	Fish, fuel wood, materials	GR	2
Ramdial 1975	Trinidad and Tobago	Fish	NFI	1
Reyes 2004	Trinidad and Tobago	Fish	NFI	6
Ruitenbeek 1992	Indonesia	Coastal protection, fuel wood, materials, fish, water quality	GR	7
Samonte-Tan, et al., 2007	Philippines	Coastal protection, fish	NFI	2
Sathirathai and Brabier, 2001	Thailand	Coastal protection, fish	NFI, PF	4
Shabman and Batie 1987	US	Coastal protection, fuel wood, materials, fish, water quality	RC	1
Tri et al., 2000	Vietnam	Fish, fuel wood, materials	NFI	5
Tri, 1996	Vietnam	Coastal protection, fuel wood, materials	PF	2
Turpie, et.al., 2000	Tanzania	Fuel wood, materials	NFI	3
Turpie, (1999)	Mozambique	Water quality	RC	2

[a] Valuation method acronyms: CE=choice experiment; CV=contingent valuation; GR=gross revenue; NFI=net factor income; PF=production; RC=replacement cost.

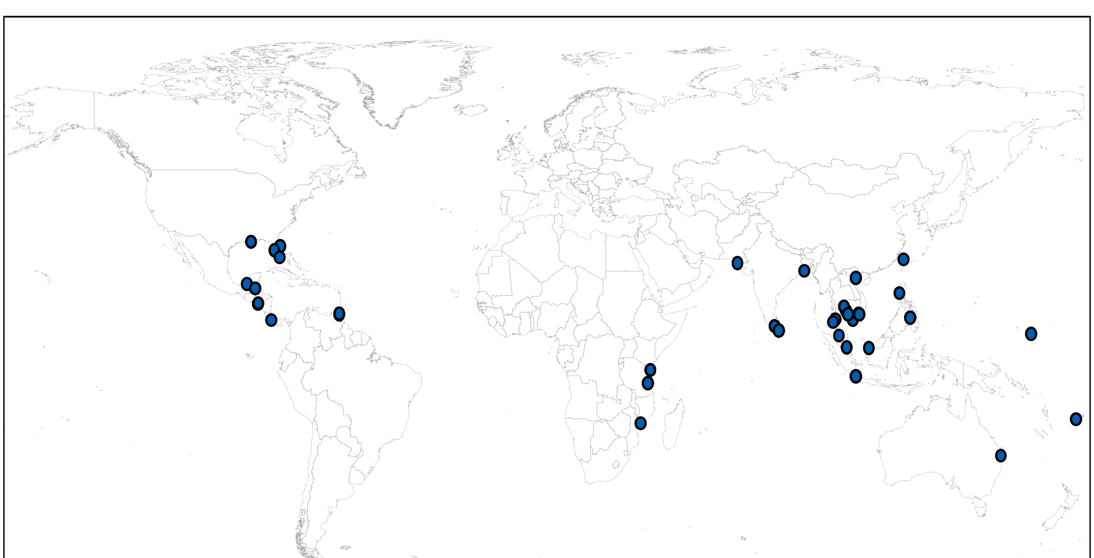

Fig. 1. Location of mangrove valuation study sites.

mangroves are well represented in the data. From the 48 selected studies we are able to obtain 130 separate value estimates. Multiple value estimates are taken from single studies if they represent different mangrove sites or services. These are distinctions that are explicitly controlled for in the meta-analysis through the inclusion of explanatory variables that represent differences in site characteristics and services valued. There are 14 estimates for North America, 18 for Latin America, 21 for South Asia, 61 for Southeast Asia, 11 for Africa wetlands, and 5 for Oceania.

The range of ecosystem services represented in the collected studies includes provisioning services (fish, fuel wood, materials) and regulating services (coastal protection, flood prevention, water quality), possibly reflecting the most important services in the contexts of the individual studies. There are gaps in coverage of the wider range of ecosystem services as defined by the Millennium Ecosystem Assessment (MA, 2005) or The Economics of Ecosystems and Biodiversity (TEEB, 2010). In particular it should be noted that the value of cultural services provided by mangroves is not represented in literature underlying our database. The values that are transferred in this paper can only reflect those that are available in the literature and so our valuation results represent only a partial set of ecosystem services.

In order to allow direct comparison of study results, all value estimates are standardised to US$ per hectare per year at 2007 price levels. Values that are reported in currencies other than US dollars are converted using purchasing parity adjusted exchange rates. Values that are initially estimated for other price level years are converted to 2007 price levels using GDP deflators. Estimates that are reported as net present values are converted to annual values using the time horizon and discount rate reported in the study. Total values or values estimated for specified changes in the area of a mangrove ecosystem are divided by the corresponding area in hectares to obtain a value per hectare. Values reported in per person or household terms are converted to a per hectare basis by computing the implied total value, e.g. multiplying the per person value by the relevant population of ecosystem service beneficiaries identified in the study, and dividing by the area of the mangrove study site.

4. Meta-analysis of mangrove values

This section describes the specification and results of the meta-regression analysis. Based on the specifications of previous meta-analyses of wetland values (Brander et al., 2006,2011a; Ghermandi et al., 2010; Salem and Mercer, 2012) and on theoretical expectations we define three groups of explanatory variables that represent different determinants of variation in value, namely the characteristics of each mangrove site, characteristics of the bio-physical context of each mangrove, and the socio-economic characteristics of the population of ecosystem service beneficiaries.[2]

Regarding study site characteristics, we define variables indicating the ecosystem service that is valued and the size of the mangrove in hectares. We have no a priori expectations for the relative value of the ecosystem services that we examine in the analysis, namely coastal protection, habitat and nursery support to commercial fisheries, water quality maintenance or improvement, fuel wood extraction, and the extraction of other materials (e.g. food, thatch). Other services from mangroves such as carbon sequestration, biodiversity and recreational opportunities have only been addressed in the valuation literature to a very limited extent and are not included in this analysis. The values that are estimated in this paper using the meta-analytic value function therefore represent a subset of the total economic value from mangroves.

There is also no clear a priori expectation for the sign of the relationship between the size of a patch of mangrove and its value per unit area. On one hand there may be diminishing marginal returns to increases in mangrove area, but on the other hand most ecosystem services require minimum thresholds of area, which implies that values would increase with scale.

For the bio-physical context characteristics we use spatial data in combination with geographic analysis to define two potentially important spatial variables for the vicinity of each study site, namely the total area of other mangroves and the density of roads. These variables were defined for three spatial neighbourhoods (i.e., within 10, 20 and 50 km radii of the centre of each study site) since a priori we do not know at what scale these potential determinants of mangrove service value operate. The total area of other mangroves in the vicinity of a valued site represents the abundance (or conversely the scarcity) of substitute or complementary mangrove sites. In the case that neighbouring mangroves that provide the same service are substitutes, we would expect that the value of ecosystem services provided by each valued site will tend to be lower when the abundance of other mangroves is higher. Alternatively, in the case that mangroves in the same region are complements and jointly enhance the provision of ecosystem services, we would expect a positive relationship between mangrove abundance and the value of individual mangrove patches. This variable may therefore capture whether the provision of mangrove ecosystem services increases at a constant, increasing or decreasing rate with total area of proximate mangroves. The density of roads variable, measured as the length of road in the vicinity of each mangrove patch, is intended to capture fragmentation effects on the provision of ecosystem services. Fragmentation of ecosystems by roads may result in a number of distinct effects on ecosystem functioning. Line infrastructure imposes a barrier to the movement of many animals, which may isolate populations and lead to long-term population decline (IENE, 2005). Fragmentation also introduces external disturbances (e.g. noise, light, pollution, water flow, air movement etc.) and can alter nutrient cycling and water quality and quantity (Geoghegan et al., 1997). We therefore expect a negative relationship between road density and the value of ecosystem services from mangroves.

The variables representing the socio-economic characteristics of the beneficiaries of mangrove services are the population (again defined within 10, 20 and 50 km radii of the centre of each study site) and the gross domestic product (GDP) per capita. The population variable is intended to capture the number of people that potentially benefit from ecosystem services provided by each mangrove site. As such we expect a positive relationship between population and mangrove value. The GDP per capita variable provides a rough measure of income for beneficiaries of ecosystem services within the vicinity of each study site and we therefore expect to find the theoretically derived, and empirically supported, positive relationship between income and the provision of normal goods. GDP per capita may also reflect the value of economic activity that is protected from flood and storm damage by mangroves, in which case we would also expect a positive relationship between this variable and mangrove value.

[2] It is also common practice in meta-analyses of economic valuation results to include a set of explanatory variables that capture the methodological characteristics of each valuation study (e.g. valuation method, sample size, author etc.). We did not include methodological variables in this analysis for two reasons: 1. For the data that we use, valuation methods are found to be highly correlated to the ecosystem service valued and would therefore result in problems of multicolinearity in the meta-regression analysis; 2. Such variables are not directly applicable in value transfer exercises, i.e. are not used to predict values for new policy sites.

Table 2
Definition and summary statistics for dependent and explanatory variables.

Variable	Variable definition	Mean	S.E. of mean
Dependent	US$/ha/year; 2007 prices (ln)	5.06	0.21
Coastal protection	Dummy variable for coastal protection ES	0.13	0.03
Water quality	Dummy variable for water quality ES	0.05	0.02
Fisheries	Dummy variable for fisheries ES	0.37	0.04
Fuel wood	Dummy variable for fuel wood ES	0.23	0.04
Mangrove area	Area of mangrove study site (ha; ln)	9.30	0.22
Mangrove abundance	Total area of mangroves within 50 km (km^2; ln)	3.73	0.21
Roads	Length of roads within 50 km (km; ln)	8.77	0.11
GDP per capita	GDP per capita (USD; ln)	8.26	0.09
Population	Population within 50 km (ln)	13.46	0.13

Table 3
Meta-regression model.

Variable	Variable definition	Coefficient[a]	S.E.
Constant		−0.590	2.193
Coastal protection	Dummy variable for coastal protection ES	1.456***	0.491
Water quality	Dummy variable for water quality ES	1.714**	0.752
Fisheries	Dummy variable for fisheries ES	0.860**	0.355
Fuel wood	Dummy variable for fuel wood ES	−1.085**	0.437
Mangrove area	Area of wetland study site (ha; ln)	−0.343***	0.065
Mangrove abundance	Total area of mangroves within 50 km (km^2; ln)	0.248***	0.082
Roads	Length of roads within 50 km (km; ln)	−0.312*	0.175
GDP per capita	GDP per capita (USD; ln)	0.785***	0.174
Population	Population within 50 km (ln)	0.284*	0.149
N	130		
Adjusted R^2	0.45		

[a] Statistical significance is indicated with ***, ** and * for the 1, 5 and 10% level respectively.

Table 2 shows the dependent and explanatory variables included in the meta-regression model together with the definition and descriptive statistics for each variable. The average mangrove value in the sample is 4185 USD/ha/annum and the median is 239 USD/ha/annum. This divergence of the mean and median values indicates a skewed distribution with a few very high outliers that is commonly observed for both values and physical variables such as ecosystem area; this is rectified in our meta-regression model through the use of a double log specification which normalises the distribution.

A number of alternative model specifications were investigated before defining the estimated meta-regression model given in Eq. (1). The dependent variable (y) in the meta-regression is a vector of values in US$ per hectare per year in 2007 prices. The explanatory variables are the site characteristics X^S (i.e., ecosystem service, mangrove size), the bio-physical context characteristics X^C (i.e., abundance of other mangrove sites, road density), and the socio-economic characteristics of the service beneficiaries X^E (i.e., population within 50 km, GDP per capita). The vectors β^S, β^C and β^E contain the estimated coefficients on the respective explanatory variables; α is the constant term; and μ is a vector of residuals with assumed well behaved underlying errors. The natural logarithms of the continuous variables (indicated in Table 2) were used in order to improve model fit and mitigate heteroskedasticity

$$y=\alpha+\beta^S X^S+\beta^C X^C+\beta^E X^E+\mu \qquad (1)$$

The results for the estimated meta-regression model are given in Table 3. A series of diagnostic tests were performed in order to test the robustness of the OLS estimation. The Shapiro–Wilk test (p level=0.892) does not reject the assumption of normally distributed residuals. Similarly, the null hypothesis of homogenous variance of the residuals cannot be rejected by White's test for heteroskedasticity (White's statistic =33.747). The adjusted R^2 statistic indicates that 45% of the variation in the dependent variable is explained by the explanatory variables, which is in line with similar meta-analyses of the ecosystem service valuation literature (e.g., Brander et al., 2006; Ghermandi et al., 2010).

In this double log model, the coefficients on the dummy variables measure the constant proportional change in the dependent variable for a given binary change in the value of the explanatory variable. The coefficients on the continuous variables expressed in logarithms can be interpreted as elasticities, i.e. the percentage change in the dependent variable given a percentage point change in the explanatory variable.

Regarding the dummy variables indicating the service that is valued, the estimated coefficients for coastal protection, water quality and fisheries are all positive and statistically significant, indicating that the value of these services are higher than the value of extracted mangrove materials (the omitted category variable). The estimated coefficient for fuel wood extraction is negative and statistically significant, indicating that the extraction of fuel wood has a lower value than the extraction of other materials.

The estimated coefficient on mangrove area is negative and statistically significant, which is evidence of diminishing returns to scale for mangrove size, i.e. the value per hectare is lower in larger mangroves than in smaller mangroves. In other words, adding a hectare to a large mangrove is of lower value than adding a hectare to a small mangrove. It is important to understand that the total value of a mangrove increases with its size but at a diminishing rate as the per hectare value decreases. In other words there is a non-linear (concave) relationship between total area and total value. The estimated coefficient shows an inelastic relationship between area and value, in which a 10% change increase in area results in a 3.4% decrease in per hectare value.

The variable measuring the abundance of other mangroves in the vicinity of the valued sites is found to have a positive effect on wetland value. As the area of other mangroves increases, the value per hectare of the valued site tends to also increase. In other words, there is a non-linear (convex) relationship between the area of other proximate mangroves and total value of each study site. This can be interpreted as the effect of complementarity between mangrove patches; as mangroves become more abundant within a given region, their productivity increases. This suggests that isolated patches of mangrove tend to be of lower value than more intact contiguous mangrove systems. This is possibly related to the services coastal protection and habitat and nursery support to fisheries, for which productivity increases in larger mangrove systems. The estimated elasticity indicates that a 10% increase in the area of other mangroves results in a 2.5% increase in mangrove value per hectare. The estimated coefficient on road density is negative and statically significant, with the implication that a 10% increase in the density of roads is associated with a 3.1% decrease in mangrove value. This suggests that the fragmentation of mangroves and surrounding landscape does have negative effects on the provision of ecosystem services. The selected scale of measurement for these two variables is for a 50 km radius from each study site based on the significantly higher explanatory power of the variables in the regression at this scale.

The two variables representing the socio-economic characteristics of beneficiaries both follow prior expectations. The estimated coefficient on the population variable is positive and statistically significant, indicating that mangrove ecosystem service values are higher in areas with larger populations. The positive effect of population on the value of mangrove ecosystem services relates to market size or demand for services. A larger population in the vicinity of a mangrove means that more people benefit from the ecosystem services that it provides. A 10% increase in population results in a 2.8% increase in mangrove value per hectare. The population variable is also found to be best measured at a scale of 50 km radius from each study site. The positive effect of the income variable (GDP per capita) indicates that mangrove ecosystem services have higher values in countries with higher incomes. GDP per capita has a positive but less than proportional relationship with mangrove value—suggesting an inelastic effect of income on the value of mangrove ecosystem services. A 10% increase in GDP per capita results in a 7.9% increase in value per hectare.

This meta-regression model provides the value function that we use to estimate the change in value of ecosystem services due to the change in the stock of mangroves in Southeast Asia under a business-as-usual scenario.

5. The value of mangrove change in Southeast Asia 2000–2050

To define a baseline scenario for mangrove change for the period 2000–2050, we make use of the results of the IMAGE-GLOBIO integrated assessment model (Alkemade et al., 2009; PBL, 2010).[3] This baseline scenario has previously been used to assess the cost of policy inaction to halt global biodiversity loss (Braat and ten Brink, 2008). Changes in the extent of mangroves are assumed to follow similar patterns to the GLOBIO modelled changes for forests and grasslands for the period 2000–2050. The reasoning behind this assumption is that the population, development and land use pressures that drive changes in the extent of forests and grasslands will also tend to drive degradation and conversion of mangroves. We recognise, however, that there are differences in the way in which development pressures affect different biomes, and indeed that mangroves face unique pressures (Duke et al., 2007). In the land use module of the IMAGE-GLOBIO model, land use change is largely a result of food demand, trade and land use intensity assumptions (Bouwman et al, 2006). Pressure due to agricultural demand on grassland and forest, however, may not necessarily translate well to pressure on mangroves. The process resulting in degradation and conversion of mangroves in Southeast Asia is largely related to shrimp aquaculture production. With this in mind and in the absence of more detailed, large-scale, land change simulations, it is considered appropriate to take a conservative approach and transfer the lowest change factor for forest or grassland to mangroves within the same geographic area (50 km grid cells for the GLOBIO output). In the case that there is no land use data available for either forest or grassland within a specific grid cell, data is taken from the nearest available cell. If changes in grassland and forest are both positive, we assume 'no change' in mangroves. In other words, we take the pessimistic view that mangroves can only decrease or remain constant in area under baseline policy conditions. It is noted that the spatial distribution and configuration of mangrove losses is somewhat artificial in that all mangroves within a 50 km grid cell experience the same proportionate change area. A more realistic pattern of change would involve total loss of some mangrove patches while others are left intact. This level of spatial modelling is beyond the scope of this paper but might form the subject of future research.

Using spatially differentiated change factors derived in this way and patch level data on mangroves from the UNEP World Conservation Monitoring Centre (described in Giri et al., 2010), we calculate the change in area of each patch of mangrove for the period 2000–2050. The aggregated change in area for each country in Southeast Asia is presented in Table 4. Indonesia has by far the largest stock of mangroves in 2000 but also faces the largest losses over the period 2000–2050 both in absolute and proportionate terms, approximately 1.7 million hectares and 38% respectively. The Philippines, Brunei and Cambodia are expected to experience relatively low rates of mangrove loss, i.e. less than 10% of the 2000 stocks, but these constitute a relatively small total area. For the region as a whole, just over 2 million hectares, or 35%, of mangrove are expected to be lost during the period 2000–2050.

For each of the 1230 mangrove patches included in the Southeast Asia database, spatial data is used to obtain information on the site characteristics (mangrove size), bio-physical context (mangrove abundance and road density within 50 km) and socio-

Table 4
Change in mangrove area and value in Southeast Asia by country 2000–2050.

Country	Mangrove area in 2000 (ha; 000's)	Change in mangrove area 2000–2050 (ha; 000's)	Total value change (US$/ annum; millions)	PI 95% low (US$/ annum; millions)	PI 95% high (US$/ annum; millions)
Brunei	16	−1	−4	−4	−4
Cambodia	54	−4	−2	−1	−2
Indonesia	4329	−1656	−1728	−1239	−2241
Malaysia	699	−220	−279	−228	−330
Myanmar	338	−80	−50	−36	−64
Philippines	102	−6	−11	−10	−12
Thailand	250	−25	−36	−32	−41
Vietnam	254	−90	−48	−33	−64
Total	6042	−2082	−2158	−1582	−2759

[3] GLOBIO is a modelling framework developed to calculate the impact of five environmental drivers on terrestrial biodiversity. GLOBIO is based on cause-effect relationships derived from the literature and uses spatial information on environmental drivers as input. This input is mainly derived from the Integrated Model to Assess the Global Environment (IMAGE). Projections for environmental drivers are based on the OECD Environmental Outlook (OECD, 2008) and cover the period 2000–2050.

economic characteristics of beneficiaries (GDP per capita, population within 50 km). At the level of individual patches of mangrove, patch specific parameter values are then substituted into the meta-analytic value function to estimate values per unit area (USD/ha/annum). These estimates are then used to calculate the value of the projected change in area of each patch. Lower and upper bound values are calculated using the 95% prediction intervals for each wetland site, which are computed using the method proposed by Osborne (2000). The prediction intervals provide an indication of the precision with which the estimated value function can predict out-of-sample values. They do not, however, reflect a number of other sources of uncertainty in the analysis, including inaccuracies in the land use data used to construct the database of Southeast Asian mangrove sites and the assumptions used to describe the baseline change in the extent and spatial distribution of mangroves.

The values of foregone mangrove ecosystem services, aggregated to the country level, are presented in Table 4. Comparing the 2000 stock of mangroves to the projected 2050 stock, the annual value of lost ecosystem services from mangroves in Southeast Asia is estimated to be approximately US$ 2.16 billion in 2050 (2007 prices), with a 95% prediction interval of US$ 1.58–2.76 billion. Assuming a linear time profile of these losses between 2000 and 2050, the present value of the stream of lost ecosystem services is US$ 40 billion using a 1% discount rate and US$ 17 billion using a 4% discount rate. This is the cumulative value of the foregone ecosystem services due to mangrove loss that is expected to occur each year over the period 2010–2050. The loss of ecosystem services is not valued only for the year in which the mangrove area is lost but for every subsequent year up to the time horizon of the analysis (i.e., 2050).

At a country level, the annual value of foregone mangrove ecosystem services in 2050 follows the pattern of loss of area, with Indonesia expected to suffer the highest losses; US$ 1.7 billion per year with a 95% prediction interval of US$ 1.2–2.2 billion. Malaysia is estimated to suffer the second highest losses in mangrove ecosystem service values; US$ 279 million per year with a 95% prediction interval of US$ 228–330 million.

6. Discussion and conclusions

The paper provides an estimate of the value of foregone ecosystem services from mangroves in Southeast Asia under a baseline scenario for the period 2000–2050. This value is estimated by combining a meta-analytic value function for mangrove ecosystem services with spatial data on individual mangrove ecosystems to produce site specific values, which are aggregated to the country level.

The inclusion of spatial variables describing the context of individual mangrove patches is shown to be important in accounting for variation in ecosystem service values. We find evidence that mangrove areas are complements, i.e. that the value of individual mangroves are enhanced when there is a larger extent of other mangrove patches in the surrounding area. This has important implications for mangrove conservation strategies and suggests that the preservation of contiguous areas is preferable to patches that are spatially dispersed. This finding is in contrast to the results of similar meta-analyses for freshwater wetlands (e.g. Brander et al., 2011), which have shown wetland ecosystems to be substitutes.

We also find that the fragmentation of mangroves and their surroundings by road infrastructure has a negative effect on the value of mangrove ecosystem services. Increasing the accessibility of mangrove areas appears to degrade the services they provide. This might particularly be the case for the coastal protection and fisheries habitat and nursery services, which are off-site services that do not require access to the mangrove itself. Mangrove conservation efforts should therefore aim to mitigate the impacts of fragmentation by transport infrastructure.

Regarding future research directions, the inclusion of other spatially defined context variables in meta-analyses of ecosystem service values offers a potentially important avenue to further account for variation in values. There is also a need for collaborative research that combines mangrove ecology and economics to jointly model the provision and value of ecosystem services from mangroves. For the value transfer analysis presented in this paper, we have modelled the variation in the economic value of ecosystem services but make the assumption that the provision of services is a constant across all mangrove sites (the value of this constant is informed by the level of service provision observed at the study sites reviewed in the meta-analysis). To a limited extent, spatial variation and non-linearity in ecosystem service provision are implicitly modelled in the meta-analytic value function through the inclusion of the mangrove area, abundance, and road density variables. Explicit ecological modelling of the potential non-linearities in the provision of ecosystem services would, however, be preferable (Barbier et al., 2008; Koch et al., 2009). The value transfer analysis should therefore be revisited when (modelled) data on the provision of services from mangroves becomes available. Similarly the estimation of changes in the stock of mangroves over time could be greatly improved by explicitly modelling the specific threats that face this biome, including sea level rise.

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