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How remote sensing supports mangrove ecosystem service valuation: A case study in Ca Mau province, Vietnam

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ABSTRACT

This paper highlights the importance of using household survey and remote sensing data for the assessment of mangrove ecosystem services (fisheries and timber related products, carbon sequestration, storm protection) in Ca Mau Province, Vietnam. The results indicate that remote sensing plays an important role in ecosystem service valuation in the large areas where mangroves and aquaculture are mixed. We estimated the value of mangrove ecosystem services using market price and replacement cost approaches to determine an initial assessment of the overall contribution of mangroves to human well-being. The total estimated value was US$ 600 million/year for 187,533 ha (approximately US$ 3000/ha/year), which is slightly smaller than the gross domestic product (GDP) of the province (US$ 0.69 billion in 2010). However, this is only a partial estimate that does not consider other services (tourism, biodiversity, cultural and social values), due to the absence of primary data. The main contribution of this study is that it is the first to combine the approaches of remote sensing and household survey for the quantification of mangrove ecosystem services in the mangrove-shrimp integrated system. Our findings indicate that the continued expansion of aquaculture has reduced the benefits to local communities provided by the mangrove ecosystem.

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1. Introduction

Mangrove forest ecosystems dominate the intertidal zone of estuaries and open shorelines along many of the World's tropical and subtropical coastlines (Alongi, 2002; Brander et al., 2012a; Giri et al., 2003; Hogarth, 2007). These ecosystems are economically valuable, providing direct livelihood benefits to local communities from fishery products (e.g., fish, shrimp, crabs, mollusks), timber products (e.g., firewood, timber, construction materials), and recreational uses such as eco-tourism (Alongi, 2008, 2002; Clough, 1998; Kuenzer et al., 2011). Mangrove forest ecosystems also provide a number of important ecosystem functions or services, including habitat and nursery functions for aquatic and non-aquatic animal species (Brander et al., 2012a; Hussain and Badola, 2010; Lewis, 2005; Rönnbäck, 1999), coastal protection (Danielsen et al., 2005; Mazda et al., 2006), carbon sequestration and storage (Bouillon et al., 2008; Donato et al., 2011; Duarte et al., 2005; Lewis et al., 2011), and management of coastal water quality (Benfield et al., 2005; Lewis et al., 2011). However, notwithstanding their significant economic and ecological benefits, mangrove forests continue to be destroyed by conversion to other land uses or degraded by over-exploitation (Alongi, 2002; Gilman et al., 2008; Kuenzer et al., 2011), in part because of the difficulty of valuing the goods and services they provide.

Many studies on the economic valuation of mangrove ecosystem services have been completed over the past 20 years (Barbier and Cox, 2002; Barbier and Strand, 1997; Hussain and Badola, 2010; Kaplowitz, 2001; Rönnbäck et al., 2007; Sathirathai and Barbier, 2001; Sathirathai, 2004; Tong et al., 2004). These studies have applied different valuation approaches for estimating the monetary value of different mangrove ecosystem services, such as avoided cost, contingent valuation, market price, production approach, replacement cost, and travel cost. The details of these methods and its advantages and disadvantages are reviewed by Vo et al. (2012).

The wide range of valuation methodologies applied to estimate the monetary values of mangrove ecosystem services has resonated in a large variability and inconsistency in terms of economic values attributed by different ecosystem valuation studies. Distinct valuation approaches are likely to result in large differences in the economic value assigned. For instance, coastal protection and sediment stabilization provided by mangroves are valued higher when a replacement cost approach is used rather than a contingent valuation method (Kuenzer and Vo, 2013; Salem and

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Mercer, 2012). Similarly, value from carbon sequestration is reported higher by a replacement cost approach in comparison to market price approaches (Salem and Mercer, 2012). In addition to the various valuation methodologies, the estimated values vary due to the specific conditions of economic activities, geographical or temporal specificity, and the culture or behavior of the local population (Brander et al., 2012a; de Groot et al., 2012; Salem and Mercer, 2012; Vo et al., 2012).

The estimated values of mangrove ecosystem services are different across study sites due to differences in the bio-physical and socio-economic characteristics of ecosystem services and are significantly affected by the prosperity of the society and its cultural characteristics (Brander et al., 2012a; de Groot et al., 2012; Gammage, 1994; Salem and Mercer, 2012; Vo et al., 2012). In addition, the price information used for cost and benefit analyses is easily distorted by distributional biases and the prosperity of the society being examined. For instance, people living in developing countries may underestimate the regulating services of mangrove ecosystems because people can have limited experience in the valuation of those services (i.e., water filtration, carbon sequestration, and pollination), which are crucial to the long-term sustainability of their livelihoods (Wegner and Pascual, 2011). Generally, ecological services are expected to have more value in countries with higher GDP per capital (Salem and Mercer, 2012). Changing perceptions and time references are also resulting in disparity of mangrove valuation (e.g. carbon sequestration only became economically valuable during the past decade) and thus leading to underestimation of mangrove ecosystem services at that time (de Groot et al., 2012). Therefore, the best solution for the assessment of mangrove ecosystem services will always be the collection and use of primary, site-specific data that reflect the characteristics and context of the study site. To be most useful for policy making, ecosystem services must be assessed within their appropriate spatial context, and economic valuation should provide estimates of value that can support decisions at the appropriate scale.

The aim of the present study is to establish a framework for linking remotely sensed spatial data, household survey data, and geophysical data to estimate the values of mangrove ecosystem services. We calculate the overall contribution of mangrove ecosystem services to the local communities, focusing on provisioning services of fishery and timber products and two regulating services (carbon sequestration, erosion control) of mangrove ecosystems. Other services, such as cultural services or genetic biodiversity, are excluded because our goal is to demonstrate the possibility of linking earth observation data, a household survey, and geophysical results for site-specific assessment of the value of mangrove ecosystems. Moreover, genetic biodiversity and cultural services are difficult to measure because these services do not enter to the market at all, so their price is also difficult to establish. Understanding the economic value of mangrove ecosystems and the services they provide to local communities has become increasingly important for local, national, and global policy and decision making. Indeed, quantifying and integrating these services into decision making will be crucial for sustainable development, where short-term economic benefits should be balanced against longer term environmental and economic sustainability.

2. Methods

2.1. Study area

The Vietnamese Mekong Delta (MD), comprising an area of approximately 40,000 km^2 located between 8°33′–10°55′N and 104°30′–106°50′E produces approximately 50% of the nation's rice and contributes more than 30% to the Gross Domestic Product of Vietnam from agricultural and aquacultural production (Gebhardt et al., 2012). Ca Mau Province, one of the biggest delta provinces, has the largest total area of mangrove forest in the MD (Fig. 1). However, the area of mangrove forest has declined about 50% over the past few decades, primarily due to increasing population pressure and the expansion of shrimp farming (Green et al., 1998; Johnston et al., 2000a; Lam et al., 2011; Tong et al., 2004). Much of the remaining mangrove forest in Ca Mau is managed under an integrated mangrove-aquaculture farming model in which farmers are required to protect and manage mangroves on at least 60% of their land holding area. Shrimp production from the remaining 40% of the land area is the primary source of income for farmers (Christensen et al., 2008; Tong et al., 2004), but the potential profitability of shrimp farming relative to mangrove protection is a powerful incentive for farmers to gradually expand their pond area by cutting down mangroves (Vo et al., 2013).

2.2. Methodology

To establish a framework of mangrove ecosystem service evaluation based on earth observation data and a household survey, we selected services that are highly relevant to the livelihoods of local communities. The household survey involved two stages. The first was the development and pre-testing of a questionnaire to ensure that relevant questions were included and captured the most robust data. The second stage consisted of a detailed survey of 300 randomly selected households, which was eventually reduced to 285 households after data exclusion due to the absence of important information such as shrimp farming area, total area as well as income and investment of shrimp farming activities. The survey used a semi-structured questionnaire with over 150 questions on different aspects of mangrove ecosystem services. The questionnaire included measures of both discrete information (land size, mangrove area, and mangrove-related income) and general qualitative information on the awareness of mangrove ecosystems, mangrove forest utilization, and the perception of mangrove forest protection. Information from all households interviewed was analyzed using SPSS statistics software.

For fisheries and wood-based products, the market price approach was used to calculate the values of fishery products and wood-related products with different mangrove forest densities using the following equation:

$$A = \sum (P_i\, Q_i - I_i)$$

where A=the total value (US$/ha/year), P_i=the product price, Q_i=the quantity, I_i=the investment, and i=the product.

Values for A, Q, I_i and i were derived from information provided by householders during the household survey. The following product market prices, current at the time of the survey, were used: an analysis of variance (ANOVA) was used to determine whether the mean values per hectare differed among the different percentages of mangrove cover (the null hypothesis states that there is no difference among the different mangrove densities in terms of the net benefit).

Multiple comparison analyses (post-hoc test) were performed to further determine the significant differences among the mangrove covers.

In general, measuring indirect-use values require different methods than measuring direct-use values because most indirect-use values are not traded in the market (Costanza et al., 1997; van Oudenhoven et al., 2012). In the present study, the valuation of carbon sequestration is estimated by benefit transfer (BT) approach. The BT approach is a technique for calculating the value of an ecosystem by employing an existing valuation estimate

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