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Economic valuation of ecosystem services fails to capture biodiversity value of tropical forests

L.R. Carrasco [a,*], T.P.L. Nghiem [a], T. Sunderland [b], L.P. Koh [c]

[a] Department of Biological Sciences, National University of Singapore,14 Science Drive 4, Singapore 117543, Republic of Singapore
[b] Center for International Forestry Research, Bogor 16000, Indonesia
[c] Environment Institute, School of Earth and Environmental Sciences, The University of Adelaide, Adelaide, Australia

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ABSTRACT

The reconciliation of biodiversity conservation, ecosystem service provision and agricultural production in tropical landscapes requires recognition of the trade-offs between competing land-uses. It is especially relevant for conservation planning to assess whether the economic value of ecosystem services is spatially congruent with biodiversity. Previous analyses have largely focused on ecosystem service provision or assumed homogeneous economic values across land uses within biomes. We relax this assumption by carrying out a spatially explicit meta-analysis based on 30 studies of ecosystem service values in tropical forests from The Economics of Ecosystems and Biodiversity (TEEB) database, while controlling for economic, environmental and methodological variables. Our results demonstrate a lack of spatial congruence between the economic value of ecosystem services and biodiversity in tropical forests. Instead, we find that economic value presents a nonlinear inverted-U relationship with site accessibility and economic activity, highlighting the importance of matching supply and demand between each ecosystem service and its beneficiaries for economic values to be realized. The implications are that conservation policies focusing solely on the economic value of ecosystem services will fail to protect biodiversity in remote and less disturbed regions.

1. Introduction

The tropical forest ecosystem is one of the most biodiverse in the world and provides a wide range of goods and services that are fundamental to human populations locally and globally (Balmford, 2002; Costanza et al., 1997; Ricketts et al., 2004). Tropical forests are currently subject to strong pressure from agricultural expansion, leading to unprecedented deforestation rates (Hansen et al., 2013; Margono et al., 2014; Miettinen et al., 2011). Mapping the economic value of the ecosystem services of tropical forests is thus necessary to support land-use decisions that can capture the trade-offs between ecosystem service provision, biodiversity conservation and agricultural production (Koh and Ghazoul, 2010; Millennium Ecosystem Assessment, 2005). Given the mounting pressure to convert forests into agriculture, particularly for highly profitable crops such as oil palm in Southeast Asia (Koh et al., 2011) or soya bean in Brazil (Ewers et al., 2008), knowing the distribution of the economic values of ecosystem services could facilitate the spatial planning and management of landscapes to maximize agricultural production while maintaining ecosystem service benefits (Sayer et al., 2013).

Previous evaluations of potential payment for ecosystem services schemes have led to mixed results (Naidoo et al., 2008; Strassburg et al., 2010). In terms of the provision of ecosystem services, such as carbon storage and sequestration, grassland production and water, strategies that target biodiversity-rich areas would not perform better than randomly distributed strategies (Naidoo et al., 2008). Whereas in other cases, congruence between carbon storage and sequestration services and biodiversity was observed (Strassburg et al., 2010). More importantly, for most ecosystem services (an example of an exception are carbon related services), the magnitude of a service provided at a site might not necessarily coincide with its realized economic value, as value will be influenced by existing demand for the service at the place where it is provided (Burkhard et al., 2012; García-Nieto et al., 2013).

Previous studies have mapped the value of tropical forests by directly transferring the average economic value of ecosystem services from existing studies in the tropics to the rest of the tropical biome. For instance, one study averaged 11 estimates of the value of climate regulation in tropical forests from previous studies and assumed that this value was homogeneous across the tropical

* Corresponding author. Tel.: +65 91377291; fax: +65 67792486.
E-mail address: dbsctlr@nus.edu.sg (L.R. Carrasco).

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biome (Costanza et al., 1997). Indeed, this study has been used to demonstrate congruence between ecosystem service value and biodiversity (Turner et al., 2007), even though it failed to account for within-biome variation in economic values—a crucial assumption that is the focus of our current analysis.

Benefit transfer meta-analysis is an alternative approach to direct benefit transfer that takes into account the potential environmental, economic and study-specific factors that might influence the estimation of economic values. Given the limitations of direct benefit transfer, meta-analyses are increasingly demanded (Hoehn, 2006; Richardson et al., 2014; Wilson and Hoehn, 2006). Meta-analyses have been successfully applied to the valuation of coastal and wetland ecosystem service values (Brander et al., 2007; Ghermandi and Nunes, 2013; Woodward and Wui, 2001). Although there have been previous applications of the meta-analytical method for assessing the value of biodiversity (Nijkamp et al., 2008) and temperate forests (Zandersen and Tol, 2009), a comprehensive meta-analysis of ecosystem services in tropical forests has, to the best of our knowledge, not yet been attempted.

Here we carry out a spatially explicit meta-analysis using The Economics of Biodiversity and Ecosystems (TEEB) dataset (de Groot et al., 2012; Van der Ploeg and de Groot, 2010), which is arguably the most comprehensive ecosystem services value database. We evaluate the environmental, economic and methodological factors that drive economic value for tropical forest ecosystem services, *inter alia* climate regulation, disturbance regulation, provision of raw materials and provision of recreation in tropical forests. The main objective of our analysis is to assess whether the economic value of ecosystem services is spatially congruent with biodiversity in tropical forests. Any demonstrable spatial congruence between biodiversity and economic value of ecosystem services would suggest the possibility of win–win conservation strategies that bundle ecosystem services with biodiversity.

2. Methods

2.1. Data collection

The TEEB dataset was queried for ecosystem service values in tropical forests (Van der Ploeg and de Groot, 2010). Studies based on benefit-transfer approaches were excluded since they did not represent independent valuation studies. The list of studies obtained was compared and complemented with the list obtained in the recent estimation of ecosystem service values of the TEEB dataset (de Groot et al., 2012) leading to 78 observations from 31 studies in 24 different countries (Table S3, "TEEB dataset" in the Electronic Supplementary Material (ESM)). The TEEB dataset is the result of selecting primary ecosystem service valuation studies that were scrutinized by TEEB experts for their originality and availability of information on surface area, valuation method and location of the study (de Groot et al., 2012).

To evaluate how well the meta-analytic model could predict the value of other studies for which it had not been trained we performed a review of the literature and compiled a combination of peer-reviewed articles, reports and theses that reported primary economic values of ecosystem services in tropical forests and that were not included in the TEEB dataset (Table S4, "validation dataset" in ESM).

The location of each study was geo-referenced using Google Earth following the name of the reserve, village or district. For studies referring to larger areas, the centroid of the referred forested area was chosen. Studies with a global or national scope were excluded from the analysis. A total of 53 value observations from 20 studies were compiled (Table S3, "validation dataset").

In both the TEEB dataset and the validation dataset, the variance associated with each economic observation was not systematically reported. This reflects the nature of economic valuations that might apply to methods that do not necessarily rely on statistical sampling, e.g. cost-based methods. Hence variance or standard errors could not be used to place weights on the certainty of each value (less variance indicating less uncertainty) as it is customary in meta-analytical studies. As a consequence all observations were implicitly given the same weight in the model.

2.2. Economic value elicitation

In the case of the TEEB dataset, economic values that were reported in different years and sometimes in different currencies have been standardized to international dollars of 2012 using purchasing power parity and deflator tables. We followed the same approach for the validation dataset so that all observations were expressed in the same units. As for the TEEB dataset, all values were expressed per hectare and per year. Some cases in the validation dataset involved eliciting the area of study and dividing the total value by it. Studies for which information on the area was not available were removed. Some studies reported benefits as a net present value. The values were annualized using the discount rate and time horizon reported in the study. Studies that did not report the discount rate and the time horizon were removed.

2.3. Variables

The variables used to explain economic value were derived from theory and previous meta-analytic approaches (Table 1 describes the variables, their estimation and rationale for their inclusion in the meta-analysis). They were grouped into three categories: (i) *methodological variables* describing valuation method (15 categories Tables S2 and S3), ecosystem service (13 categories described in Table S1), whether studies were peer-reviewed or not, and year of publication; (ii) *context variables* capturing the local factors affecting value, which were average temperature and precipitation (New et al., 2002), accessibility (Nelson, 2009), elevation (New et al., 2002), geographically-based GDP (Nordhaus et al., 2006), area of the forest, protected area status (WDPA Consortium, 2004), type of soil (Zobler, 1986), species richness of birds (Jenkins et al., 2013) (species richness of vascular plants (Kreft and Jetz, 2007) was also used as an alternative), types of land use (Bartholomé and Belward, 2005) and carbon content (Ruesch and Gibbs, 2008); and (iii) *variables controlling for sources of non-independence*: country and continent (Table 1).

2.4. Regression meta-analysis

The statistical model had the following form:

$$V_i = \alpha + \sum_{1}^{J}\beta_{Cj}X_{Cji} + \sum_{1}^{K}\beta_{Sk}X_{Ski} + \varepsilon_i \text{ where } \varepsilon_i \sim N(0, \sigma^2)$$

where V_i represents the logarithmic transformation of the economic value estimate of observation i; α is the intercept; β_C and β_S are the coefficients for the J context variables (X_{Cji}) and K methodological variables (X_{Ski}) respectively; and ε is the error term that will be modified when considering heterogeneity of variance, spatial autocorrelation and non-independence using random effects.

For most ecosystem services there were not enough observations to conduct a separate analysis, so the analysis was conducted simultaneously for all the ecosystem services. This was done by adding an explanatory categorical variable indicating the type of ecosystem service (Zuur et al., 2009). Before proceeding to fit the meta-analytic models, multicollinearity was checked using a linear regression model containing the main effects and using variance inflation factors in the R statistical environment (R Development