Valuation of Mangrove Ecosystems along the Coast of the Mekong Delta in Vietnam an approach combining socio-economic and remote sensing methods

Dissertation

Zur Erlangung des Doktorgrades
der Mathematisch-Naturwissenschaftlichen Fakultät
der Christian-Albrechts-Universität zu Kiel
vorgelegt von

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May 2013

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Tag der mündlichen Prüfung: 24.05.2013

Zum Druck genehmigt:

Der Dekan

Summary

Mangrove ecosystem is among the most productive and valuable ecosystems in the world. The services provided by mangrove ecosystems to human well-being are well acknowledged in literature. Mangrove forests provide not only direct use values such as timber materials and fisheries resources but also indirect use values, for instance coastal protection, carbon sequestration as well as biodiversity. Although mangrove forests play an important role in providing goods and services to humans in both direct and indirect ways, they are declining at alarming rates. Overexploitation of mangrove for timber, urban development, increase population in coastal areas, and especially conversion to aquaculture are the major threats to mangrove forests worldwide. Over the last two decades, many studies on the valuation of mangrove ecosystems using different valuation approaches have been carried out in order to increase the awareness of decision makers to mangrove ecosystems. This dissertation investigates a new approach for quantifying the value of mangrove ecosystem services using remote sensing and household socio-economic data. Specifically, the method differentiates mangrove cover fractions in a mangrove-aquaculture integrated farming system in Ca Mau Province, Mekong Delta using an object-based approach. Ca Mau Province serves as an interesting case study as it has special conditions. First, it is the Province that hosts one of the largest mangrove forest areas in the Mekong Delta. Second, mangrove forests in this Province have been declining rapidly due to expansion of shrimp farming. Last, it is the Province that has special characteristics of the integrated mangrove-aquaculture farming system, where mangroves are planted in a shrimp pond with different mangroves densities. This dissertation reviews a comprehensive overview of methods applied for the valuation of mangrove ecosystem services undertaken for the last decades. The main findings of this research include the following: 1) a need for site/landscape-specific valuation of mangrove ecosystem due to the socio-economic context as well as inconsistency in the value-transfer approach; monetary valuation should be used to increase awareness of the importance of mangrove ecosystems to decision makers/local communities. 2) developed an object-based approach for estimating the percentage of mangroves in mixed mangrove-aquaculture farming systems. This approach is a first attempt to quantitatively estimate mangrove percentages within the special mangrove-aquaculture farming system in the Mekong Delta of Vietnam. The method comprises multi-resolution segmentation and classification of SPOT5 data using a decision tree approach as well as local knowledge from the region of interest.

The results demonstrate that the predominantly mono-cultivation areas, i.e., above 70% or below 30% mangrove forests, were detected with high accuracies compared with existing approaches, 3) the valuation of mangrove ecosystem services using combined approach of remote sensing and socio-economic household survey data. The total estimated value was US$ 600 million/year for 187,533 ha with the mean value was US$3,000/ha/year, which significantly greater than gross domestic product (GDP) of the Province (US$ 1.25 million in 2010). The results demonstrate advancements in remote sensing techniques in combination with household survey data in quantifying the value of mangrove ecosystems. However, future challenges remain before this approach can be applied in monitoring the extent of mangrove and estimating the total economic value of the mangrove ecosystem. Based on these results, future research should focus on the integration of additional geodata, such as cadastral maps in the segmentation process, or emerging remote sensing technologies such as LiDAR or hyper-spectral data to characterize mangrove species and structure. Primary research on the valuation of recreation, water filtration or biodiversity needs to be done in order to estimate the total economic value of mangrove ecosystems.

Zusammenfassung

Evaluation von Mangroven Ökosystemen entlang der Küste des Mekong Deltas in Vietnam: ein Verfahren zur Kombination sozioökonomischer und fernerkundlicher Methoden

Mangroven-Ökosysteme gehören zu den produktivsten und wertvollsten Ökosystemen der Welt. Die zahlreichen Ökosystemfunktionen, die von Mangrovenwäldern bereitgestellt werden und zum Wohlbefinden des Menschen beitragen, sind in der Fachliteratur wissenschaftlich anerkannt. Mangrovenwälder liefern nicht nur direkte Nutzungsgüter wie Holzwerkstoffe und Fischbestände, sondern auch indirekte Ökosystemfunktionen, wie zum Beispiel ihr Beitrag zum Küstenschutz, zur Kohlenstoffbindung sowie zur Biodiversität. Obwohl Mangrovenwälder bei der Bereitstellung von direkten und indirekten Gütern und Funktionen für den Menschen eine wichtige Rolle spielen, ist der Rückgang der Bestände alarmierend. Zu den größten Bedrohungen für Mangrovenwälder weltweit gehören der Ababu der Bestände im Rahmen der Holzproduktion, städtische Entwicklung, ein erhöhter Bevölkerungsdruck in den Küstengebieten und vor allem die zunehmende Landnutzungsveränderung hin zur Aquakultur. In den letzten zwei Jahrzehnten wurden zahlreiche Studien über die Bewertung von Mangroven Ökosystemen mit unterschiedlichen Ansätzen durchgeführt. Dies hat zum Ziel das Bewusstsein der Entscheidungsträger zu schärfen und über den Wert von Mangroven Ökosystemen verstärkt zu informieren.

In der vorliegenden Dissertation wird ein neues Verfahren zur wirtschaftlichen Bewertung von Mangroven-Ökosystemfunktionen vorgestellt welches auf der Kombination fernerkundlicher Methoden mit empirisch erhobenen sozioökonomischen Daten basiert. Im Detail differenziert das Verfahren verschiedene Mangroven-Bewuchs-Dichten mittels eines objektorientierten Klassifikationsansatzes, welches auf sogenannte integrierte Mangroven-Aquakultur-Anbausysteme in der Provinz Ca Mau im Mekong Delta angewendet wurde. Die Provinz Ca Mau dient als interessante Fallstudie, da sie sehr spezielle Rahmenbedingungen aufweist. Erstens, beherbergt die Provinz eine der größten Mangrovengebiete im gesamten Mekong Delta. Zweitens, sind die Mangrovenbestände in dieser Provinz aufgrund des zunehmenden Ausbaus der Garnelenzucht stark rückläufig. Außerdem weist die Provinz besondere Merkmale des integrierten Mangroven-Aquakultur-Landwirtschaftssystems auf, in dem Garnelen in Teichen mit unterschiedlichen Mangrovendichten gehalten werden.

Die Dissertation gibt einen umfassenden Überblick über Methoden zur Bewertung der Ökosystemfunktionen von Mangrovenwäldern, welche in den letzten Jahrzehnten

durchgeführt wurden. Die wichtigsten Ergebnisse dieser Untersuchung sind: 1) Die Notwendigkeit von orts-spezifischen Bewertungsansätzen für Mangroven-Ökosysteme aufgrund variierender sozio-ökonomischen Rahmenbedingungen sowie Inkonsistenzen bei Wert-Transfer-Ansätzen; monetäre Bewertungsansätze sollten verwendet werden, um die Bedeutung von Mangroven-Ökosystemen für Entscheidungsträger/Gemeinden zu erhöhen. 2) Ein objekt-basierter Ansatz zur Abschätzung von Mangrovenanteilen in gemischten Mangroven-Aquakultur-Anbausystemen wurde entwickelt. Dieser Ansatz ist ein erster Versuch, quantitativ Mangrovenanteile innerhalb des speziellen integrierten Mangroven-Aquakultur-Systems im vietnamesischen Mekong-Delta abzuschätzen. Das Verfahren umfasst einen multi-skaligen Segmentierungsansatz, die Klassifizierung von SPOT5 Satellitendaten mit Hilfe eines Entscheidungsbaums sowie die Integration von lokalem Wissen über die Testregion. Die Ergebnisse zeigen, dass, im Vergleich zu bestehenden Ansätzen, homogene Flächen, nämlich Gebiete mit über 70% oder unter 30% Mangrovenbeständen, mit hohen Genauigkeiten erfasst werden konnten. 3) Die Bewertung von Mangroven-Ökosystemfunktionen mittels eines kombinierten Ansatzes von Fernerkundungsmethoden und empirischen Haushaltsbefragungen. Der geschätzte Gesamtwert beläuft sich auf ca. 600 Mio. US $ / Jahr für eine Gesamtfläche von 187,5 ha. Der durchschnittliche Wert pro Hektar wird auf ca. 3.000 US $ / Jahr geschätzt, welcher wesentlich höher liegt als das Bruttoinlandsprodukt (BIP) der Provinz (1,25 Mio. US $ in 2010). Das Ergebnis des verwendeten Ansatzes stellt einen wesentlichen Fortschritt dar in der Kombination von Fernerkundung und sozioökonomischen Daten aus Haushaltsbefragungen zur wirtschaftlichen Bewertung von Mangroven Ökosystemen. Allerdings bleiben noch Herausforderungen zu bewältigen, damit dieser Ansatz zur Überwachung von Mangrovenbeständen und zur Schätzung ihres wirtschaftlichen Gesamtwertes umgehend angewendet werden kann. Basierend auf den erzielten Ergebnissen, sollten sich zukünftige Forschungstätigkeiten darauf konzentrieren, zusätzliche Geodaten, wie z.B. Katasterkarten, in den Segmentierungsablauf zu integrieren, oder auf neue Fernerkundungstechnologien wie die Nutzung von LiDAR oder hyper-spektralen Daten zur Charakterisieren von Mangrovenarten und deren Strukturen fokussieren. Nicht zuletzt ist es notwendig weitere Forschungstätigkeiten in die wirtschaftliche Bewertung weiterer Ökosystemfunktionen zu investieren, wie z.B. der Freizeitfunktion, der Wasser-Filtration oder der Biodiversität, um letztendlich den gesamt-wirtschaftlichen Wert von Mangroven-Ökosystemen abschätzen zu können.

Acknowledgements

This dissertation is a result of nearly 4 years work in the Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR), Germany within the team "Land Surface Dynamics". I would like to acknowledge the generous support of the Teaching and Research Innovation Grant (TRIG) implemented at Can Tho University, Vietnam for a Doctoral grant for the first two years, and the WISDOM project for acquisition of remote sensing data and funding to support field work in Vietnam. Many people have supported me during the completion of this dissertation. I would like to acknowledge the following people for their assistance and support.

First of all my thanks go to my first supervisor Prof. Natascha Oppelt at the University of Kiel for her constructive guidance and encouragement and for reviewing and improving my manuscripts throughout my research. She has been very stimulating and I admire her patience and her perseverance in reading manuscripts and providing comments.

My special thanks go to Dr. Claudia Kuenzer (DLR) for giving me the opportunity to work in the WISDOM project and supporting my work from the very beginning with helpful advice and critical opinions on my work, which had a great impact on the result of this dissertation.

I would like to thank Prof. Vo Thi Guong, Prof. Vo Quang Minh from Can Tho University for their encouragement and support during my study.

I would like to thank my friends in the WISDOM project: Juliane Huth for helping me during my time at DLR, Patrick for helping me during the revision of manuscripts and translating this summary to German, Dr. Stefen Gebhardt for supporting me at the beginning of the research, Florian for giving me comments on my first manuscript, Dr. Thilo Wehrmann, Binh, Verena, Manuel, Corinne, Vahid, Marthe, and Tyler for their general support; Marco, Malte, Tim, and Andreas for the unforgettable time in Germany.

I am thankful to the people that helped me with the fieldwork, among others:
Mr. Nguyễn Như Độ (Director of Ca Mau Forestry Department) for his introduction to the local forest management units, as well as providing useful information on mangrove forests in Ca Mau Province. My MSc students from Can Tho University: Hưỡng, Nhàn, Thọ, Nhân for their contribution to the household survey in 2010. Technical staff: Mr. Nhị, Mr. Điều, Mr. Họp, Mr. Ái, Mr. Bắc from Năm Căn, Đầm Dơi, Kiến Vàng forest compartments with

their extensive knowledge of mangrove species and wonderful information about mangrove forests in Ca Mau Province, and Mr. Ngà (boat driver) who knows almost every creek, canal, and river in Ca Mau Province. I would like to thank all of those people that supported me up to this point, especially my parents, brothers and sisters, who always believe in my work and encourage me during the time study abroad.

Finally, I would like to express my deepest appreciation to my loving wife Trần Ngọc Thiền, who takes care of our sons Tuấn Khanh and Tuấn Tài during my long absence. I apologize for all difficulties that you faced during my time in Germany.

Thank you all the people that I did not mention, but that played an important part in this dissertation.

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Chapter I Introduction

1.1. Background and literature review

The term “mangrove” describes both the ecosystem and the plant families that have developed specialized adaptations to live in the tidal environment (FAO, 2007 cited from Tomlinson, 1986). Mangrove forests are situated in tropical and sub-tropical regions around the world (Alongi 2002). Tropical regions are dominant in terms of spatial distribution of mangroves which cover up to 75% of the tropical and sub-tropical shorelines (Alongi 2002; FAO 2007; Spalding et al. 2010). They grow in high salinity, high temperature, high sedimentation and muddy lands Mangroves are known as one of the riches biodiversity ecosystems with about seventy known mangrove species, which are all tolerant to salt and brackish waters (Myint et al. 2008). The total mangrove area worldwide is estimated by many studies and resulted in different numbers depending on different years and methodologies. Table 1. 1 shows the results of previous estimates of total mangrove area globally by different authors. Recently, Giri et al., (2011), applied hybrid supervised and unsupervised image classification techniques for 1000 Landsat scenes to estimate the total area of mangrove worldwide. The result showed that total mangrove area globally in the year 2000 was 137,760 km^2 and distributed in 118 countries and territories (Figure 1. 1), which is 12.3% smaller than estimate by FAO, 2007 (157,050km^2).

Table 1. 1. Previous estimates of mangrove area worldwide (FAO, 2007, modified)

Authors	Publication Year	No. countries	Total area (km^2)
FAO and UNEP	1981	51	156,426
Saenger, Hegerl & Davie	1983	65	162,210
FAO	1994	56	165,000
Groombridge	1992	87	198,478
ITTO & ISME	1993	54	124,291
Fisher & Spalding	1993	91	198,818
Spalding, Blasco & Field	1997	112	181,000
Aizpuru, Achard & Blasco	2000	112	170,756
FAO	2007	124	157,050
Giri et al	2011	118	137,760

Mangrove ecosystems are the most productive ecosystems in the world (Christensen 1982; FAO 2007; Kathiresan and Bingham 2001; Kuenzer et al. 2011). The importance of mangrove forests as a coastal resource is well acknowledged in many studies (Alongi 2008; Alongi 2002; Rönnbäck 1999; Thampanya et al. 2006). Mangrove forests not only provide commercial fishery resources (Hammer et al. 2003; Rönnbäck et al. 2007; Seto and Fragkias 2007), they also play a crucial role in stabilizing coastlines, dissipating the destructive energy of waves and reducing the impact of hurricanes, cyclones, tsunamis and storm surges (Badola and Hussain 2005; Danielsen et al. 2005; Mazda et al. 1997; McIvor et al. 2012; Tran 2011). Many studies have shown that regions with intact mangroves have been exposed to significantly lower levels of devastation from cyclones than those with degraded or converted mangroves (Badola and Hussain 2005; Barbier 2006; Dahdouh-Guebas et al. 2005a). Mangroves are known as a resource for exporting organic matter to the marine environment, producing nutrients for fauna in both the mangroves themselves and adjacent marine and estuarine ecosystems (Bann 1997). Additionally, mangrove forests are often a rich source of timber, fuel wood, medicinal plants and other raw materials for local consumption (Walters et al. 2008). Carbon sequestration provided by mangroves is also well acknowledged (Fujimoto 2000; Mcnally et al. 2011). Lastly, mangrove ecosystems attract many recreation purposes such as eco-tourists, hunters, and birdwatchers, providing economic value for local communities (Gammage 1994; Hussain and Badola 2010; Kaplowitz 2001).

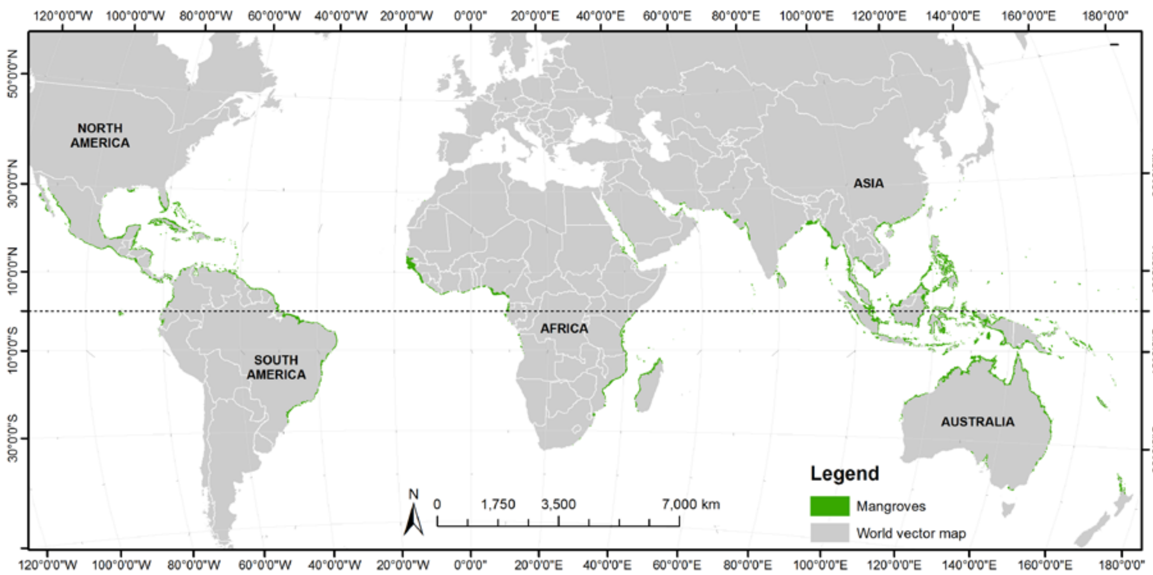

Figure 1. 1. Mangrove forest distribution of the world – 2000, modified from Giri et al, 2011

However, mangrove forests are declining rapidly due to high population pressure in coastal areas, urban development, and especially conversion of mangrove areas to others land uses, e.g. aquaculture, agriculture, settlement areas (Alongi 2002; Van Lavieren et al. 2012). According to Millennium Ecosystem Assessment - MA (2005b), approximately 35% of mangroves were lost from 1980 to 2000, and if the present rate of loss continues, 100% of mangrove forests could be lost in the next 100 years due to sea-level rise (Duke et al. 2007). A recent study by the FAO (2007) showed that although the rate of net loss of mangrove has slowed down since 1980, more than 100,000 hectares of mangroves were still lost every year during the period of 2000 to 2005.

1.2. Study area

Located at 8°33'-10°55'N, 104°30'-106°50'E; the Mekong Delta (MD) from the border with Cambodia to the East Sea (Figure 1. 2) includes the Provinces of Long An, Tien Giang, Ben Tre, Tra Vinh, Dong Thap, An Giang, Kien Giang, Vinh Long, Can Tho, Hau Giang, Soc Trang, Bac Lieu and Ca Mau. The MD comprises an area of approximately 39,000 square kilometers, of which 24,000 square kilometers are now used for agriculture and aquaculture 4,000 square kilometers for forestry (including mangroves and melaleuca forests), and the remaining area for settlement and construction purposes (Leinenkugel et al. 2011; Thu and Populus 2007). Cultivation in the Delta is mostly irrigated rice crops and numerous aquaculture farms in the coastal Provinces. Primary products from the Delta contribute over 30% of the Gross Domestic Product (GDP) and the Delta is Vietnam’s rice bowl, producing 50% of the nation’s rice and contributing to Vietnam’s place as the second largest rice exporter in the world. (Evers and Benedikter 2009; Nguyen et al. 2012).

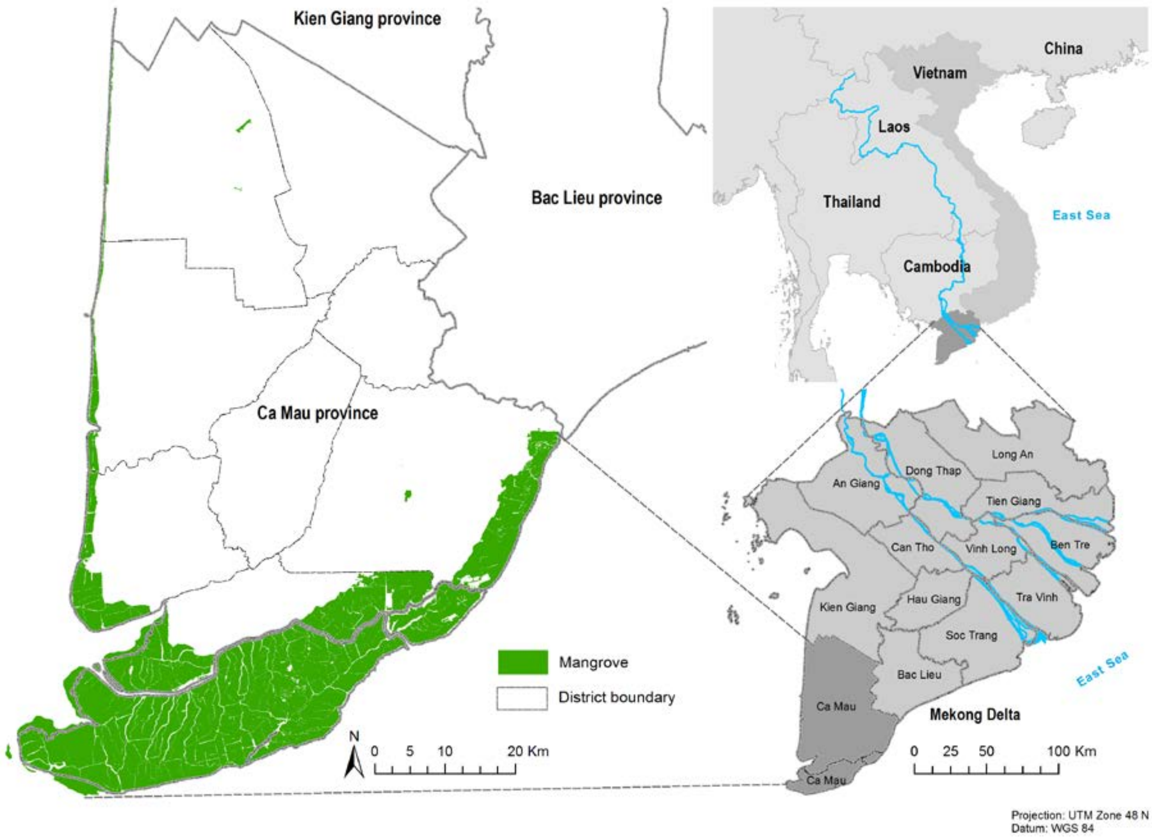

Figure 1. 2. Overview of the Ca Mau Province of the Mekong Delta

The original area of mangroves has been reduced considerably, mainly due to the chemical warfare (herbicides and napalm) undertaken during the Viet Nam war (1962-1972) as mangrove forests served as bases for military operations. Thousands of hectares of mangroves were destroyed in the eastern part of the South zone, the coast of the Mekong Delta and the Ca Mau Peninsular, where primary forest is now absent. Remaining forests consist mainly of secondary growth, much of it scrubby, and plantations.

Ca Mau Province was estimated to have about 150,000 hectares in 1943 (Tong et al. 2004). Like other areas in Vietnam, the mangrove forest area was sprayed with herbicides and defoliants during the second Indochina war, leading to about 45,000 hectares being destroyed (Binh et al. 2003). *Rhizophora apiculata* is a main mangrove species in Ca Mau Province with more than 80% (Clough et al. 2002). After the war, natural regeneration and many planting programs led to partial recovery of mangrove forests. However, population pressure and conversion to aquaculture hampered the restoration of mangroves (Binh et al. 2003; Clough et al. 2002). (Figure 1. 3).

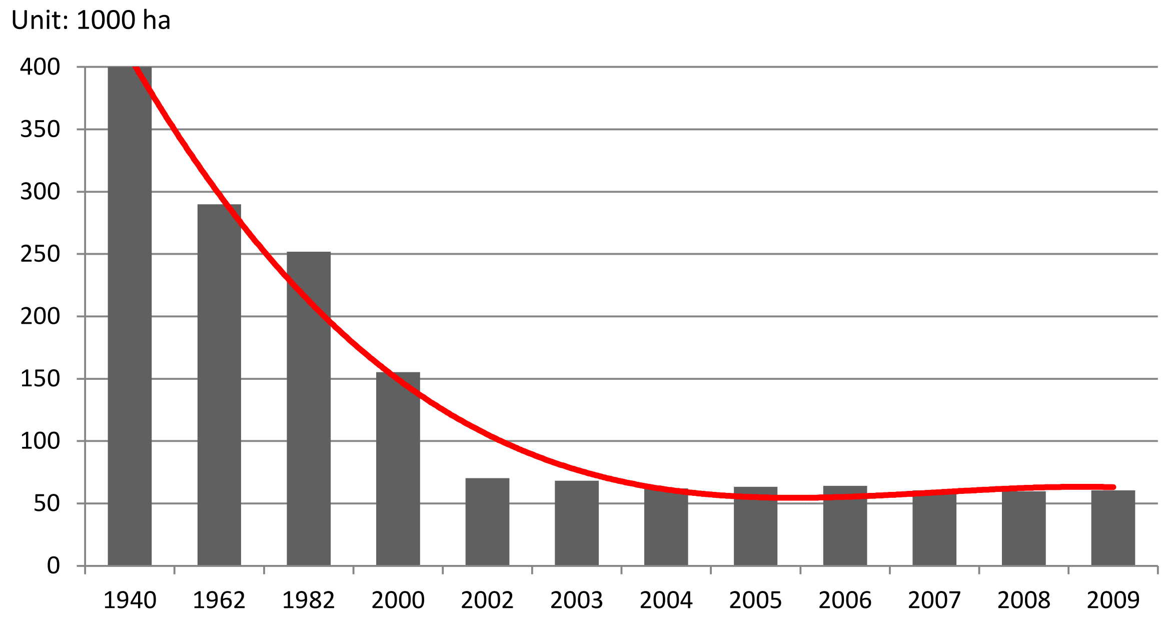

Figure 1. 3. Mangrove forest area in Vietnam (Source: GOV, 2011)

Mangrove ecosystems are highly productive, but also very vulnerable (Tabuchi, 2003). According to Alongi, (2002) “approximately one third of the mangrove forests over the world have been lost in the past 50 years”. However Kairo et al., (2001) report that “less than 50% of the original total cover of mangroves” has remained. The losses of mangroves can be attributed to the fact that they are heavily exploited, since mangroves are highly productive ecosystems. The main threats for mangroves are overexploitation of the natural resources, deforestation, conversion to aquaculture and salt-ponds, mining, pollution and industrial or urban development (Alongi 2002; Field 1998). Natural disasters like tropical cyclones and the Asian tsunami of 26 December 2004 can also devastate mangrove ecosystems (Barbier and Cox 2002; Danielsen et al. 2005).

Figure 1. 4. Examples of different mangrove cover in an integrated shrimp-mangrove farming system.

Mangroves are valuable ecosystems that provide a natural barrier against storms, stabilize coastlines and have a high economic value for humans, who depend on their natural resources (Figure 1. 5). Therefore rehabilitation and restoration projects are carried out all over the world to prevent further degradation and losses of mangrove areas. Rehabilitation is defined by Field (1998) as “partially or fully replacing structural or functional characteristics of an ecosystem”. Field emphasizes that ecological rehabilitation may also include substitution of the disturbed or degraded state to a situation of alternative characteristics than those originally present, as long as these alternative characteristics have more social, economic or ecological value. Restoration on the other hand is described by Field as “bringing an ecosystem back into its original condition”. Rehabilitation projects in general have three main objectives: conservation of a natural system and landscape, sustainable production of natural resources and protection of coastal areas (Barbier 2006; Field 1998).

Figure 1. 5. Goods and services provided by mangrove ecosystem in the Mekong Delta

1.3. Objective and outline

The objective of this dissertation is to develop a conceptual framework for the economic valuation of mangrove ecosystem services using remote sensing and socio-economic household survey data. The dissertation is cumulatively structured as separate manuscripts that are published or awaiting publication in international peer-reviewed scientific journals. These papers are reproduced here without modification except for the style format and cross-references.

Chapter 2 is a review paper on the valuation methods for mangrove ecosystem services published in *Ecological Indicators*, May 2012. This chapter provides a comprehensive overview and summary of studies undertaken to investigate the ecosystem services of mangrove forests. We address the variety of different methods applied for different ecosystem services evaluation of mangrove forests, as well as the methods and techniques employed for data analyses, and further discuss their potential and limitations.

Chapter 3 explores a new approach to map mangrove densities in a mangrove-shrimp integrated farming system published in *Remote Sensing*, January 2013. This paper presents an object-based classification approach for estimating the percentage of mangroves in mixed mangrove-aquaculture farming systems to help the government monitor the extent of the shrimp farming area. The method comprises multi-resolution segmentation and classification of SPOT5 data using a decision tree approach as well as local knowledge from the region of interest. The results show accuracies higher than 75% for certain classes at the object level. Furthermore, we successfully detect areas with mixed aquaculture-mangrove land cover with high accuracies. Based on these results, mangrove development, especially within shrimp farming-mangrove systems, can be monitored. However, the mangrove forest cover fraction per object is affected by image segmentation and thus does not always correspond to the real farm boundaries. It remains a serious challenge, then, to accurately map mangrove forest cover within mixed systems.

Chapter 4 examines the potential for using earth observation data and household survey for estimating mangrove ecosystem services in monetary terms submitted in *Ecosystem Services*, April 2013. This paper emphasis the importance of combining socio-economic and remote sensing data for the assessment of mangrove ecosystem services in the Ca Mau Province (partly), Vietnam. The role of remote sensing for the quantification of mangrove ecosystems is highlighted, especially in the large areas where mangroves and aquaculture are mixed. The monetary value of mangrove ecosystem services was estimated in Ca Mau Province using market price and replacement cost approaches to determine an initial assessment of overall contribution of mangroves to human well-being. The total estimated value was US$ 600 million/year for 187,533 ha (approximately US$3,000/ha/year), which is significantly greater than gross domestic product (GDP) of the Province (US$ 1.25 million in 2010).

Chapter 5 reviews the findings from the results chapters and reflects on the contribution made. The dissertation concludes with an outlook on the state of mangrove ecosystem services assessment in the Mekong Delta and future research directions.

Chapter II Review of valuation methods for mangrove ecosystem services

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Ecological Indicators, Volume 23 (2012), Page 431-446.

Submitted 6 September 2011, Accepted 21 April 2012, Published 24 May 2012

Abstract

The goods and services provided by natural ecosystems contribute to human well-being, both directly and indirectly. The ability to calculate the economic value of the ecosystem goods and services is increasingly recognized as a necessary condition for integrated environmental decision-making, sustainable business practice, and land-use planning at multiple geographic scales and socio-political levels. We present a comprehensive overview and summary of studies undertaken to investigate the ecosystem services of mangrove forests. We address the variety of different methods applied for different ecosystem services evaluation of mangrove forests, as well as the methods and techniques employed for data analyses, and further to discuss their potential and limitations.

2.1. Introduction

The term “ecosystem service” (ES) comprises all goods and services provided by natural and modified ecosystems that benefit, sustain and support human well-being. This includes benefits of the ecosystem based on the food production, building materials, medicines, regulation of microclimate, disease prevention, pro- vision of productive soils and clean water resources, as well as landscape opportunities for recreational and spiritual benefits (Banzhaf 2007; Costanza and Folke 1997; Daily 1997; MA 2005a; Wallace 2007). Such services are provided by ecosystems which consist of a combination of soil, animals, plants, water, air and other services such as the service that maintaining biodiversity or contribute to climate stability. If these elements are depleted, the ability or capacity of ecosystems to provide services is diminished. ES support our well-being, including the production of most of our living needs, and thus are of significant value. However, the services from the ecosystems are greatly undervalued by society. Most of them are not traded in the formal market, and its value is not easy to be estimated (Daily 1997). ES are often neglected or even ignored by the economy, industry, and local habitants; even though most of them strongly depend on the flow of ES.

Knowing the economic value of an ecosystem and its services is an important asset, because a major demand is the support of human wellbeing, sustainability, and distributional fairness (Costanza Farber,S et al. 2002). From the human perspective, natural ecosystems not only provide life supporting services, but also services beyond basic life support (e.g. recreational and aesthetic enjoyment) (Daily 1997; Farber et al. 2002). Over the past two decades, humans changed ecosystems more rapidly and comprehensively than in any comparable period before. This was mainly due to the rapidly growing demands for food, fresh water, timber, fiber, and fuel. This transformation of the planet has contributed to substantial net gains in human well-being and economic development (MA 2005a).

This review paper gives a comprehensive overview of studies on the concept of ecosystem functions and services, and synthesizes the methodologies for assessing the value of mangrove ecosystem services. ES concepts and valuations itself, which have been developed so far, are introduced briefly. The paper highlights key issues and trends in the application of economic valuation techniques on natural ecosystems. It reviews different valuation techniques and illustrates applications with examples drawn from empirical literature studies. The paper also includes a brief discussion of how results of previous valuation studies might be used for future evaluation methods of natural ecosystem services.

The paper summarizes and discusses studies on ES and functions in the context of environmental protection as well as climate change mitigation, published over the last two decades. The focus is set on ES in coastal areas, where mangrove wetlands are prevailing, which are an important asset for coastal protection, and provide numerous additional services for the coastal communities.

The next section describes the importance of ES research and the increasing focus on ecosystem studies. In Section 2, the general concept of ecosystem functions and services in the context of coastal environmental protection is discussed.

Section 3 reviews research papers on the valuation of mangrove ecosystem services based on different approaches. In Section 4, the different approaches to assess ecosystem functions and ecosystem evaluations are discussed. This section also discusses the difficulties of ES assessment especially concerning the definitions of economic values of ecosystem services.

2.1.1. Definition of ecosystem services

The concept of ES and their valuation was first introduced in the 1960s by King, (1966) and Helliwell, (1969) who referred the nature's functions in serving human societies. Afterwards, ecosystem services has been the focus of many publications (e.g. (Banzhaf 2007; Costanza and Folke 1997; Daily 1997; de Groot 2002; MA 2005a; Pearce and Moran 1994; Pearce 1993; Wallace 2007). The widely accepted definition of ES is: "Ecosystem services are the benefits provided by ecosystems to humans, which contribute to making human life both possible and worth living". (Díaz et al. 2006; Layke et al. 2012; MA 2005a; Van Oudenhoven et al. 2012). This includes goods such as food-crops, seafood, for- age, timber, biomass fuels, natural fiber, pharmaceuticals, geologic resources, and industrial products, services such as the maintenance of biodiversity and life-support functions, including waste assimilation, cleansing, recycling and renewal (Table 2. 1) (Busch et al. 2011; Costanza et al. 1998; Costanza and Folke 1997; Daily 1997; Eisfelder et al. 2011; Norberg 1999), and intangible aesthetic and cultural benefits (Bengtsson 1997; de Groot et al. 2002; King et al. 2000). According to the MA, (2005a), ES are indispensable for both the natural environment and human beings. Four major categories of ES were identified by the MA, which are (i) provisioning services, (ii) regulating services, (iii) cultural services, and (iv) supporting services (MA,2005a) (Figure 2. 1).

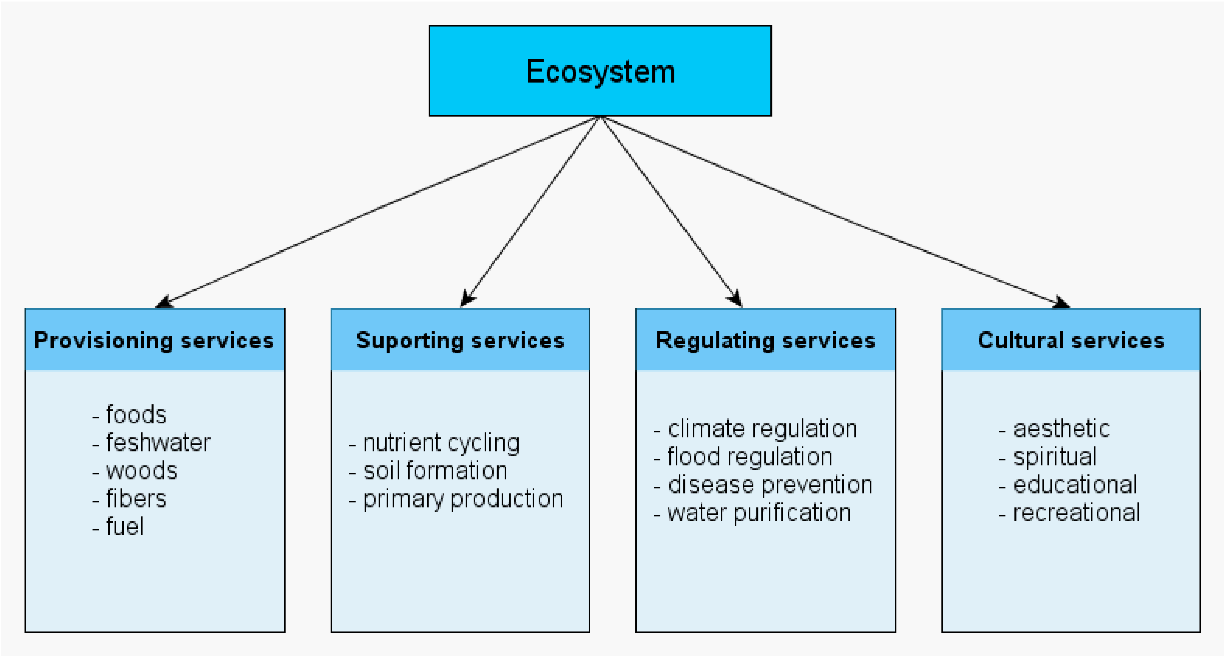

Figure 2. 1. Ecosystem services (adapted from MA, 2005a,b), modified.

In ecological literature, the term "ecosystem services" has been subject to various and sometimes contradictory interpretations. Some authors use the term to describe the internal function such as nutrient cycling or energy maintenance (Daily 1997; Fisher Turner, R. K. and Morling, P 2009; Wallace 2007); others relate ES to the benefit for humans, which can be derived from the processes of the ecosystem (e.g. food production, recreation) (Brown et al. 2007; de Groot et al. 2002; Luck et al. 2009). According to Jewitt, (2002), ecosystem services are generated by a complex interplay of natural cycles, powered by solar energy, and operating across a wide range of space and time scales, incorporating both biotic and abiotic components.

Banzhaf, (2007) integrated economic principles in their definition "Ecosystem services are components of nature, directly enjoyed, consumed, or used to yield human well-being". The important aspect of their work is that they distinguished between "end-products" and "intermediate products" to account welfare. "End products" are consumed directly by a household such as clean drinking water, but clean drinking water is depending on ecological processes, which are described as "intermediate products". They argue that if intermediate and final goods are not distinguished, the value of intermediate goods are double counted because the value of intermediate goods is embodied in the value of final goods (e.g. the value of steel used in for the production of cars is already part of the car's total value) (Banzhaf 2007).

In general, definitions of ES are as diverse as the number of studies published in this context. All studies, however, acknowledge the strong relation between ecosystem function and human well-being. In other words, ecosystem services consist of flows of materials, energy, and information from natural capital stocks, which can be combined with manufactured and human capital services to produce human welfare.

The publication of the MA reports and their definition of ES also lead to intense discussions criticizing the concept and several modified classification approaches were published (De Groot 2002; Haines-Young, R.H. and Potschin 2009; TEEB 2008; Wallace 2007). The main critics regarding the MEA definition of ES complain the simplified and very generic framework as well as an imprecise differentiation between services themselves, ecosystem processes and benefits (Banzhaf 2007; Fisher et al. 2007; Wallace 2007). Banzhaf (2007) tried to solve the mixing problem with an economical principle that should also standardize the concept of ES. Wallace, (2007) also favours a standardized framework that only counts endpoints (final services) as ES and fits to all applications to facilitate the concept for landscape planners. However, each of them considers the need of multiple and context-based classification systems to fit the complexity of the human-ecosystem interface and find valuable benefits. Most authors suggest frame- works that separate the MA supporting services (e.g. nutrient or water cycling) in ecosystem functions and processes. Recently, multinational gatherings, including the "Convention on Biological Diversity", the "Ramsar Convention on Wetlands and Migratory Species", and the "Convention to Combat Desertification", have incorporated the ES concept into their discussion and convening. Also major Non-Governmental Organizations (NGO) including The Nature Conservancy, the World Wildlife Fund (WWF), the International Union for the conservation of Nature (IUCN), and the World Resource Institute (WRI) have begun to piloted ES programs, as have major intergovernmental agencies including the United Nations Development Program (UNDP), and the World Bank (Tallis et al. 2008). Their projects have variously been categorized as integrated conservation–development projects, focusing on community-based natural resource management. Many lessons have been learned based on these projects already conducted by conservation NGOs, in which efforts have been made to both improve human well-being and the state of the ecosystem (Tallis et al. 2008).

Table 2. 1. Ecosystem services and functions as presented in Costanza and Folke (1997) and Rönnbäck (2007)

Ecosystem Service	Ecosystem Function	Examples
Gas Regulation	Regulation of atmospheric chemical composition	CO_2/O_2 balance,O_3 for UVB protection, and SO_x levels
Climate Regulation	Regulation of global temperature, precipitation, and other biologically mediated climatic processes at global or local levels	Greenhouse gas regulation, Dimethyl sulfide (DMS) production affecting cloud formation
Disturbance regulation	Capacitance, damping and integrity of ecosystem response to environmental fluctuations	Storm protection, flood control, drought recovery, and other aspects of habitat response to environmental variability mainly controlled by vegetation structure
Water Regulation	Regulation of hydrological flows	Provisioning of water for agricultural (such as irrigation) or industrial (such as milling) processes or transportation
Water Supply	Storage and retention of water	Provisioning of water by watersheds, reservoirs and aquifers
Erosion Control and Sediment Retention	Retention of soil within an ecosystem	Prevention of loss of soil by wind, runoff, or other removal processes, storage of silt in lakes and wetlands
Soil Formation	Soil formation processes	Weathering of rock and the accumulation of organic material
Nutrient Cycling	Storage, internal cycling, processing, and acquisition of nutrients	Nitrogen fixation, N, P, and other elemental or nutrient cycles.

Waste Treatment	Recovery of mobile nutrients and removal or breakdown of excess or xenic nutrients, and compounds	Waste treatment, pollution control, detoxification
Pollination	Movement of floral gametes	Provisioning of pollinators for the reproduction of plant populations
Biological Control	Trophic-dynamic regulations of populations	Keystone predator control of prey species, reduction of herbivores by top predators
Refugia	Habitat for resident and transient populations	Nurseries, habitats for migratory species, regional habitats for locally harvested species, or overwintering grounds
Food Production	That portion of gross primary production extractable as food	Production of fish, game, crops, nuts, fruits by hunting, gathering, subsistence farming or fishing
Raw Materials	That portion of gross primary production extractable as raw materials	The production of lumber, fuel, or fodder
Genetic Resources	Sources of unique biological materials, and products	Medicine, products for materials science, genes for resistance to plant pathogens and crop pests, ornamental species (pets and horticultural varieties of plants)
Recreation	Providing opportunities for recreational activities	Eco-tourism, sport fishing, and other outdoor recreational activities
Cultural	Providing opportunities for non-commercial uses	Aesthetic, artistic, educational, spiritual, and/or scientific values of ecosystems

Over the last two decades, ES and the natural capital from which these services originate have increasingly caught the interest of environmental researchers, policy makers, as well as economists. More recently, there has been an almost exponential growth in publications on the ecosystem functions and services, value of natural ecosystems, how people benefit from the services provided by the ecosystem functions and services, value of natural ecosystems, how people benefit from the services provided by the natural ecosystem, and methods of assessing the values of natural ES. (e.g. De Groot, 1992, 1994; Pearce, 1993; Bingham et al., 1995; Pimentel Wilson,C., 1997; Costanza and Folke, 1997; Daily, 1997; Limburg and Folke, 1999; Wilson, 1999; Daily et al., 2000; Guo et al., 2001; Lal, 2003; MA, 2005; TEEB, 2008; Burkhard et al., 2010, 2011; Kumar, 2010).

2.1.2. Ecosystem services versus ecosystem functions

The term “ecosystem function” (EF) is interpreted differently by different authors. Sometimes the concepts are used to describe the internal functioning of the ecosystem (e.g. nutrient cycling and maintaining energy fluxes, nutrient recycling, food–web interactions) (Bingham et al. 1995; Costanza and Folke 1997; Daily et al. 2000; Daily et al. 1997; De Groot 1994; De Groot 1992; Nedkov and Burkhard 2011; Pearce 1993), and sometimes it refers to the internal functioning of the ecosystem (Costanza Folke, C 1997; Daily et al. 2000; de Groot 2002; De Groot 1992). De Groot, (1992) defined an EF as “the capacity of natural processes and components to provide goods and services that satisfy human needs directly or indirectly”. They attempted to provide a comprehensive and consistent overview of all functions, goods and services provided by natural and semi-natural ecosystems, and grouped ecosystem functions into four primary categories, which are listed in Table 2. 2, Table 2. 3, Table 2. 4, Table 2. 5.

- *Regulation functions*: This group of functions relates to the capacity of natural and semi-natural ecosystems to regulate essential ecological processes and life support systems through biogeochemical cycles and other biosphere processes.

- *Production functions*: These functions provide many ecosystem goods and services for human consumption such as food, raw materials, energy resources and genetic material.

Table 2. 2. Regulation functions of ecosystems (De Groot, 1992).

Regulation functions	Examples
Gas regulation	Maintenance of chemical composition of air and ocean, and provision of clean air, prevention of diseases such as skin

	cancer, and general habitability of the earth
Climate regulation	Provision of favorable climate, which enables us to maintain health, produce crops, have recreation
Disturbance prevention	Provision of buffer to natural hazards such as storms, floods, and droughts
Water regulation	Provision of irrigation, drainage, river discharge, channel flow, and transportation medium
Water supply	Provision of water for human
Soil formation	Provision of a medium for production of crops
Nutrient regulation	Provision of nutrients such as N, P, K, sulfur, calcium, magnesium and chlorine through recycling
Waste treatment	Assimilation, dilution, and chemically decomposition of organic and wastes
Pollination	Provision of services to enable plants to reproduce
Biological control	Interaction and feedback mechanisms, which stabilize population of various species, thereby preventing outbreaks of pests and diseases

Table 2. 3. Production function of an ecosystem (according to De Groot, 1992).

Production functions	**Examples**
Food	Food sources that allow a diverse number of plants and animals to thrive and evolve
Raw materials	Include wood and fibers, chemicals and compounds (e.g. latex, gums), energy sources, and animal fodder

Genetic resources	Provide source of genes to improve characteristics (taste, pest resistance) of cultivated crops
Medicinal resources	Provide chemicals that are used as drugs, or as models for synthetic drugs
Ornamental resources	Provide materials for fashion, crafts, cultural objects, decoration, etc.

Table 2. 4. Habitat functions of an ecosystem (according to De Groot, 1992).

Habitat functions	**Examples**
Refugium function	Provides living space, cover, and food sources that allow a diverse number of plants and animals to thrive and evolve
Nursery function	Provision of breeding and nursery grounds for species that are harvested elsewhere as adults

Table 2. 5. Information functions of an ecosystem (according to De Groot, 1992).

Information functions	**Examples**
Aesthetic information	Provide scenery and landscape for human enjoyment; can influence real estate prices
Recreation	Provide venue for recreation such as camping, hiking and other ecotourism activities
Cultural and artistic information	Nature often as basis for cultural traditions; provides inspiration for artistic pieces
Spiritual and historic information	Provide sense of continuity and place and can be important part of religion

Science and education	Provide sense of continuity and place and can be important part of religion

- *Habitat functions*: Natural ecosystems provide refuge and reproduction habitat to wild plants and animals and thereby contribute to the conservation of biological and genetic diversity and evolutionary processes.

- *Information functions*: Natural ecosystems provide an essential "reference function", and contribute to the maintenance of human health by providing opportunities for reflection, spiritual enrichment, cognitive development, recreation and aesthetic experience (Costanza and Folke 1997; Daily 1997; de Groot et al. 2002)

The EFs that are apparently valuable to society are called ES. However, given the early stages of human knowledge regarding ecosystems, it would be both untimely and imprudent to exclude any EF from this category. ES clearly provide life support services for both humans and other species. ES go beyond the direct economic benefits derived from exploitation of very specific EF such as timber from forests. It is ecosystems' ongoing capacities to provide a stream of life supporting and life enhancing services that are vital to human well being. Many of these services are non-market services by virtue of their inherent characteristics (e.g. both the atmospheric ozone layer, and the climate stability provided by the global carbon cycle, cannot be owned by anyone who can control their use by others; both ownership and control are conditions for a good or service to be traded in a market).

Within the study by Banzhaf, (2007) on What are ecosystem services? The need for a standardized environmental accounting unit, the authors concluded: "Ecosystem components include resources such as surface water, oceans, vegetation types, and species. Ecosystem processes and functions are the biological, chemical, and physical interactions between ecosystem components. The reason is that functions and processes are not services, they are not end-products; functions and processes are intermediate to the production of final services". Many components and functions of an ecosystem are intermediate products; they are necessary to the production of services but are not services themselves (Banzhaf 2007)

Bengtsson, (1997) published a paper on "What are the relationships between ecosystem functions and biodiversity". The author used different aspects of diversity and ecosystem complexity, such as species richness, variety of diversity indices, or the number of functional groups to explore the relationship between EF and biodiversity. The author concluded that diversity and EF has no direct relationship to each other, but both are functions of the presence and activities of species, functional groups, and their interactions. It has already been pointed out that it is difficult to predict, which species will be important for EF as environmental conditions change, even in fairly well studied types of ecosystems (Bengtsson 1997; Schneiders et al. 2011).

EFs and ES can overlap, leading to the possibility of economic "double counting" in calculating the value of an ecosystem. De Groot et al., (2002) revealed that EF and ES do not always show a one-to-one correspondence, sometimes a single ES is the product of many functions, whereas in other cases a single function contributes to more than one service (Figure 2. 2) (e.g. gas regulation is based on biogeochemical processes which maintain a certain air quality as well as influence the greenhouse effect and thereby climate regulating processes).

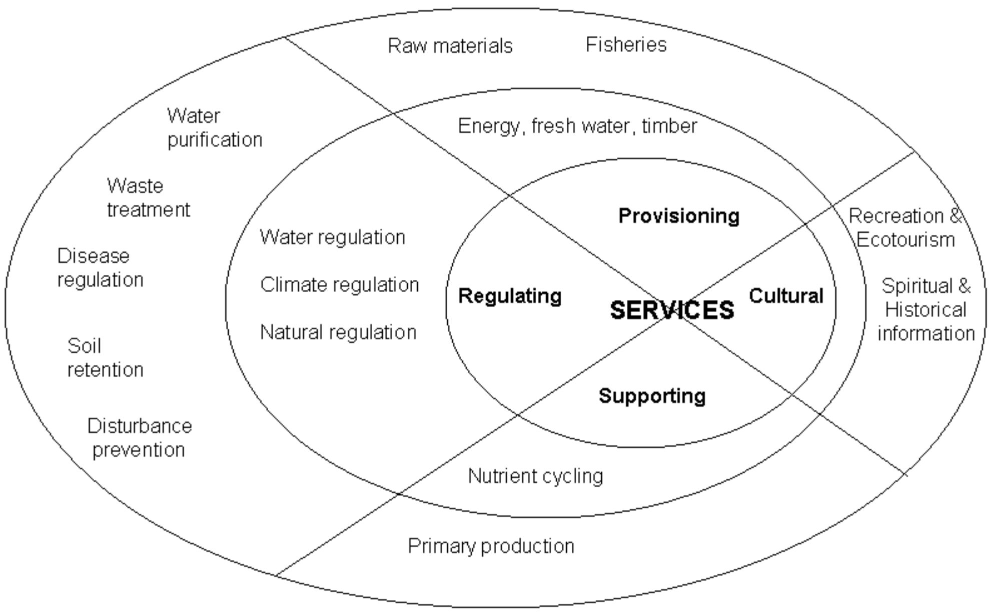

Figure 2. 2. Schematic representation of the ecosystem functions and services (UNEP, 2009), modified.

2.2. Ecosystem services in the context of coastal environmental protection

2.2.1. Ecosystem services and coastal biodiversity

The concept of ES encompasses not only delivery, provision, and production but also includes the protection and maintenance of a set of goods and services that people perceive to be important (Chee 2004). In the context of environmental protection, mangrove ES play a crucial role in the maintenance of biodiversity, waste assimilation, cleansing, recycling and renewal as well as in protecting coastal areas from disturbance events (Alongi 2008; Dahdouh-Guebas et al. 2005b; Daily 1997; Hussain and Badola 2010; Norberg 1999; Sathirathai S 2001). In addition, mangrove habitats have a diversity promoting function (Hogarth 2007; Li Lin, G.Z 2005; Moreno and Laine 2004). According to Article 2 of the Convention on Biodiversity (CBD, 2001), biodiversity is defined as "the variability among living organisms from sources including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, and between species and ecosystems" (CBD 2001).

Preservation of biodiversity is partially based on the belief that loss of biodiversity would result in the loss of EF and many ES they provide to society (Costanza and Folke 1997). Based on a marine sea grass ecosystem, Duarte, (2000) pointed out that an indirect relationship exists between species richness and EF. The study concluded "a link between EF and ES and species richness has remained elusive when tested for specific communities, except for a few clear demonstrations such as outlined for sea grass communities" (Duarte 2000). The arguments presented provide, however, strong reasons to expect this link to be a general rule in marine ecosystems. Moreover, they call for increasing conservation efforts to ensure the maintenance of marine biodiversity as a means of maintaining the functions of marine ecosystems and, thereby, the services they deliver to human welfare. A positive relationship between the number of species in an ecosystem and the level and stability of ecological processes was stated by Balvanera et al., (2006) and Díaz et al., (2006)

Naeem (1997); (Naeem et al. 1994; Naeem 1997) carried out experimental studies to manipulate species richness using a synthesized model ecosystem in both terrestrial and aquatic environments, comparing the species richness and mean value of biomass. Both approaches suggest that a large pool of species is required to sustain the assembly and functioning of ecosystems in landscapes subject to increasingly intensive use. It is not yet clear, whether this dependence on diversity arises from the need for recruitment of a few key species from within the regional species pool or due to the need for a rich assortment of complementary species within particular ecosystems.

2.2.2. Evaluation of ecosystem services regarding to coastal environment protection

In some areas, natural resource management involves conflicts between environmental rotection and economic development. In order to choose between alternative uses of land, it is important to know the direct and indirect economic value of natural ecosystems. It is assumed that the use of economic values as additional information would strengthen arguments to elucidate the intrinsic value of an ecosystem to key decision-makers and stakeholder.

Coastal management and policy decision making for instance require information that ranges between land-use impacts on natural resources and economic implications of changes to aquatic

ecosystems. Examples are the storm protection functions of a mangrove forest or the biological diversity within a seagrass community. Since environmental goods and services are often available free of charge, they do not have markets, and therefore cannot be rated as easily as marketed goods. However, environmental goods and services typically have a positive value and many people are willing to pay to insure these services (Pearce et al. 1989; Seppelt et al. 2011; Verdú et al. 2011).

Sathirathai (2004) illustrates the importance of valuing ES to policy choices in Thailand. These services are 'non-marketed', therefore their benefits are not considered in commercial development decisions. For example, the excessive mangrove deforestation is clearly related to the failure to measure the values of habitat and storm protection services of mangroves. Consequently, these benefits have been largely ignored in national land-use policy decisions.

Sathirathai (2004) call to improve protection of remaining mangrove forests as well as enlist the support of local coastal communities through legal recognition of their real property rights over mangroves. Unless the value of the ES provided by protected mangroves is estimated, it is difficult to convince policymakers in Thailand and other countries to consider alternative land-use policies. Mangrove loss results in a decrease of marine fish stock and increases the vulnerability of many coastal areas to natural disasters. The Thailand case study reveals that the challenge of ES valuation is also a challenge for policy makers. To manage coastal areas sustainably the decision-makers have to realize the importance of ES. Thus, economic valuation is becoming more widely used to demonstrate the multiple benefits provided by ecosystems.

2.2.3. Ecosystem services provided by mangrove in the context of climate change mitigation

Natural mangrove ecosystems play an essential role in gas regulation and climate regulation, hich both are EF directly related to climate change. Main services provided by the gas regulation function are the maintenance of clean, breathable air and prevention of diseases (De Groot et al. 2002; Ren et al. 2009). For example, mangrove ecosystems are valuable in terms of direct and indirect use values (Figure 2. 3). Direct use values are products and uses directly derived from the mangrove (e.g. firewood, food, construction materials, building land). Indirect use values support economic activities.

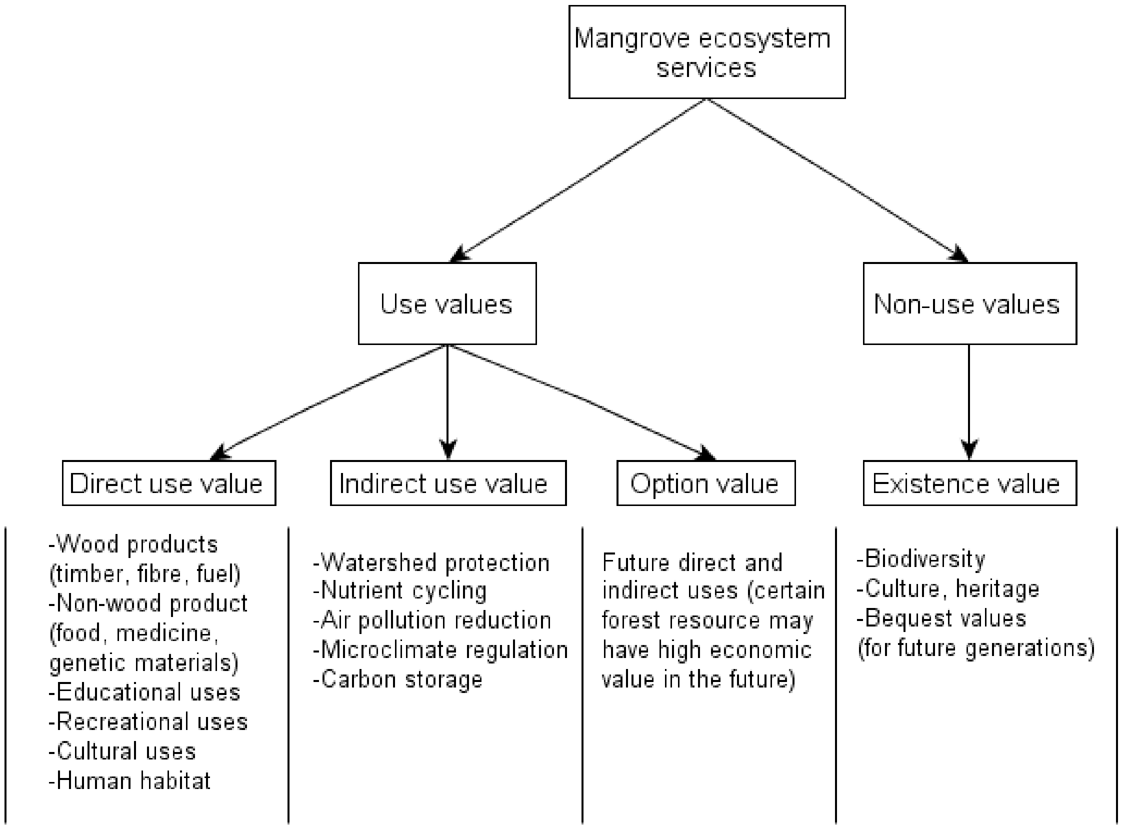

Figure 2. 3. Total economic value of mangrove ecosystem, (adapted from Barbier, 1991), modified.

Mangroves act as a natural barrier, stabilize fine sediment and thereby prevent coastal erosion. Moreover, they reduce effects of storms and flooding, maintain water quality and support a wide range of wildlife. Mangroves may have a indirect value through the protection of coastal property and economic activities such as fishery. A summary of functions of mangrove ecosystem goods and services is shown in Table 2. 6.

Table 2. 6. Ecosystem functions and services provided by mangrove ecosystems (Gilbert and Janssen, 1998).

Ecosystem functions	Goods and Services	User
Watershed protection	Provision of protection	Aquaculture farmers and industry adjacent to mangrove forests
Production of food and nutritious drink	Offshore fish and shellfish, on-site crabs	Artisanal fisheries
Production of other biotic resources	Medicinal resources (e.g. Skin disorders and sores…)(Horst, 1998)	Local communities
Production of raw material for construction and industry	Wood, leaves, tannins, nypa palm	Local communities
Production of fuel and energy	Wood, charcoal	Local communities
Production of juveniles for cultivation	Mangrove propagules	Government (afforestation and re-afforestation programs)
Regulation of environmental quality	Improving air quality	Aquaculture adjacent to mangrove forests
Prevention of soil erosion	Shoreline protection	Local communities,

		aquaculture adjacent to mangrove forests
Flood mitigation	Reduce floods and recharge aquifers, reducing storm risks	Local communities, aquaculture adjacent to mangrove forests
Maintenance of biodiversity	Crops pollination, pests control	Global population
Scientific and educational information	Knowledge	Scientific and educational community

Mangroves are known to remove CO2 from the atmosphere through photosynthesis. This has a small but nonetheless noticeable impact on the counterbalancing of green house gas emissions leading to global warming. Furthermore, mangroves are capable to accumulate and store large quantities of carbon in the soil. For example, a 20-year old plantation of Rhizophora mangroves stores 11.6 kg m^{-2} of carbon with a C burial rate of 580 g m^{-2} $year^{-1}$ (Fujimoto 2000). Duarte et al., (2005) recently estimated the average global rate of carbon accumulation in mangrove systems at 10.8 mol m^{-2} yr^{-1}.

Most mangroves fix carbon in excess of ecosystem requirements, with the excess carbon representing 40% of net primary production (Duarte and Cebrian 1996). Herbivores consume 9% of the carbon stored, 30% is exported, 10% is stored in sediments, and 40% is decomposed and recycled within the system (Duarte and Cebrian 1996). Measurements of mangrove photosynthesis Clough, (1998) imply that either more carbon is stored in the wood and eventually decomposed within the system, or more carbon is stored in sediments, and exported to the adjacent coastal zone, than estimated by Duarte and Cebrian, (1996). Hence, the plantation of mangroves provides a great benefit to control regional climate change by stabilizing atmospheric carbon. However, not only the carbon storage and potential decrease of GHG emissions show the mangrove ecosystems contribution to mitigate climate change. Mangroves protect the coastline and therefore are a direct protection against climate change induced sea level rise. A few studies in the past decades have tried to estimate the values of a coastal or mangrove ES. Pearce and Moran, (1994) discussed methods of economic valuation of different biological resources and their interpretations. They listed the values of tropical wetlands, marine systems, rangelands and forests worldwide. Costanza and Folke, (1997) assessed the value of the world's ES based on a synthesis of published studies and a few original calculations.

2.3. Review of studies in ecosystem service assessment in the mangrove wetlands

2.3.1. Valuation methods of mangrove ecosystem services

Economic valuation is an effort to allocate quantitative values to the goods and services provided by natural ecosystems. (Costanza and Folke 1997; Daily 1997). Economic valuation of mangrove ecosystem can be useful in indicating the opportunity cost of other land-use practices. The range of value may vary according to specificity approach used, but it can help in land-use decision making.
One of the difficulties at environmental valuation is that there is no market to capture or express the values of ecosystems, especially their indirect use values (Curtis 2004). Thus, all ES fall outside the sphere of markets and tend to be "invisible" in economic analyses (Alongi 2002; Chee 2004). Costanza et al.'s (1997) seminar paper on the value of the world's ES and natural capital, asserted that "because the ecosystem services are not fully "captured" in commercial markets or adequately quantified in terms of comparability with economic services and manufactured capital, they are often given too little weight in policy decisions".

The total economic value (TEV) of a natural resource is the sum of its direct, indirect, option, bequest, and existence values (Sorg 1987). In this paper, TEV is divided into two main components: use and non-use values (Figure 2. 4).

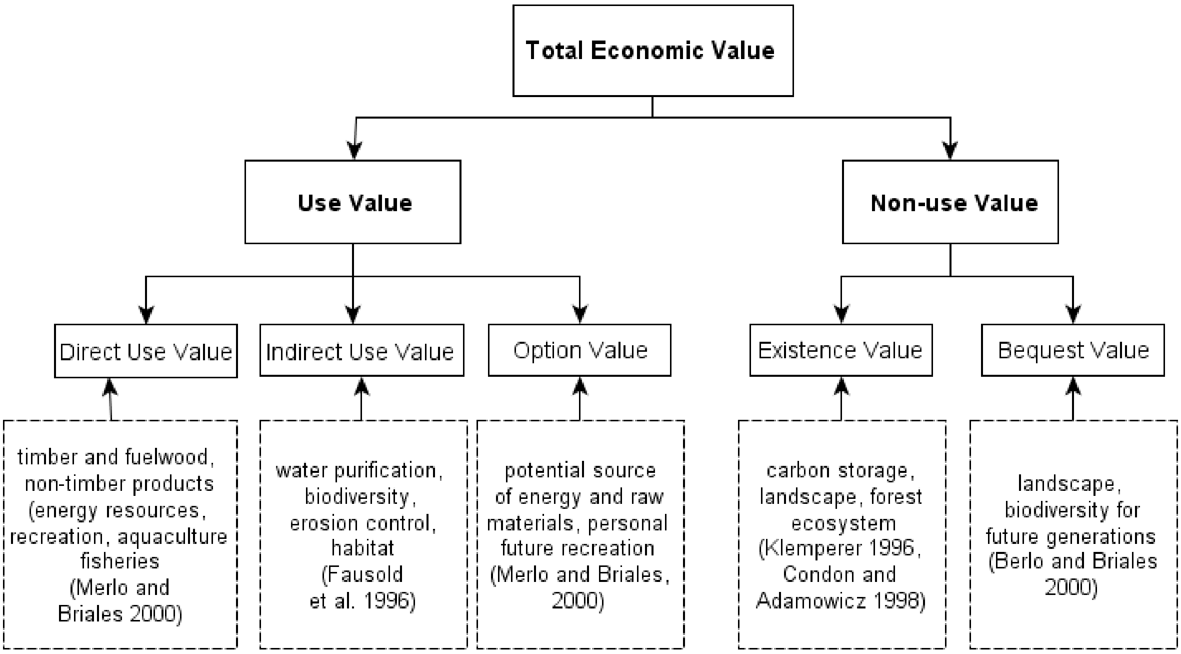

Figure 2. 4. Framework of total economic value (adapted from Sorg, 1987), modified.

TEV of mangrove habitat has been estimated by many studies, the global value was estimated as US\$181 billion (Alongi 2002), or US\$10,000 ha^{-1}, and between US\$475 and US\$1675 ha^{-1} (Rönnbäck 1999).

Another recent study by (Tong et al. 2007), investigated wetland restoration, using both structural indices and valuation of the wetland's ES, thereby linking science to human welfare. The study investigated both potential and current values of the main ES in Sanyang wetland, China. The authors concluded that in Sanyang wetland there are six main services (e.g. production output, water supply, disturbance regulation, environment purification, gas regulation, and biodiversity support), and revealed that the potential services value is about 8000 US\$ ha−1 yr−1. The potential environmental purification service was quite high, accounting for 43.0% of the total value. Due to its location, the potential value of the habitat service of the ecosystem was relatively low at 6.3% of the total value. However, the services that currently exist at Sanyang wetland, as based on the current state of the ecosystem, added up to only 850 US\$ ha−1 y−1. This current value is only 10.5% of the potential value. The current values of all of the services were much lower than what they potentially could be if restored, except for the current production output value. In particular, the environmental purification service was negative and owed 1000 US\$ ha−1 yr−1 due to the water pollution and lack of vascular wetland plants. Additionally, the gas regulation value was only 5.5% of the potential value. In terms of future work that was recommended about 90% of the wetland's ES need to be restored.

A widely accepted and often used framework for decisionmaking is the cost benefit analysis (CBA).This method is increasingly being used to evaluate the benefits of alternative uses of ecosystem in order to guide the selection of projects (Carpenter et al. 2009; Daily et al. 2009; Pearce 1998). Many authors applied CBA in terms of ecosystem services for coastal habitat assessment. Duvivier, (1997) gave an example of the practical application of CBA as a means of project appraisal and its use assessing coastal defense options for the sand dunes of Tramore, Ireland. An assessment of economic benefits and costs of different coastal defense options for a deteriorating sand dune system revealed dune rehabilitation to be the best solution from both, the environmental and economic point of view. Comparing discounted scheme costs (66,000 US$) to discounted scheme benefits (380,000 US$) produced a benefit to cost ratio of almost six (Duvivier 1997). TEEB (2008) also carried out CBA of ES decline caused by the loss of biodiversity. Howver, this method has some limitations due to the complexity of natural ecosystems and the distributional biases markets (Wegner and Pascual 2011).

The contingent valuation method (CVM) is used to estimate the economic values of ES including both use and non-use values. This method is the most widely used method for calculating the non-use values. The purpose of CVM is to obtain individuals' preferences (willing to pay for such a service) in monetary terms, for changes in the quantity or quality of nonmarket environmental resources (Birol et al. 2006). With regard to ecosystem services applications, CVM is useful for examining direct use values such as forest production, fishery, and indirect use values such as water filtration or climate cycling. Despite the strengths of CVM regarding its ability to estimate non-use values and evaluate irreversible changes, this method has been criticized for its lack of validity and reliability (Diamond and Hausman 1994; Kahneman and Knetsch 1992).

A large number of CVM studies focus on the use and non-use values of wetlands. The reasons for this are the substantial local and global indirect and non-use values inherent in this resource (see Crowards and Turner, 1996; Brouwer et al., 2003) for a review). Pate and Loomis, (1997) found that "willing to pay" for a wetlands (San Joaquin Valley and San Joaquin River) improvement program in California, USA, was about 183 US$ household^{-1}. This value decreases as the distance from the site increases. The average willingness to pay per household was estimated to be 13 US$ month^{-1}, or 156 US$ yr^{-1}. When multiplied by the number of households in California, the total benefits exceeded the 26 million US$ cost of replacing the water supply by a factor of 50. Finally, Brouwer et al., (2003) used 30 wetland CV studies to conduct a meta analysis of wetland valuation studies, where a meta analysis is the statistical analysis of the summary findings of empirical studies (Champ et al. 2002). They found that use values (such as flood control, water generation and water quality attributes) have a stronger influence on the willingness to pay than non-use elements such as the biodiversity function of wetlands.

2.3.2. Economic valuation of ecosystem services in literature

The trend in ES valuation has been rapidly increasing over time. The key words "valuing ecosystem services" in Science Direct search, yielded 1793 articles published in the past 20 years (April, 2011). Most of them are journal papers (1666), and the rest are reference works and books. The journal "Ecological Economics" has the highest publication record (483), followed by the Journal of Environmental Management (66), and Forest Policy and Economics (49). For example, in 2010, more than 200 papers were published on ES valuation (Figure 2. 5).

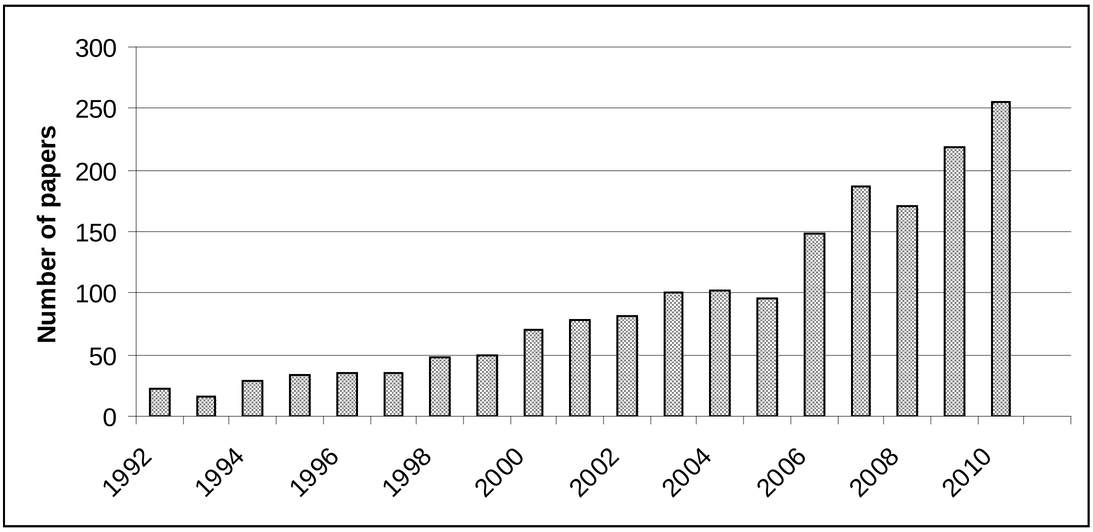

Figure 2. 5. Number of ecosystem services valuation publications in Science Direct over time (accessed April, 2011).

Using "ecosystem services" as key words, a search in the ISI Web of Knowledge shows the total number of papers published and the number of disciplinary categories in which they occur over time (Figure 2. 6).

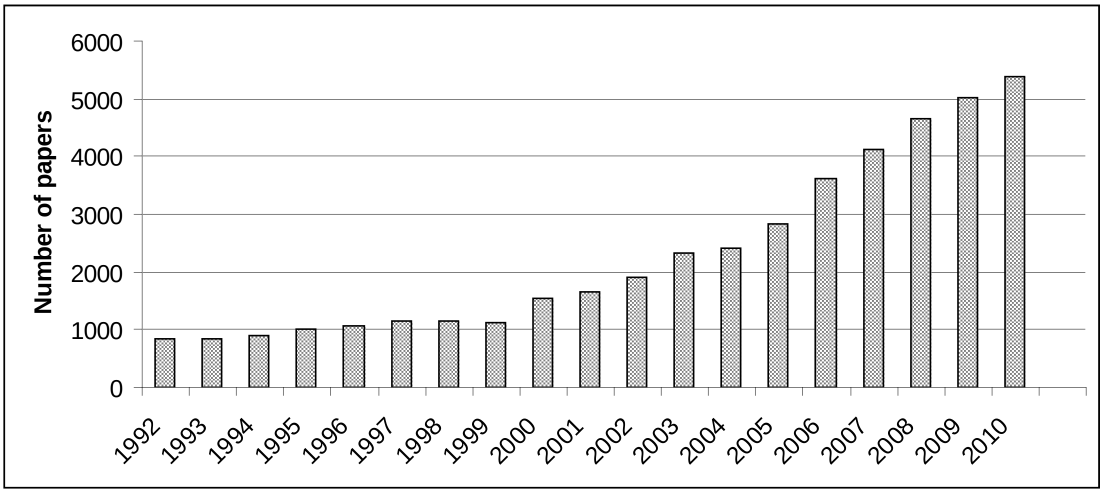

Figure 2. 6. Number of Ecosystem services publication over time (accessed April, 2011).

The valuation approaches and key assumptions for different mangrove studies are summarized in Table 2. 7.

Table 2. 7. Valuation techniques and key assumptions for different mangrove ecosystem assessments including theirs economic values.

Authors	**Valuation techniques**	**Key Assumptions**	**Direct use value**	**Indirect use value and non use value**
Christensen, (1982)	- **market price**: both commercial and subsistence forest, fisheries and agricultural products are valued at market prices (costs to maintain and raise the plants or animals are practically ignored).	- **discount rate & time horizon**: future developments are ignored. - **environmental linkage**: removal of mangroves results in total disappearance of mangrove-dependent fish species.	- **local uses** : fruits, cigarette wrappers and nipa thatch for roofing. *US$230/ha/year*. - **on-site fisheries** : commercial harvest by small, medium and large scale fishermen of fish, trash fish, prawns and shrimp, based on a weighted market price of US$.0.35/kg. *US$30/ha/year*. - **forestry:** charcoal production is 1 m3/ha/year (potential of 12 m3/ha/year). *US$30/ha/year*. - **aquaculture**: the current yield	- **off-site fisheries** : Mangrove related shrimp (80kg/ha), and fish species such as mullet, snapper, whiting. *US$100/ha/year*.

			from shrimp farming is 184 kg/ha/year at a price US$.1.1/kg *(US$206/ha/year).* The potential yield is 541 kg/ha/year of better species (US$3.9/kg) leading to a yield of *US$.2,106/ha/year*. **- agriculture:** annual rice yield of 1,700 kg but fails every fourth year. *US$165/ha/year*.	
Lal, (1990)	- **market price**: the value of commercial forest and fisheries products is based on market prices **- shadow price**: for subsistence fisheries products a shadow price is derived from the average price paid by commercial fishermen when they buy surplus fish from villagers.	- **discount rate**: 5 % which is the average real interest rate for 1983 to 1986. - **time horizon**: 50 years. - **environmental linkages**: linkage scenarios varying from 20% to 100% decline in fish harvest if mangroves are destroyed. In main the	**- on-site fisheries** : total production of commercial (147 kg) and subsistence (184 kg) harvest in mangrove-ecosystem is 331 kg/hectare/year based on a weighted average market price by species of US$2.61/kg; *US$60-US$240/ha/year with average of US$100/ha/year*. **- forestry**: net benefits are retrieved for commercial	**- off-site fisheries** : these values are Included in the category onsite fisheries. **- nutrient (waste) filtering service**: derived from conventional treatment plant (alternative cost approach). *US$5,820/ha/year*.

	- **surrogate or substitute price**: The value of the mangrove soils' filtering capacity is based on the costs of the treatment of comparable sewerage volume costs by a conventional treatment plant.	valuation it is assumed that 1 hectare of mangrove produces 331 kg of fish per annum. - **economic assumptions**: marginal values of labour and capital in fishing and forestry industries are zero. -**other assumptions**: 40 year forestry rotation cycle.	forestry from market prices and for subsistence consumption from next best alternative approach (buying from saw mill plus transport). *US$6/ha/year*. - **agriculture & aquaculture**: opportunity costs development into sugarcane production and aquaculture were estimated to be negative. *US$52/ha/year*.	
Bennet & Reynolds (1993)	- **market price**: commercial forestry and fisheries are valued at market prices.	- **discount rate & time horizon**: future developments mentioned, but ignored in the actual valuation exercise. - **environmental linkage**: removal of mangroves results in total disappearance of mangrove-	- **on-site fisheries** : commercial harvest of prawns and fish based on 95% of total catch in Sarawak. - **forestry:** commercial harvest of building poles, charcoal, semi-charcoal and cordwood of the whole West of Sarawak.	- **tourist industry:** the revenues in and around the Mangrove Forest Reserve is assumed to disappear. - **off-site fisheries:** deep-sea and coral reef fishing is incidental.

		dependent fish species which is 95% of the total catch.		
Ruitenbeek (1992)	- **market price**: local farming products are not corrected for transportation costs because these are not traded outside the region. - **shadow price**: livestock, fish and fuel wood are corrected for transportation costs at US$ 0.25 per kg. - **other prices**: biodiversity benefit of mangrove ecosystems is based on international transfers for rainforests (50% of US$.3000 per kilometre); erosion is valued through valuing the benefits of local agricultural production.	- **discount rate**: 7.5% reflects the opportunity cost of risk-free investment. - **time horizon**: costs and benefits are extended over a 90 year period to allow three full rotations in forestry evaluations, and to accommodate potential delays in environmental linkage effects. - **environmental linkages**: scenarios depend upon impact intensity and impact delay parameters. Various ecosystems (i.e. mangrove	- **local uses** : traditional household production from hunting, fishing, gathering, and manufacturing are based on "shadow" prices. This conversion into shadow prices is based on transportation cost of Rp500/kg. *US$33/ha/year*. - **on-site fisheries** : sustainable shrimp harvest based on real average export prices US$6.25/kg. Costs are based on investment and operation costs. Taxes, royalties and compensation payments are excluded. *US$94/ha/year*. - **forestry:** cutting for export of	- **erosion control**: based on agricultural output from local production. *US$3/ha/year*. - **off-site fisheries** : imputed (potential) value of Rp300/kg for by catch which is 90% by weight of total shrimp catch (assumption of future commercial use). Costs are based on investment and operation costs. *US$23/ha/year*. - **biodiversity**: ascribed as the "capturable biodiversity benefit".

		and fisheries) are linked. - **other assumptions**: 30 year forestry rotation cycle.	woodchips based on real average export prices US$40 per cubic metre. Sago production is valued at constant local market prices Rp300/kg. Costs are based on investment and operation costs. *US$67/ha/year*.	Maximum for ecosystems (rainforest) reaches US$3,000/km2. For Bintuni Bay US$1,500/km2. *US$15/ha/year*.
Gammage, (1994)	- **market price**: timber is valued at local market prices net of input costs and extraction costs; the same is applied for salt, shrimp and fish. Fuel wood is valued at market prices for the traded wood, and at gathering costs of the non-traded wood. Opportunity costs of allocating labour time for fuel wood collection are zero. - **other prices:** for comparison, “the least alternative cost” of substitutes were reported but not	- **discount rate**: various rates were applied. 19.08% which is the foregone return on other investment projects, 8% which the costs of external borrowing, and 4.64% reflecting the social rate of time preference. - **time horizon**: 56 years going till 2050. - **environmental linkages**: a linear relationship between mangrove area and	- **local uses** : The seeds of mangrove trees are used as fodder for the local cattle, yet this was not included. Also honey and fruits were used but not valued. - **on-site fisheries** : the annual sustainable shrimp harvest based on local market prices are approximately 5.5 kg/ha priced at US$14/kg. Related costs were not mentioned. - **forestry**: local firewood	- **off-site fisheries**: a pseudo production function including mangrove coverage and effort was used to estimate artisanal and commercial fishery. Subsistence fishing is negligible.

	applied to the actual C/B analysis.	artisanal fish production was estimated implying a decrease of 14 kg in annual fisheries yield for each hectare of mangrove cut. - **economic assumptions**: fishery benefits are gross of costs.	consumption is valued through shadow wage and input cost methodology at approximately US$100 per m2. Local timber consumption is valued at local market prices. Total annual sustainable wood consumption is determined at approximately 6 m2 per hectare.	
Gilbert AJ and Janssen (1998)	- **market price**: commercial forestry and fisheries are valued at market prices.		- **forestry:** 251 US$/ha/year - **fisheries**: 60 US$/ha/year	NA
Sathirathai, (1998)	Cost and benefit analysis	- **economic assumptions**: fishery benefits are gross of costs.	- **forestry:** 140-1059 US$/ha/year - **fisheries**: 8-63 US$/ha/year	- **erosion control:** 2990 US$/ha/year - **carbon sequestration:** 86 US$/ha/year

Naylor and Drew, (1998)	- **market price**: commercial forestry and fisheries are valued at market prices method	NA	- **forestry:** 178 US$/ha/year - **fisheries**: 461 US$/ha/year	NA
Sathirathai and Barbier (2001)	**-market price:**	NA	-88 US$/ha/year	NA
Ruchi Badola and S.A. Hussain (2005)	**-damage-cost avoided**	Household based	153.74 US$/household	
Hussain and Badola, (2010)	**-market price**	Household based	107US$/household/year	NA

Mangroves are estimated to extend over 15 million hectares world-wide (Lacerda and Diop 1993); there are about 6.9 million ha in the Indo-Pacific region, 3.5 million ha in Africa and some 4.1 million ha in the Americas including the Caribbean (Figure 2. 7). For ecosystem and environmental protection, mangroves serve as link between the marine and terrestrial ecosystem. They play an important role in stabilizing shorelines in coastal areas and estuaries, protecting them against sea level rise, hurricanes, and coastal erosion (Aksornkoae and Tokrisna 2004). However, mangroves are depicted the most rapid loss rates of ecosystems world-wide (Valiela et al. 2001), and in 2001 approximately 50% of all coastal wetlands have been lost (Upadhyay et al. 2002) and Rosen (2000) stated that about 50% of global mangrove cover has been destroyed in 2000. It is very important to evaluate the value of wetland ecosystems like mangroves, which are affected by sea level rise induced by climate change and environmental change due to the negative consequences of rapid industrialization and urbanization as well as marina development, aquaculture (Rönnbäck 1999).

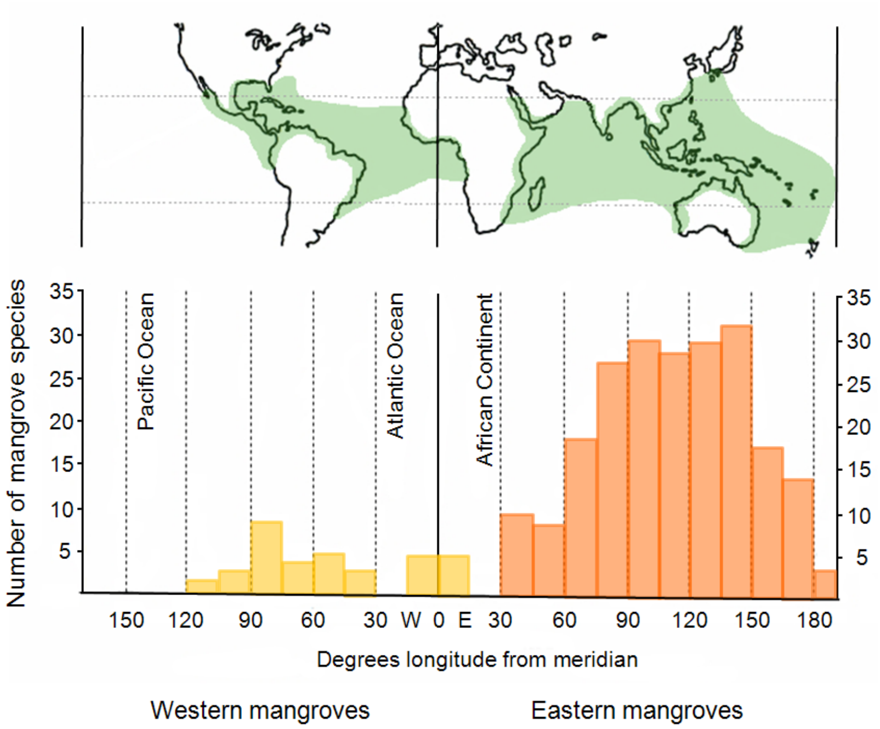

Figure 2. 7. Generalized global distribution of mangroves and diversity of mangrove species per 15◦ of longitude.

Mangrove forests provide timber materials to well-established markets, but the associated habitat values of forests are also given by un-marketed recreational activities (Lal 1990; Naylor and Drew 1998; Sathirathai 1998). The chain of effects from ES to human welfare can range from extremely simple to exceeding complex. Mangrove forests provide timber, but also hold soils and moisture, and create microclimates, all of which contribute to human welfare in complex, and generally non-marketed ways (Alongi 2002; Costanza et al. 1997b; Hogarth 2007).

Economists have argued that a mangrove ecosystem as a whole and many of mangrove associated goods and services do not have market values. One reason why mangrove values are not fully considered in the appraisal process is that many of these values are not "sold" at the conventional market, so they do not have a market price (e.g. storm protection function of mangroves) (Bann 1997; Lal 1990). The values of goods and services supported by mangrove ecosystems have been studied since the 1990s, including direct and indirect values. The measurements of these goods and services were based on the production method (Barbier 1994; Gilbert and Janssen 1998; Jack Ruitenbeek 1994; Lal 1990; Rönnbäck 1999; Ruitenbeek 1992; Sathirathai 1998), contingent method (Naylor and Drew 1998), or replacement techniques (Lal 1990; Sathirathai 1998). However, the valuation of some intangible services such as ecological process value or cultural function values has not been widely conducted. The production method is commonly used to determine the economic value of extractive uses, such as for forestry and fisheries (Gilbert and Janssen 1998; Lal 1990; Rönnbäck 1999). For indirect uses such as storm buffer or water filtering services, the replacement cost method is commonly used (Lal 1990; Sathirathai 1998). Naylor and Drew (1998) also applied the contingent valuation method to determine the value locals placed on the protection and use of mangrove ecosystems as a whole in Kosrae, Micronesia.

There are many further approaches, which have been used to determine the economic impact of changes in wetland areas, the goods and services produced by underlying ecological processes and the environmental functions. For example, Barbier and Strand, (1997), Lal, (1990) and Nickerson, (1999) assumed a proportionate linear relationship between the area of mangroves and the mangrove dependent species harvested. Others, such as Sathirathai (1998) used a static optimization Cobb-Douglas model and an assumption of direct non-linear proportionate relationship between the quantity of shellfish and fish harvested and the level of fishing effort, keeping the area of mangroves constant. Barbier and Strand, (1997) adopted a dynamic approach production function analysis to value the mangrove dependent shrimp fishery of Campeche, Mexico. The summary of these studies including economic values and approaches applied are listed in Table 4.

Some papers applied general methodologies such as TEV, or the cost and benefit analysis for evaluating mangrove-fishery linkages which can be used for a variety of mangrove and coastal wetland systems found around the world. These approaches have been used to assess the economic value of coastal wetland habitats to support marine fisheries and other ecological functions, such as determining the value of marshlands. Examples are the Gulf Coast fisheries in the southern United States (Bell 1997; Ellis and Fisher 1987; Farber Costanza, R 1987; Freeman 1991; Lynne et al. 1981), mangroves areas in relation to coastal and marine fisheries in Thailand (Sathirathai 1998) and Mexico (Barbier and Strand 1997). These approaches are consistent with other related studies attempting to analyze habitat-fishery problems more generally; examples are analysis of the competition between mangroves and shrimp aquaculture in Ecuador (Parks and Boniface, 1994), the determination of the value of a multiple-use mangrove system under different management options in Bintuni Bay, Irian Jaya, Indonesia (Ruitenbeek, 1992) or the examination of general coastal system trade-offs, such as the effects of development and pollution on habitat-fishery linkages (Kahn and Kemp 1985; Knowler et al. 1997; Swallow 1994; Swallow 1990). It has been estimated that the economic value of mangrove ES are nearly 10,000 US$ ha−1. Sathirathai and Barbier (2001), however, showed that the economic value for mangroves of a local community in Thailand is much higher, ranging between 27,264 US$ and 35,921 US$ ha−1. This differences are due to differences between geographical and temporal specificity; the same type of ecosystem could have varying values in different geographical areas caused by differences in economic activities, and cultures of local people. Corps (2007) focused on the valuation of mangrove and shrimp farming cultivation. The study's main hypothesis was that "the direct use value and indirect use values are not considered when converting mangroves to shrimp farms". With the traditional way of valuation, it is revealed that the total revenue from mangrove use was approximately 160 US$ ha−1. In contrast, shrimp farmers have a net income of approximately 2000 US$ ha−1, exceeding the revenues receivable from owning the land as a mangrove swamp (Corps, 2007). However, looking at what mangrove swamps provide additionally such as coastal protection or reduced pollution the total value of mangroves is much higher. The study concluded that "the mangrove swamp is financially superior to the taxpayer since its coastal protection value is substantial" and combined with revenues from the mangroves it results a total value of about 4000 US$ ha−1 (Corps 2007). Where ES have been diminished as a result of ecosystem degradation, there may also be the potential to restore flows of ES by rehabilitating coastal ecosystems. This has most widely been attempted with mangrove replanting in Asia, although only a fraction of deforested mangroves have been replaced (Rönnbäck et al. 2007). (Rönnbäck et al., (2003) argue that rehabilitation of coastal ecosystems is inevitably more expensive than preservation of existing habitats. Rönnbäck et al., (2007) found that coastal dwellers in Kenya derived significantly more ES from natural mangroves than from replanted mangroves. This suggests that efforts to maintain existing ecosystem services present a more efficient way to benefit the well-being of the poor than rehabilitating ecosystems after degradation. In cases, however, where extensive a part of natural habitat has been lost, research on affordable restoration techniques is needed that rehabilitate the flow of ES.

2.4. Discussion

Numerous studies on ESA were published during the last two decades. ESA is a relatively new and emerging science. As methodologies continue to develop and evolve it is important that those undertaking such valuations should share their results and experiences.

The literature review points to a growing recognition of the numerous products and services provided by natural ecosystems in general and by mangrove ecosystems in particular. Yet most studies still limit valuation to use values because the availability of market prices indicates their easy valuation.

It is difficult to state the monetary value of all goods and services provided by a natural ecosystem. However, some researches make an effort to put value on non-market goods and services in the developed and developing countries (Costanza and Folke, 1997; Daily, 1997; Shrestha et al., 2002; de Groot et al., 2002, MA 2003). In order to provide robust valuation methods, we first need to know how to categorize ecosystem services for valuation. The ecosystems should be divided into a few comprehensible categories. For example, MA (2005) classified “supporting services” as an underpinning to other service categories. Final services and intermediate services should also clearly be delineated, e.g. hydroelectric power requires water provision and regulation from the ecosystems, but also damns and transmission infrastructure.

Many ecosystem services are not complementary; the provision of one is precluded by others. Adding up estimates from separate studies on the value of various individual ES might result in some double counting of benefits (Serafy 1998) or confusion between EF and ES, which might also create double counting, such as valuing the same wetland for effluent treatment and storage (Turner et al. 2003a). Fox example, economic values of mangroves depend not only on the interaction between social, economic and institutional forces and their variations between countries, but also on the local use of products, whether the fishery is open-access or managed (Lal 2003) (Table 2. 8)

Table 2. 8. Categories of ecosystem services and economic methods for valuation (Farber et al. 2006)

Ecosystem service	**Amenability to economic valuation**	**Most appropriate method for valuation**	**Transferability across sites**
Gas regulation	Medium	CV, AC, RC	High
Climate regulation	Low	CV	High
Disturbance regulation	High	AC	Medium
Biological regulation	Medium	AC, P	High
Water regulation	High	M, AC, RC, H, P, CV	Medium
Soil retention	Medium	AC, RC, H	Medium
Waste regulation	High	RC, AC, CV	Medium to high
Nutrient regulation	Medium	AC, CV	Medium
Water supply	High	AC, RC, M, TC	Medium
Food	High	M, P	High
Raw materials	High	M, P	High
Genetic resources	Low	M, AC	Low
Medicinal resources	High	AC, RC, P	High
Ornamental resources	High	AC, RC, H	Medium
Recreation	High	TC, CV, ranking	Low
Aesthetics	High	H, CV, TC, ranking	Low
Science and education	Low	Ranking	High
Spiritual and historic	Low	CV ranking	Low

AC: avoided cost; CV: contingent valuation; H: hedonic pricing; M: market pricing; P: production approach; RC: replacement cost; TC: travel cost.

The table above illustrates some valuation tools that are appropriate ESA. For example, Travel Cost (TC) is primarily used for calculating recreation values while Hedonic Pricing (HP) is associated with the aesthetic qualities of natural ecosystems. Contingent Valuation (CV) and Conjoint Analysis (CA) are methods to measure non-use values, such as the existence value of wildlife. Finally, nonmonetary methods do not require valuation results expressed in a single monetary unit (EPA, US, 2009). For instance, group valuation (GV), a type of civic valuation, is a more recent addition to the valuation literature and addresses the need to measure social values directly in a group context (Howarth and Wilson 2006; Wilson and Howarth 2002)

2.4.1. Need for site-specific economic valuation of an ecosystem

The ability to transfer values from an ecosystem to others is service-specific. Values of local scale services such as flood control and storm protection may have limited transferability (Liu et al. 1994). Moreover, due to differences in economic activities, cultures, and lifestyles of the local people, the same type of ecosystem might have different values in different locations and time (Burkhard et al. 2011b). Extrapolation of ES values from one place to another is containing error (Costanza and Folke 1997; Lautenbach et al. 2011), and those errors depend on the ES type and its spatial heterogeneity. Values also depend on current market prices and preferences, both of which can change over time. Future generations may value a particular service differently than the current one. The geographical and temporal specificity of any service valuation limits extrapolation of current, local values beyond local or bioregional scales and for all times (Daily 1997; Turner et al. 2003a).

2.4.2. Need for standardized definition of ecosystem services and its valuations method for a specific landscape

As we mentioned in the definition of ES and EF, they interact with each other. Classifications of ES are useful, but in reality these services are inter-dependent. Sometimes a single ES is a product of more processes (De Groot 2002). Because of multiple goals, valuation must be performed from multiple perspectives using multiple methods. Recognizing the existence of multiple values and encouraging open and pluralistic discussion of values will lead to new solutions for conservation practice (Norton 1998). Therefore, we need a multiple classification systems for different purposes, and this is an opportunity to enrich our thinking about ecosystem services rather than a problem to be defined away (Costanza 2008; Müller et al. 2008).

In literature, the economic values of ES valuation are bias for a number of reasons, including social fairness and ecological sustainability. In other words, asking people in the developed countries (under ecologically sustainable and socially fair conditions with knowledge of their connection to ES), then the total economic values of an ecosystem (both direct use values and indirect use values) would probably yield very different results than in the developing countries.

2.4.3. Need for strengthen the link between economic evaluation of ecosystem and policy makers

Even if these services are useful, some argue that they do not provide enough information to decision-makers. Aggregating individual willing to pay values is not enough when decisions involve large scale consequences to society and future generations. There is also a question if policy and decision-makers will actually use these values from economic evaluation. However, Power (2001); Stavins, (2003) pointed out that even politicians and other decisionmakers are usually not based on quantified values, but on cost and benefits analyses. A tool for accessing economic values of a certain ecosystem (like coastal areas in developing countries) is required to enhance a more balanced decision-making regarding the sustainable use and conservation of natural ecosystems as well as their many goods and services. Therefore, it is important for decision-makers to consider values of an ecosystem in comparison with others ecosystem management regimes. Furthermore, quantifying ES might encourage politicians and financers to recognize the importance and values of services as well as their conservation. Society is governed by money and numbers, and if we do not put a value on ecosystem services, they might be ignored in favor of the quantifiable. In addition, ES valuation can be an important tool for ecosystem policy and management, although valuation becomes more difficult and uncertain because ES become more complex.

Land-use changes may significantly affect the ecosystem processes and services that they provide, evaluating the impacts of land-use changes is not easy (Kreuter et al. 2001; Müller et al. 2008; Müller et al. 2006; Petrosillo et al. 2010; Petrosillo et al. 2009; Zhao et al. 2004). Monitoring changes at the regional scale is difficult because of the large amount of data and the effort for interpretation. Furthermore, lack of information on land-use change (such as conversion of mangrove area to shrimp farming) will significantly affect the value of ES.

Additionally, comprehensive decision-making based on comparisons of the impact of land-use changes on ecosystems requires more explicit measures than simple indices for the value of affected ES. The actual services provided by ecosystems and the values of these services depend on site specific conditions and the valuation of the local community; therefore, it is preferable to determine the nature and value of ES at a small spatial scale.

The use of Earth observation data and Geographic Information Systems (GIS) enable the calculation of the values of ES at larger scales to classify land into representative ecosystems for which benchmark service values have been determined (Dekker et al. 2009; Gstaiger et al. 2012; Kuenzer et al. 2011; Kuenzer et al. 2008). High resolution spatial data area needed for conducting context-based ES valuation and mapping of different ecosystem goods and services under different social and ecological characteristics. Using such an approach, it is important to realize that accurate coefficients are often less critical for land-use change analyses than time specific analyses of ES values because coefficients tend to affect estimates of directional change less than estimates of the magnitude of ecosystem values at a specific point in time.

2.5. Conclusion

This review paper provides a comprehensive overview of ecosystem services evaluation studies undertaken during the last decades, focusing on studies on mangrove forests in different regions and emphasizing different valuation methods.

Major damage to existing coastal ecosystems has occurred and is further expected as a result of climate change. Coastal ecosystems are already under pressure from overexploitation, pollution, deforestation and the loss of mangroves is linked to infrastructure development, conversion into agricultural or aqua-cultural land (Feresi et al. 2000). A growing variety and intensity of human activities such as coastal development, transportation, and land use change have been threatening the sustained delivery of these coastal ES.

The degradation of coastal and marine resources poses critical challenges for the maintenance of ES. The degradation of reefs and mangroves is already supposed to have a major impact on the livelihoods of thousands of coastal communities in the tropics through loss of earnings and food security. Both overexploitation and habitat deterioration (particularly of nursery areas which cause disruptions to marine productivity) are leading to reduced catches in most tropical regions. For the Caribbean, it is predicted that, in the absence of reef degradation, fisheries production in 2015 could be 100,000 tones with a revenue of 310 million US$ (Burke and Maidens 2004).

The services provided by wetlands include habitat for species, protection against floods, water purification, amenities and recreational activities. These services typically have no market price, therefore a measure of their values can only be obtained through non-market valuation techniques. Many wetland valuation studies with a remarkable range of the estimates have been conducted. A review by Heimlich et al., (1998) lists 33 studies over the last 26 years with per acre values ranging from 0.06 US$ to 22,050 US$. Even within the same study looking at a single ecosystem function, Batie, (1978) calculated values per acre that differ by two orders of magnitude from one site to another.

Scientific evidence regarding the contribution of ES for the coastal poor is related mainly to provisioning services, particularly fisheries and other resources. It is predicted that, for example, over a 20-year period, blast fishing, overfishing and sedimentation in Indonesia and the Philippines could lead to a net economic loss of 2.6 billion US$ and 2.5 billion US$ respectively for these two countries (Burke and Maidens 2004). Coastal zones and their associated ecosystems specifically prodive a wide range of services which across these groups: coastal protection, the maintenance of global biogeochemical cycles are source of income and employment, destination for tourism, environments for recreation, source of building material, provision of human living space, as well as are the contribution to cultural and spiritual value. The MA, (2005) and other publications (Adger et al. 2005; Donner and Potere 2007; Jackson et al. 2001) have demonstrated how these systems and the services they support are under increasing pressure from a range of drivers. They are being seriously degraded and if trends persist, they will be unable to support future human well-being. Pressures due to climate change, population increase in coastal areas, pollution, aquaculture development, greater human mobility and the spread of invasive species are likely to further exacerbate these trends (Brown et al. 2007).

Ecosystems provide numerous services that contribute to human well-being and quality of life. Through many services overlap and are interdependent, their classification is a useful attempt (De Groot 2002; MA 2005a). These services can be applied to local ecosystems, such as coastal ecosystems. Humans value each service in different ways, including direct and indirect use as well as non-use values. The services and values in turn can be quantified using economic methods, such as direct market pricing, travel cost evaluations, or contingent valuation approaches. Each approach has advantages and disadvantages, and should be carefully chosen based on the specific goals and subject to the study.

Chapter III Remote sensing in mapping mangrove ecosystems – An object-based approach

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Remote Sensing, Volume 5 (1), Page 183-201.

Submitted 20 November 2012, Accepted 28 December 2012, Published 7 January 2013

Abstract

Over the past few decades, clearing for shrimp farming has caused severe losses of mangroves in the Mekong Delta (MD) of Vietnam. Although the increasing importance of shrimp aquaculture in Vietnam has brought significant financial benefits to the local communities, the rapid and largely uncontrolled increase in aquacultural area has contributed to a considerable loss of mangrove forests and to environmental degradation. Although different approaches have been used for mangrove classification, no approach to date has addressed the challenges of the special conditions that can be found in the aquaculture-mangrove system in the Ca Mau Province of the MD. This paper presents an object-based classification approach for estimating the percentage of mangroves in mixed mangrove-aquaculture farming systems to assist the government to monitor the extent of the shrimp farming area. The method comprises multi-resolution segmentation and classification of SPOT5 data using a decision tree approach as well as local knowledge from the region of interest. The results show accuracies higher than 75% for certain classes at the object level. Furthermore, we successfully detect areas with mixed aquaculture-mangrove land cover with high accuracies. Based on these results, mangrove development, especially within shrimp farming-mangrove systems, can be monitored. However, the mangrove forest cover fraction per object is affected by image segmentation and thus does not always correspond to the real farm boundaries. It remains a serious challenge, then, to accurately map mangrove forest cover within mixed systems.

3.1. Introduction

The mangrove forests of Vietnam are among the most productive and biologically complex ecosystems in the world. Mangrove ecosystems are highly productive and provide many ecosystem services for human wellbeing (Alongi 2002; Giri and Muhlhausen 2008; Kathiresan and Bingham 2001; Rönnbäck et al. 2007; Vo et al. 2012). The importance of mangrove forests as a coastal resource is well acknowledged (Alongi 2002; Kuenzer et al. 2011; Thampanya et al. 2006). Not only do mangrove forests provide commercial fishery resources by acting as nurseries, breeding places and habitat for offshore fisheries (Rönnbäck et al. 2007), they also play an important role in stabilizing coastlines, where they serve as natural barriers, dissipating the destructive energy of waves and reducing the impact of hurricanes, cyclones, tsunamis and storm urges (Badola and Hussain 2005). Many studies have acknowledged that regions with intact mangroves have been exposed to significantly lower levels of devastation from cyclones than those with degraded or converted mangroves (Badola and Hussain 2005; Barbier 2006; Dahdouh-Guebas et al. 2005b; Gstaiger et al. 2012; Kuenzer et al. 2011). Mangroves are known as a resource for exporting organic matter to the marine environment, producing nutrients for fauna in both the mangroves themselves and adjacent marine and estuarine ecosystems (Bann 1997). Additionally, mangrove forests are often a rich source of timber, fuel wood, honey, medicinal plants and other raw materials for local consumption (Walters et al. 2008). Finally, mangrove forests attract eco-tourists, fishers, hunters, hikers and birdwatchers, providing valuable or potential sources of national income; moreover, they provide high economic value for residents, who depend on their natural resources (Alongi 2002; Penha-Lopes et al. 2010; Primavera 2000).

There are different approaches to quantifying the economic value of goods and services provided by mangrove ecosystems. These approaches include total economic value (TEV) derivation, cost and benefit analysis (CBA), and the contingent valuation method (CVM) (Vo et al. 2012). However, mangrove ecosystems also provide economic value that decision-makers often do not recognize (Alongi 2002; Costanza et al. 1997a; Rönnbäck 1999; Tue et al. 2012). The importance of mangroves is reflected in the high variability of their economic value, which ranges between US $ 475 and US $ 11,675 $ha^{-1} \cdot year^{-1}$ globally, depending on the selection of the valuation approach or market conditions (Rönnbäck 1999). Therefore, rehabilitation and restoration projects are conducted worldwide to prevent further degradation and loss of mangrove areas.

Mangrove forests are declining worldwide (Alongi 2002; Giri and Muhlhausen 2008; Valiela et al. 2001). In various countries, mangrove areas have been rapidly converted to other types of land cultivation. According to (Alongi 2008), “approximately one third of the mangrove forests over the world have been lost in the past 50 years”. The main threats to mangroves are the overexploitation of natural resources, deforestation, mining, pollution and industrial or urban development spreading into coastal forest areas (Alongi 2002; Barbier and Cox 2002; Barbier 2006; Huth et al. 2012; Kuenzer et al. 2011; Kuenzer and Renaud 2012), and conversion to aquaculture and salt-ponds. Seto and Fragkias (Seto and Fragkias 2007), for instance, analyzed mangrove changes in the Red River Delta (Vietnam) utilizing Landsat images from 1975 to 2002. They calculated the conversion rate between mangrove area and aquaculture development and found a strong correlation between the decrease of mangrove areas and the increase of aquaculture area (Seto and Fragkias 2007).

Kuenzer et al., (2011a) recently published a detailed review on remote sensing methods for mangrove mapping, with approaches ranging from employing aerial photography to multispectral satellite imagery and hyperspectral and radar data. Their paper summarized the most commonly applied methodologies applied over the last 20 years and gave an overview of the sensors and approaches that might be best suited for a particular focus. For a detailed overview of the numerous techniques and approaches applicable to the mapping of mangrove ecosystems, readers can refer to their paper. Pixel-based classification approaches are most frequently applied for mapping mangrove forests (Binh et al. 2003; Green et al. 1998; Kamal and Phinn 2011; Lee and Yeh 2008; Rasolofoharinoro and Blasco 1998; Thu and Populus 2007; Tong et al. 2004). Tong *et al.* (Tong et al. 2004), for example, applied Maximum Likelihood classification to map the mangrove distribution in Ca Mau Province based on SPOT 4 images. Pixel-based approaches are the subject of a study by Béland *et al.* (Béland et al. 2006), who investigated land cover changes related to aquaculture in the Red River Delta (Vietnam). The authors used multi-temporal Landsat data (1986, 1992 and 2001) to detect changes from mangrove forest to aquaculture using Tasseled Cap-derived information. In addition to these pixel-based approaches, several applications use spatial neighborhood information in object-based classification. Recently, object-based approaches have been applied successfully in many ecology-related remote sensing studies, such as landslide inventories (Hölbling et al. 2012), mapping burned areas using different sensors (Polychronaki and Gitas 2012; Polychronaki and Gitas 2010), monitoring land conversion (Dupuy et al. 2012), or assessing forest structural complexity (Lamonaca et al. 2008). In mangrove studies, for example, Conchedda *et al.*

(Conchedda et al. 2008) used an object-based approach to map mangrove cover change in Casamance (Senegal) based on SPOT XS data. The authors performed a change-detection analysis based on object-based mapping results. For their mapping, they applied a multi-resolution segmentation and class-specific rules incorporating spectral properties and spectral/spatial relationships between image objects. Also, Wang *et al.* (Wang et al. 2004) demonstrated in their study on mangrove mapping for the coast of Panama that an improvement of classification accuracy resulted from object-based classification in comparison to pixel-based classification. Heumann (Heumann 2011b) applied object-based image analysis and support vector machines for differentiating fringe-mangrove and true mangrove species. The result showed an overall accuracy greater than 94% (kappa = 0.863). Myint *et al.* (Myint et al. 2008) used spatial data as an input into the image object segmentation process and reported an accuracy greater than 90%. The superiority of object-based approaches over traditional pixel-based classification exercises for high-resolution satellite data has been demonstrated in numerous studies (Hay et al. 2005; Heumann 2011b; Huth et al. 2012; Kamal and Phinn 2011; Lamonaca et al. 2008; Wang et al. 2004)

As outlined above, most applications related to mangrove mapping usually focus on the discrete differentiation between mangrove and non-mangrove areas or on the qualitative assessment of species, growth status, or condition to derive classes such as “dense” or “sparse” mangrove forests. The mangrove ecosystem of Ca Mau in the Mekong Delta (MD), however, is characterized by a very special integrated farming system consisting of mixed aquaculture farming and mangrove cultivation, with governmental guidelines on the exact share of mangrove forest that a farmer should maintain on his land. Against this background, the current study presents an object-based classification approach that allows the quantitative estimation of mangrove fractions within the aquatic shrimp farming system of Ca Mau Province in the MD.

3.2. Study Area and Data

3.2.1. Study Area

Located between 8°33'–10°55'N and 104°30'–106°50'E; the MD is one of the largest river deltas in the world; it consists of 13 Vietnamese Provinces inhabited by approximately 18 million people (Kuenzer et al. 2012). The MD comprises an area of approximately 39,000 km^2; of which 24,000 km^2 is now used for agriculture and aquaculture; 4,000 km^2 for forestry; and the remaining area for settlement and construction (Clough et al. 2000; Leinenkugel et al. 2011). In the coastal Provinces, the main forms of cultivation are irrigated rice and aquaculture. Primary products from the MD contribute more than 30% of the Gross Domestic Product of Vietnam. The MD produces 50% of the nation's rice; contributing to Vietnam's place as the second-largest rice exporter in the world (Evers and Benedikter 2009; Gebhardt et al. 2012).

Mangrove forests cover the intertidal area created by coastal accretion as a result of the interaction between river and sea. Our main study area, Ca Mau Province, is located in the southwest of the MD, is one of the largest delta Provinces and hosts some of Vietnam's largest mangrove areas (Figure 3. 1). The Province has an area of 5,331 km^2 and a population of 1.2 million inhabitants (Goverment of Vietnam 2011). The mangrove forest area has declined significantly in Ca Mau, primarily due to the expansion of shrimp farming and ongoing population pressure. Because of its high economic return, shrimp farming has been promoted to boost the national economy, to provide a potential source of income for local communities and to alleviate poverty (Corps 2007; Lebel et al. 2002).

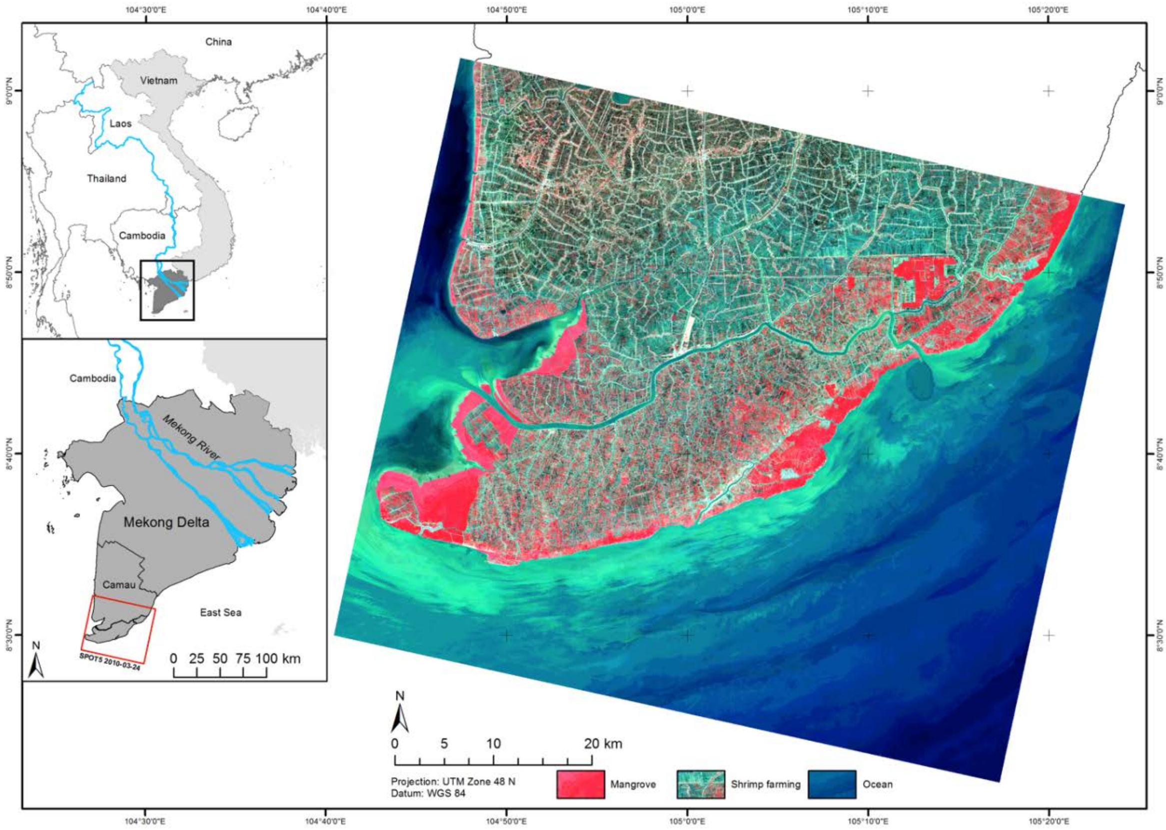

Figure 3. 1. Overview of the Ca Mau Province of the MD (SPOT5 data acquired on 24 March 2010, RGB = NIR-red-green).

3.2.2. Mangrove Forest Management in Ca Mau

During the Vietnam war, approximately 100,000 ha of mangrove forests were destroyed due to the spraying of aerial defoliants (Binh et al. 2003). In the early 1970s, the mangrove forest area in Ca Mau Province covered approximately 200,000 ha. In the 1980s and early 1990s, the mangroves were further reduced due to the overexploitation of timber for construction and charcoal (Green et al. 1998; Lebel et al. 2002; Tong et al. 2004) and the conversion of forest land into shrimp-farming land (Kovacs et al. 2004) (Figure 3. 2). Forest enterprises were established to ensure the sustainable management of mangroves. However, the forest area in Ca Mau was at its minimum of 51,000 ha in 1992 (Clough et al. 2000): the highly diverse mangrove forests of Ca Mau had been turned into monoculture forests consisting primarily of planted *Rhizophora apiculata* (Vaiphasa et al. 2005). By the mid-1990s, deforestation bans had been imposed, and the forest enterprises were now replanting and protecting forests rather than utilizing them (Christensen et al. 2008). Currently, the mangrove forests in Ca Mau Province are divided into two main land use zones. The first is a conservation zone named the Full Protection Zone (FPZ), in which all land must be forested and conserved; no human settlement is allowed except for fishing communities at the river mouths (Christensen et al. 2008). The second is the Buffer Zone (BZ), where 60% of the area must be covered by mangrove forests, while the other 40% can be used for aquaculture or agriculture (Goverment of Vietnam 1999). Consequently, the shrimp-mangrove integrated farming system in the BZ is characterized by a highly structured geometrical pattern. Typically, shrimp ponds have an area of approximately 5 ha and are surrounded by small dikes that control the water level and form a border with neighboring shrimp farms (Figure 3. 2). Within the ponds, the remaining mangrove forests are typically replanted in a row pattern. The mangrove forest in Ca Mau Province is under the state-owned management of the provincial Department of Agriculture and Rural Development (DARD) (Thu and Populus 2007; Tong et al. 2004). Farmers lease a 20-year land-use right on forest-farm land, which can be renewed provided that they adequately protect the 60% forest cover. For these farmers, shrimp farming and catching natural fish resources in tide-operated sluice gates on the shrimp-ponds remain the main sources of income (Christensen et al. 2008; Tong et al. 2004). The high income from shrimp farming encourages the farmers to increase the area of aquaculture by cutting off mangroves, which may result in a further increase of land used for aquaculture and domestic purposes instead of maintaining the status of the mangroves and complying with the demanded 60% coverage.

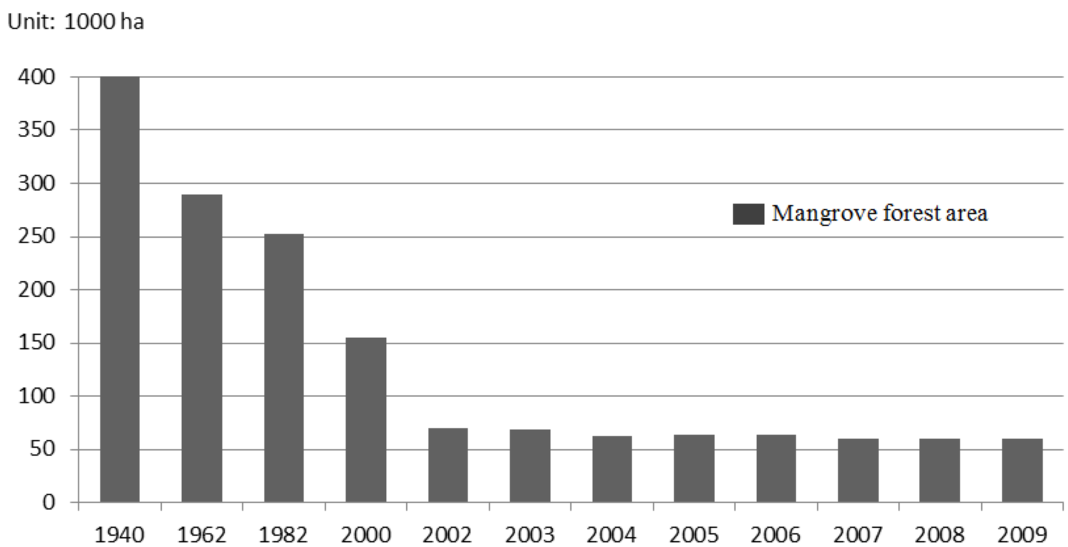

Figure 3. 2. Mangrove distribution in Vietnam (Source: (GOV 2011)).

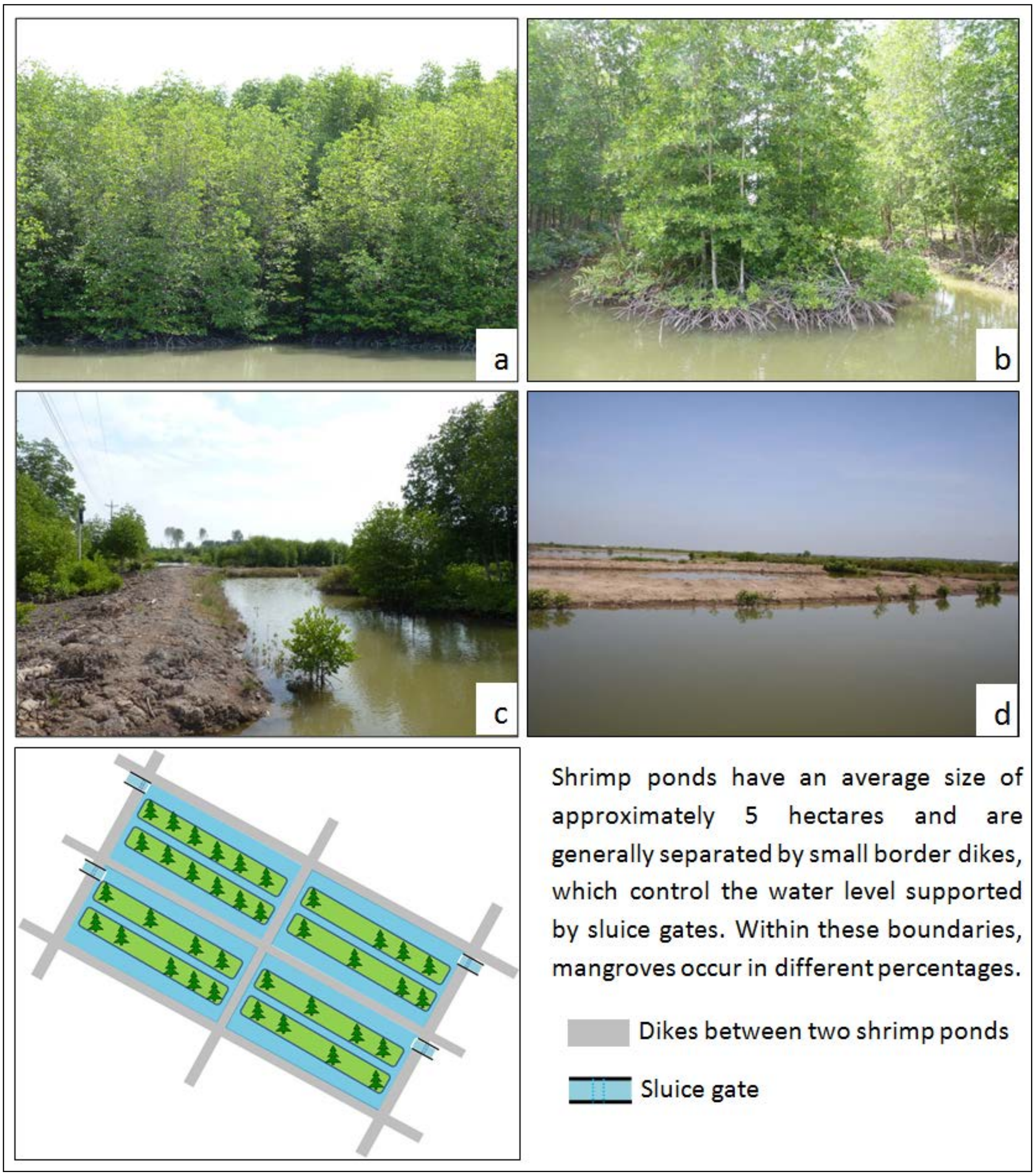

Figure 3. 3. Examples of different mangrove cover and schematic sketch of an integrated shrimp-mangrove farming system: (a) dense mangrove, more than 70%; (b) less dense mangrove forest: density 50% to 70%; (c) mixed mangrove and shrimp farming: density 30% to 50%; and (d) shrimp farming with less than 30% mangrove (Source: own photographs, 2011)

3.2.3. Data

The remote sensing data available for this study consist of multi-spectral SPOT5 data and TerraSAR-X (used for geometric correction). All scenes were stored in the GeoTIFF format and featured in a UTM map projection (UTM-48N, WGS-84 datum). Table 3.1 presents configuration details of the SPOT5 imagery. A provincial forest map for 2006 was provided by the Institute of Forest Inventory and Planning (FIPI) together with an administrative map of the study area. In addition, 222 validation points were collected during field research in 2010. A wide range of ground-truth information on mangrove conditions, density and species composition was collected. Mangrove forest cover density and additional information were retrieved via extensive household interviews (including a question on how many hectares of mangrove the household owns per total area) and were further validated by field observation. The location of each point was measured using a Trimble GPS (Trimble Navigation Limited, Sunnyvale, CA, USA).

Table 3. 1. Technical parameters and properties of the sensors used in this study.

	SPOT-5 (HRG)
Band Wavelength (nm)	480–710 (pan)
	500–590 (green)
	610–680 (red)
	790–890 (NIR)
	1580–1750 (mid IR)
Spatial Resolution (m)	2.5 × 2.5 (pan)
	10 × 10 (multi)
Swath Width (km)	60
Revisit Time (days)	26

3.3. Methodology

3.3.1. Preprocessing

The SPOT scene (acquired on 23 April 2010, 10 m spatial resolution) was geometrically registered to the TerraSAR-X data (acquired on 24 February 2010, with 2.75 m resolution). Polynomial coefficients were estimated using ground control points, and a root mean square error (RMSE) of 0.83 pixels was obtained. Next, atmospheric correction was conducted using

ATCOR-2 software. ATCOR contains a large number of pre-calculated atmospheric conditions based on the MODTRAN radiative transfer code. Standard parameters for tropical maritime land surfaces were used, and sun and sensor geometries were modified according to the image recording conditions as extracted from the image's metadata. Due to the low topographic variation in Ca Mau Province, the incorporation of a DEM for topographic radiometric correction was omitted. The detailed parameters applied for atmospheric correction are presented in Table 3. 2. More information about the functionality of ATCOR-2 can be found in (Richter and Schläpfer 2011).

Table 3. 2. Parameters applied for atmospheric correction.

Sensor	SPOT-5 MS
Date	24.03.2010
Solar zenith angle (deg)	27.3
Solar azimuth angle (deg)	105.0
Sensor tilt angle (deg)	19.7
Sensor view azimuth angle (deg)	102.5
Water vapor category	Tropical
Aerosol type	Maritime
Average visibility (km)	80.0

3.3.2. Image Segmentation

The segmentation was performed using the eCognition 8.7 image analysis software (Baatz et al. 2004). Two segmentation levels were generated in a top-down hierarchy. The first coarse segmentation level holds large objects, meant to represent the individual pond areas in the scene. As illustrated in Figure 3.4, the pond areas are clearly demarcated by circumjacent dikes, providing an ideal structure for segmentation. The super-objects are further segmented by a second, finer layer that allows differentiation of the super-objects into water and mangrove components.

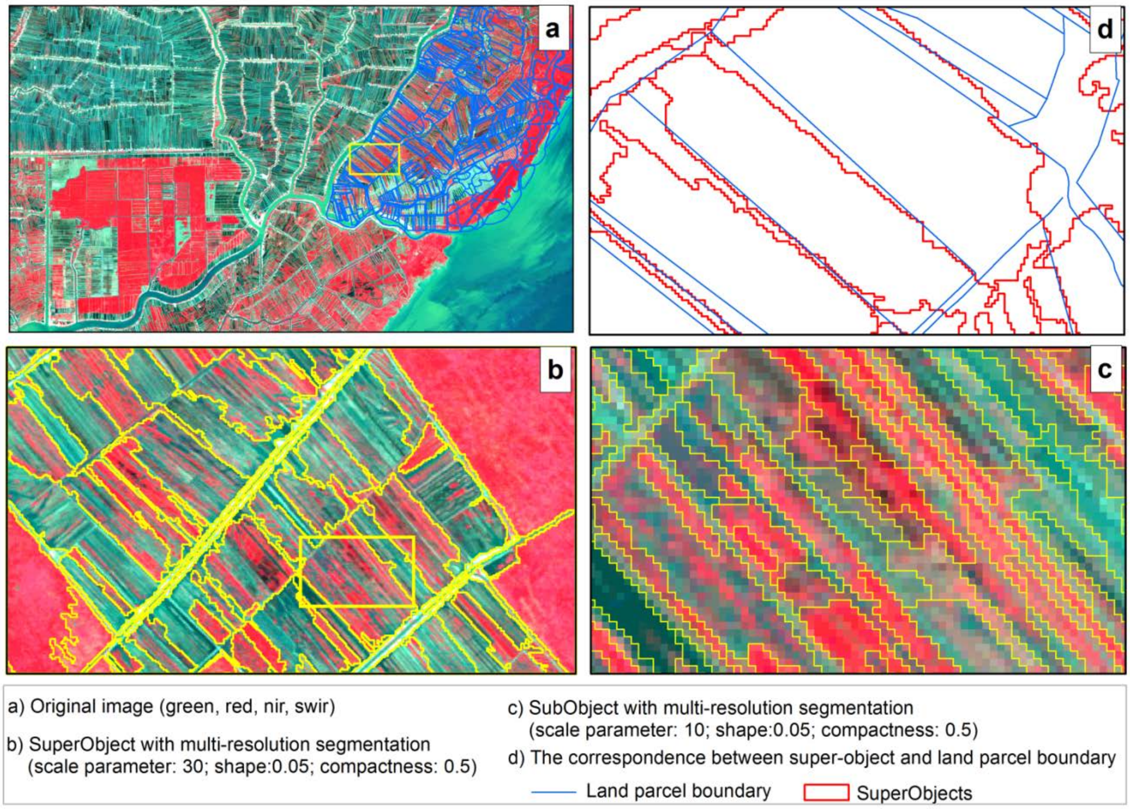

Figure 3. 4. Segmentation layers and correspondence of super-objects to cadastral map.

The segmentation algorithm applied in this study is the so-called “multi-resolution segmentation”. The algorithm was applied to all four SPOT bands (green, red, NIR and SWIR) with the same weight for each band; the NDVI was calculated and added as a fifth band with the same weighting. A scale factor and a heterogeneity criterion control the outcome of the segmentation algorithm. The scale factor is indirectly related to the average size of the objects to be detected. The heterogeneity criterion controls the merging decision process and is computed using spectral layers. This involves evaluation of two mutually exclusive properties, color and shape. Color refers to spectral homogeneity, whereas shape considers the semantic characteristics of the objects. Shape is divided into two equally exclusive properties: smoothness and compactness (Baatz et al. 2004). For a deeper understanding of the algorithm, the reader is referred to (Baatz and Schäpe 2000).

The most important and most critical aspect of this approach is the parameterization of the coarse segmentation layer so that each shrimp pond is represented by an individual object. Therefore, the different parameters were tested systematically by comparing the resulting objects with a cadastral map that was available for a small test case area (Figure 4). Starting with a low scale parameter, the threshold was increased until the super-objects had an average size that corresponded to the mean shrimp pond size of approximately five hectares (scale parameter = 30, shape = 0.05, and compactness = 0.5). The parameters for the second segmentation level were defined so that the resulting objects represented the smallest isolated mangrove forest patches within the shrimp pond areas (scale parameter = 10, shape = 0.05, and compactness = 0.5).

3.3.3. Classification

The definition of the classification scheme was based on existing provincial map legends and field surveys. In addition to the mangrove classes, four non-vegetative classes, *i.e.*, settlement area, river/canal, mud flat and ocean water, were defined for the study area. The classes were derived utilizing a decision tree approach in combination with interactive visual interpretation, expert knowledge, training data, and existing maps of the area (Figure 3. 5).

At the super-object level, the ocean water was separated from land based on the object feature "brightness" (brightness > 0, number of overlapping pixels = 1), the threshold of which was defined using an administrative map available for the area. The mud flat class was manually edited using expert image interpretation. At the sub-object level, settlement areas were identified based on the object feature "brightness" (brightness ≥ 15), and rivers and canals were classified by applying an NDVI threshold (NDVI ≤ 0, number of overlapping pixels = 1). Mangrove patches within the super-objects were classified using an NDVI threshold of 0.4.

Finally, the area of each super- and sub-object was calculated. Mangrove fractions for each pond were defined as the sum of the classified mangrove patches within each super-object divided by the total pond area. The mangrove fractions for each super-object were further grouped into four density classes, *i.e.*, below 30%, 31−50%, 51−70%, and 71−100% mangrove forest.

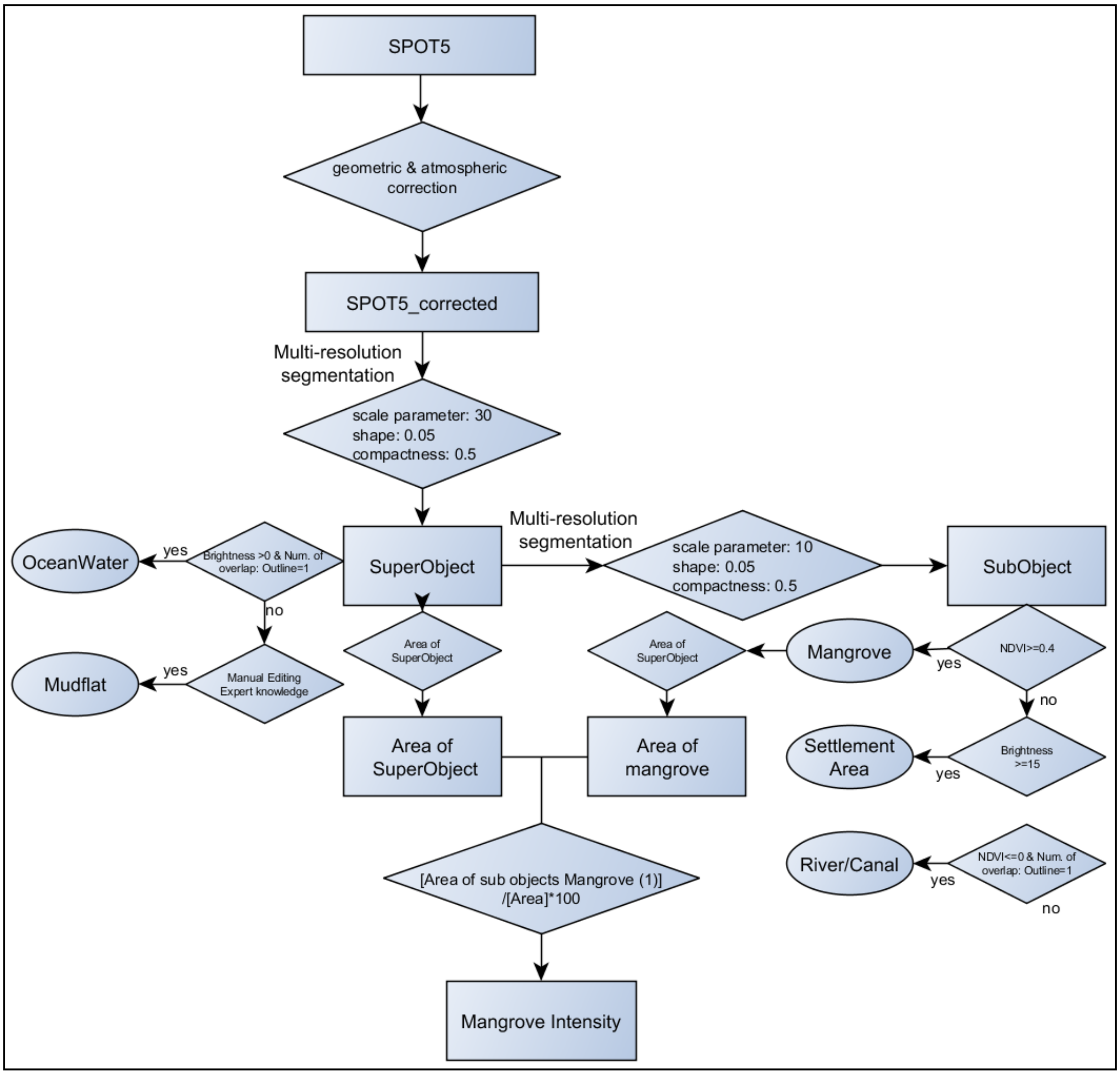

Figure 3. 5. Object-based image analysis decision tree (rectangle = image; diamond = rule; oval = class).

3.3.4. Validation

Accuracy assessment is an important part of the image classification procedure and can be computed by assessing either positional or thematic accuracies. Positional accuracy is defined as the accuracy of the location of a point in the satellite imagery with reference to its location on the ground, whereas thematic accuracy is the accuracy of a mapped land cover class at a certain time compared with what was actually on the ground at that time (Congalton and Green 2009). In this study, a total of 222 reference points were surveyed in the field to serve as validation samples for the classification (Figure 3.6). The number of validation samples selected for each class was proportional to its importance in terms of area covered, with a minimum of 10 samples for each class. At each reference location, the respective land cover class and mangrove density within a farmer's parcel were visually estimated, and GPS coordinates were recorded. Each land cover class was then compared with the results of the classified image. A confusion matrix together with descriptive statistics (user's accuracy, producer's accuracy and overall accuracy) was then computed to conduct an accuracy assessment for the land cover classification.

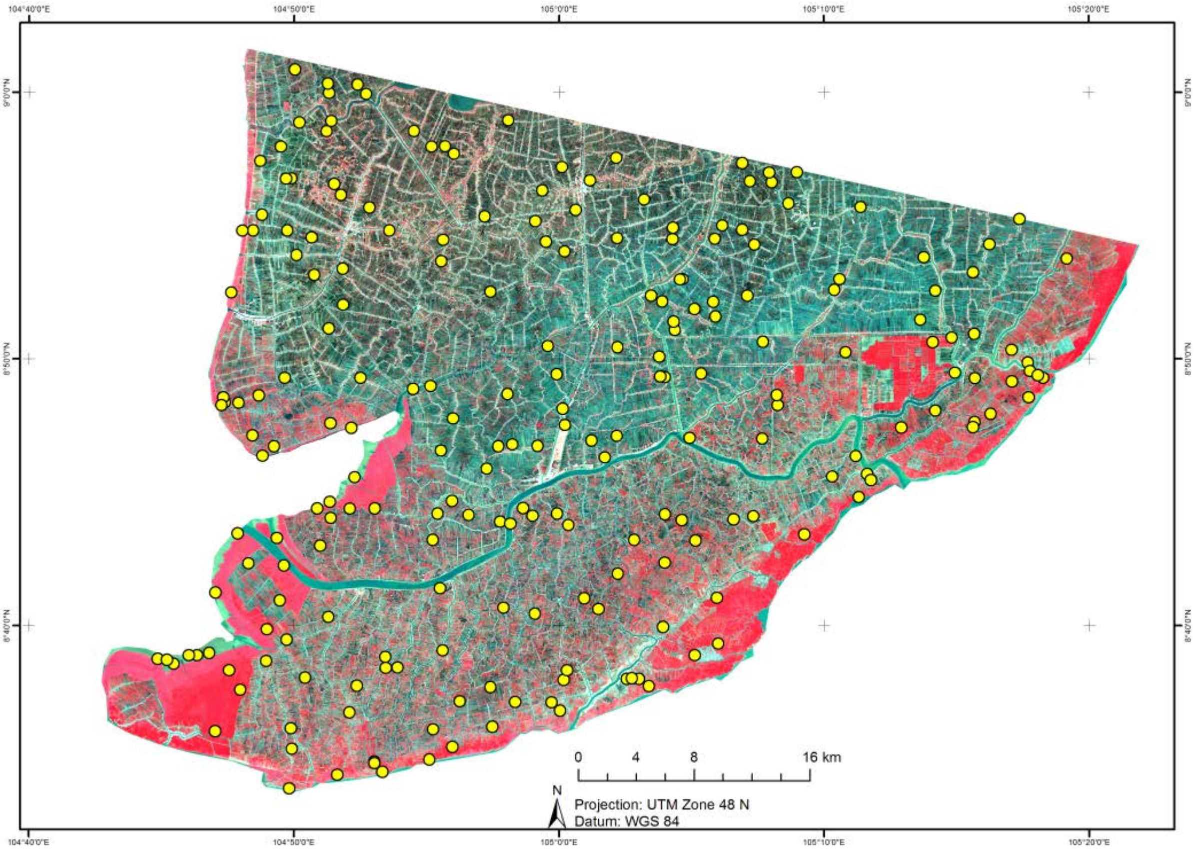

Figure 3. 6. The distribution of validation points in the test area.

3.4. Results

As previously stated in Section 1, a major focus of this study is the derivation of the mangrove cover fraction. Figure 3.7 presents the results of the image classification, including four mangrove classes with different densities, rivers/canals, mud flats and settlement areas. The dense mangrove areas were found primarily along the coastline, where more than 70% of farmland is occupied by mangroves. Low amounts of forest cover (e.g., 31% to 50%) were distributed inland, where land is utilized for aquaculture and shrimp farming. Water canals and small tidal creeks are distributed within the entire area. Mud flats occur along the southwestern corner of the Ca Mau Peninsula. These flats are a result of the accumulation of coastal sediments during monsoons and sediment transport from the Mekong River. Table 3 shows a comparison of the mangrove fraction with estimates from the field data. The classification resulted in an overall accuracy of 75.68%. The "pure" classes had particularly high accuracies. For example, settlement areas, patches with less than 30% mangrove coverage, and rivers-canals had accuracies of 68.00%, 89.86% and 94.44%, respectively. The mixed classes, however, *i.e.*, the classes with 30–50% or 51–70% mangrove forest cover, show lower accuracies, with omission and commission errors between approximately 39% and 58%. This result means that misclassification occurred primarily for ponds with more balanced fractions of mangroves and aquaculture.

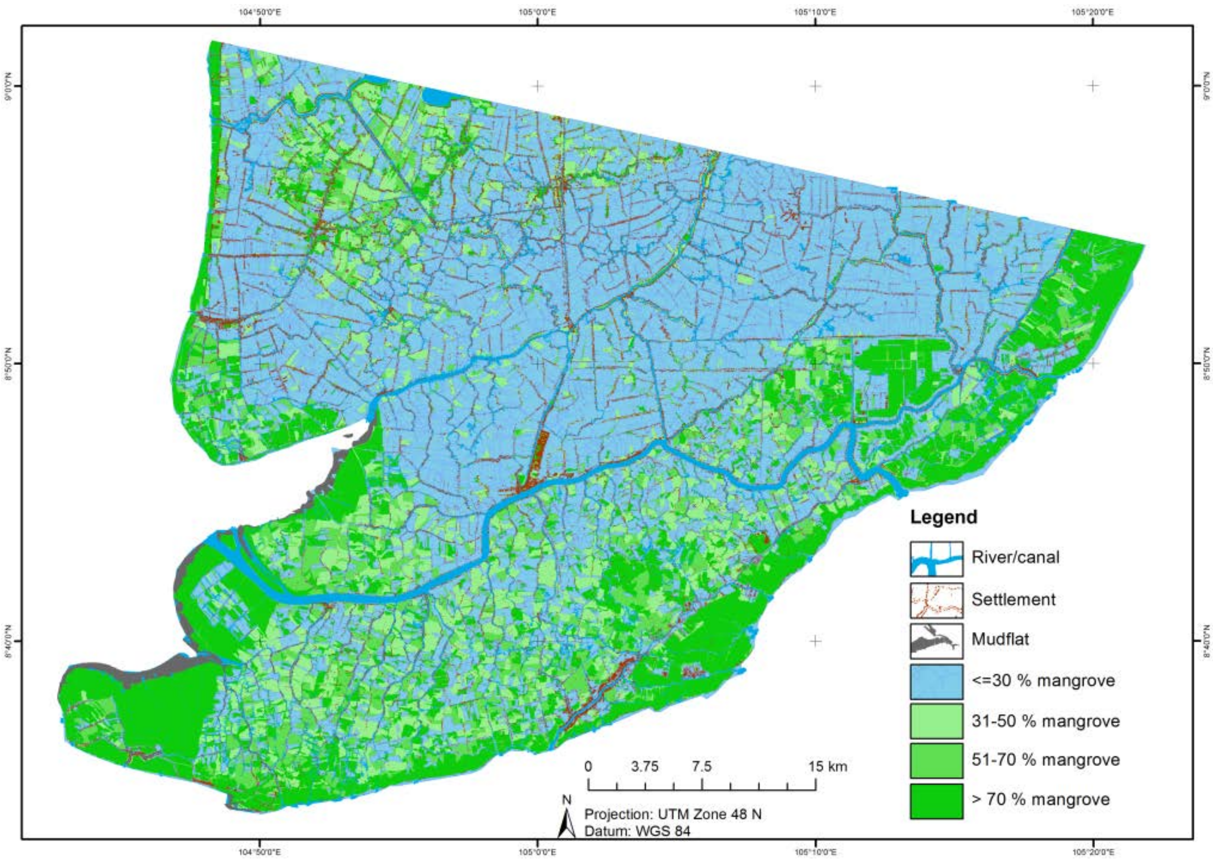

Figure 3. 7. Land cover classification results in Ca Mau Province.

Table 1. The classification confusion matrix.

	≤30 %	31%–50%	51%–70%	>70 %	River-Canal	Mudflat	Settle-Ment	Producers Accuracy	Users Accuracy
≤30%	**62**	11	5	0	1	0	2	89.86%	76.54%
31%–50%	3	**16**	10	1	0	0	1	53.33%	51.61%
51%–70%	2	1	**14**	3	0	0	3	42.42%	60.87%
>70%	1	2	4	**32**	0	0	1	86.49%	80.00%
River-canal	1	0	0	0	**17**	0	1	94.44%	89.47%
Mudflat	0	0	0	0	0	**10**	0	100.00%	100.00%
Settlement	0	0	0	1	0	0	**17**	68.00%	94.44%

* Overall Classification Accuracy = 75.68%. Overall Kappa Statistics = 0.6975.

3.5. Discussion

To our knowledge, no study or region-specific dataset on the quantification of mangrove cover exists for the Ca Mau Peninsula in the MD. The only available dataset on forest cover quantification for this region is the global MOD44B vegetation continuous fields (VCF) product. MOD44B VCF is a standard product of the Land Processes Distributed Active Archive Center (LP DAAC) and holds sub-pixel estimates of tree cover at 250 m resolution that were derived from the MODIS sensor aboard the platforms Aqua and Terra (Hansen et al. 2005). The MODIS VCF tree cover product is frequently used for validation and comparison at regional to local scales (Hansen et al. 2005; Montesano et al. 2009; Ranson et al. 2011). Figure 3.8 shows the MODIS VCF product in comparison to our object-based classification result. To achieve a better comparison, we resampled our object-based classification to a 250 m spatial resolution and reclassified the MODIS VCF product into the four mangrove fraction classes corresponding to our classification.

Although the same general patterns of forest fractions can be observed in both products, significant differences were evident in the comparisons of the actual proportions in the mangrove fraction classes Figure 3.8 (c–d). Although there was an overall agreement of approximately 100,000 ha between the two products, approximately 45% of the study area showed different class assignments. From the difference image (Figure 3. 8(c)), it is evident that there is a clear trend toward lower forest fractions in the MODIS VCF product compared with those of our approach. Although the proportions of very low mangrove fractions (≤30%)

are nearly twice as high in the MODIS VCF product compared with our results, the proportions of MODIS VCF estimates in the intermediate classes are less than one-third of those obtained with the regional classification approach. The lowest agreement can be found for the highest fraction class (>70%), where the MODIS VCF product estimated only one-sixth of the area of our approach.

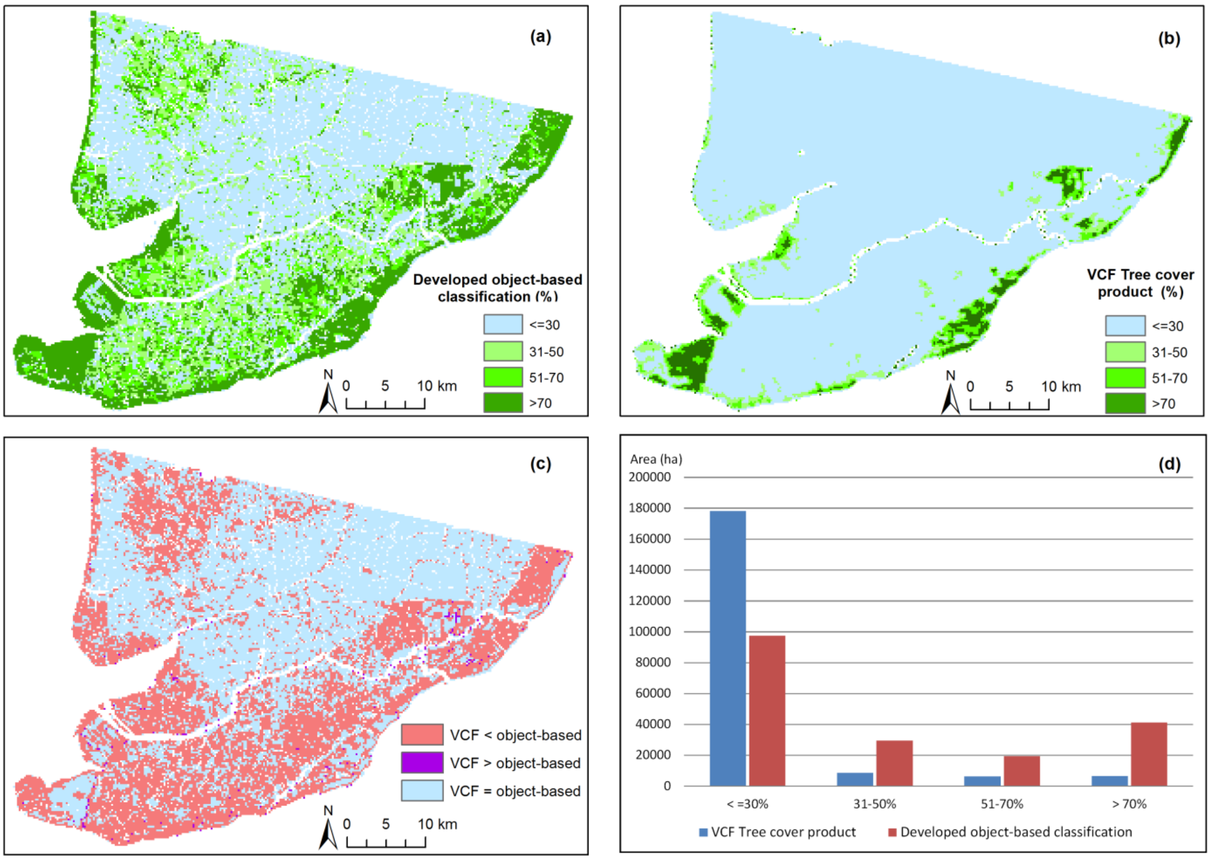

Figure 3. 8. (a) Developed object-based classification result derived from SPOT5, (b) VCF tree cover product derived from MODIS, (c) spatial agreement between two products, and (d) comparison between the two products in the area.

The results of the comparison demonstrate the shortcomings of global products based on low-resolution data compared with the regionally tuned approach utilizing high-resolution image data. The MODIS VCF product is derived through a regression model based on a global data set of tree cover densities. However, the structure of the mangrove forests in Ca Mau Province differs substantially from the global average forest structures (Figure 3. 3). The very distinct spectral properties of the surface water among the forest areas significantly influence the overall spectral response of the MODIS pixels. The object-based approach, in comparison, classifies patches of mangrove forests and water areas separately at the pond level. Even for the very dense mangrove patches at the corner, water still influences a pixel's overall spectral appearance as a canopy background signal. This influence is particularly apparent for the dense mangrove forests along the coast, which are planted for coastal protection.

Although the results of the accuracy assessment demonstrated that the overall agreement between the estimated fractions and the field data was satisfactory, the intermediate fractions showed larger disagreements. As noted by many authors (Conchedda et al. 2008; Dupuy et al. 2012; Hölbling et al. 2012; Lamonaca et al. 2008; Wang et al. 2004), multi-resolution segmentation is a powerful technique, and the selection of an appropriate scale parameter is crucial for creating meaningful objects. As illustrated in Figure 4, the super-object segments in this study correspond reasonably well to the shrimp pond boundaries. It must be noted, however, that the shapes and sizes of the resulting super-objects, with an average size of five hectares, are only an approximation to the underlying shrimp pond structure and that a substantial number of plots in the field, as well as super-objects in the segmentation layer, showed large deviations from this average size. Furthermore, the image segmentation is influenced by physically visible natural boundaries such as the shrimp pond dikes and, therefore, does not necessarily correspond to actual ownership structures. During the field trip, however, interviews and mangrove quantification were performed for each farming system. In addition, the estimation of mangrove fractions in the field for plot areas of 5 ha is not straightforward and introduces additional uncertainties into the field data. A further source of uncertainty is that even though mangroves are the dominant vegetation type in this area, the mangrove class may contain other types of vegetation (e.g., garden trees). Because we decided not to further differentiate between different vegetation types, the derived mangrove fractions may be overestimated in certain areas.

Despite these limitations, the results demonstrate the general suitability of the object-based approach for the quantification of the mangrove fraction in a highly structured environment, such as the integrated aquaculture-mangrove farming system of the Ca Mau Peninsula. Further reseach will focus on the integration of additional geodata, such as cadastral maps in the segementation process, and on the general transferability of the approach to comparably structured environments. Although most previous studies related to mangrove mapping generally focus on the discrete differentiation between mangrove and non-mangrove areas, qualitative descriptions of mangrove densities, and mangrove species, our study focuses on the quantitative estimation of mangrove fractions at the parcel level.

3.6. Conclusions

The approach followed in this study represents a first attempt to quantitatively assess mangrove percentages within the special mangrove-aquaculture farming system in the MD. Existing approaches on mangrove classification are limited to qualitative mangrove characteristics such as “dense”, “medium” and “low” densities. Our approach, in contrast, provides continuous forest fractions at the “pond level” without utilizing auxiliary information on ownership structures. This precondition is of high importance, particularly in developing countries where geoinformation is rare or nonexistent. Because no comparable information on mangrove percentages exists for the region, the results are of great value to natural resource managers in terms of mangrove inventory mapping and enforcing the guidelines related to mangrove fractions in the respective zones.

The results demonstrate that the predominantly mono-cultivation areas, *i.e.*, above 70% or below 30% mangrove forests, were detected with high accuracies compared with existing approaches. The quantification of mangrove-aquaculture percentages toward more balanced fractions, however, is becoming increasingly challenging. This challenge can also be attributed to the difficulties of obtaining reliable and consistent field estimates for validation.

Although there are still a number of challenges, the derived super-objects and the resulting mangrove fractions reflect the given conditions in the delta better than using a regular grid, for example, when applying spectral unmixing approaches based on medium-resolution data. Further improvements of the approach could include the incorporation of information on ownership structures, such as cadastral maps, in the segmentation process once such geo-information is available for this region.

Acknowledgments

This research was undertaken within the framework of the German-Vietnamese research project “WISDOM”, funded by the German Ministry of Education and Research-BMBF and the Ministry of Science and Technology of Vietnam (MOST). We thank three anonymous reviewers for their valuable and instructive comments on the manuscript.

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

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Ecosystem Services

Submitted 19 April 2013

Abstract

This paper highlights the importance of using household survey and remote sensing data for the assessment of mangrove ecosystem services in a portion of Ca Mau Province, Vietnam. The results indicate that remote sensing plays an important role in mangrove ecosystem service valuation, particularly 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$ 3,000/ha/year), which is significantly greater than the gross domestic product (GDP) of the Province (US$ 1.25 million in 2010). However, this is only a partial estimate that does not consider other services, such as 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 detailed household survey for the quantification of mangrove ecosystem services, particularly 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.

Keywords: Mangrove; Valuation; Ecosystem services; Remote sensing; Household survey

4.1. Introduction

Mangrove forest ecosystems are represented by a variety of trees, including palms, and other species, in addition to shrubs and ferns, dominating in coastal and river estuarine areas of tropical and subtropical zones (Alongi 2002; Giri et al. 2012; Hogarth 2007). Mangrove ecosystems are very important coastal resources and are essential to local communities in providing both economic and ecological functions and services (Alongi 2002; Hussain and Badola 2010; Kuenzer et al. 2011; Rönnbäck 1999; Vo et al. 2012). Economically, mangroves forest have been identified as important resources that provide direct benefits to the local population through fishery products (e.g., fish, shrimp, crabs, mollusks), forestry products (e.g., firewood, timber, construction materials), and recreational purposes (e.g., tourism) (Alongi 2008; Alongi 2002; Kuenzer et al. 2011). The ecological functions of mangroves include serving as a protected area for many aquatic organisms and the provision of habitat and shelter for numerous non-aquatic species (Brander et al. 2012; Hussain et al. 2010; Lewis 2005). Moreover, mangroves act as a filter system for water and sediments in estuaries and simultaneously provide buffer zones against typhoons and floods. Additionally, due to climate change-induced sea-level rises, mangrove ecosystems have become increasingly important as natural protection against shoreline erosion by stabilizing shorelines and reducing the devastating impact of such natural disasters as tsunamis and hurricanes. Furthermore, mangroves partially stabilize the climate through carbon sequestration and the moderation of temperature extremes (Conchedda et al. 2008; Kathiresan 2006; Kovacs et al. 2011; Kovacs et al. 2004; Thampanya et al. 2006; UNEP-WCMC 2006). Regardless of their ecological and economic value, mangrove ecosystems are among the most threatened ecosystems in the world (Alongi 2002; Giri et al. 2011; Kairo et al. 2001). Based on earth observation data, the global mangrove area was estimated at 137,760 km^2 in 2000; Figure 4. 1 presents the mangrove distribution in 118 countries and territories in tropical and subtropical regions of the world (Giri et al. 2011). The main threats to mangroves are the overexploitation of their natural resources, deforestation, conversion to aquaculture and salt-ponds, mining, pollution, and industrial or urban development (Alongi 2002; Gilman et al. 2008; Kuenzer et al. 2011).

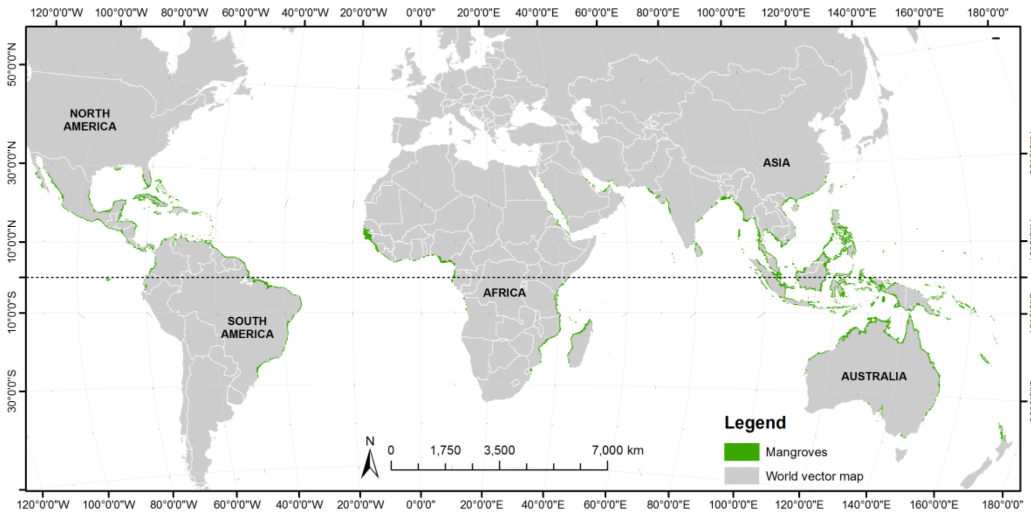

Figure 4. 1. Global distribution of mangrove forests (Source: Authors, 2013. Generated from world vector map - Natural Earth, mangrove data from Giri et al., 2011, available online at www.unep-wcmc.org)

Many studies on the economic valuation of mangrove ecosystem services have been completed over the past 20 years (Bann 1997; Barbier and Strand 1997; Hussain and Badola 2010; Kaplowitz 2001; Othman 1994; Rönnbäck et al. 2007; Sathirathai 2004; Sathirathai and Barbier 2001; 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 estimated values are diverse due to the specific conditions of economic activities, geographical or temporal specificity, and the culture or behavior of the local population (Brander et al., 2012; de Groot et al., 2012; Salem and Mercer, 2012). Recent publications on mangrove economic value using meta-analysis and value transfer approaches were conducted in Southeast Asia (Brander et al., 2012) and more broadly in Asia, the Americas, the Middle East, and Africa (Salem and Mercer 2012). These studies presented a synthesis of mangrove ecosystem valuation from the literature and estimated the change in the value of mangrove ecosystem services. However, although similar approaches were used (meta-analysis), the findings were not always consistent (i.e., with regard to the relationship between value and protected sites).

The aim of the present study is to establish a framework for linking remotely sensed 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 the provisioning services (fisheries products, timber, and tourism) and 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, household survey, and geophysical results for the assessment of mangrove ecosystems. 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.

This paper is structured as follows. The next section contains a discussion of the inconsistency between mangrove ecosystem service valuations, emphasizing the limitations of the benefit transfer approach for the estimation of mangrove ecosystem services. The main types of inconsistencies are also reviewed in this section. Section 3 discusses the roles and limitations of remote sensing for mangrove ecosystem service assessment and valuation. Section 4 proposes a case study that features the benefits of using detailed household survey data and earth observation data to estimate the economic value of mangrove ecosystem services. We conclude by highlighting the key points raised in the paper.

4.2. Inconsistency among mangrove ecosystem service valuations

The economic valuation of mangrove ecosystems is generally a complex process that is based on the availability of appropriate and accurate bio-physical data on ecosystem processes and functions in addition to appropriate valuation methods (Spalding et al. 2010; Vo et al. 2012). Therefore, 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. 2012; Gammage 1994; de Groot et al. 2012; 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 (i.e., water filtration, carbon sequestration, and pollination), which are crucial to the long-term sustainability of their livelihoods (Wegner and Pascual 2011). One of the most common approaches for the assessment of mangrove ecosystem services is the benefit transfer (value transfer) approach, which applies economic value estimates from one location to a similar site in another location. However, this approach involves errors due to the differences in the economic activities, cultures, and lifestyles of the local people: the same type of ecosystem service may have different value in different locations and at different times (Brouwer 2000; Burkhard et al. 2011a; Hussain et al. 2009). The value of local-scale services, such as flood control and storm protection, may have limited transferability because of a lack of correspondence among the sites considered (De Groot et al. 2012; Plummer 2009). Moreover, value also depends on current market price and preferences, both of which change over time. The geographical and temporal specificity of any service valuation limits extrapolation of the current local values beyond the local or bioregional scale and across all times (Turner et al. 2003a). The main types of inconsistencies for mangrove ecosystem service assessment are summarized in Table 4. 1. The utilization of different ecosystem service assessment approaches can also introduce inconsistencies because each approach has unique advantages and disadvantages (De Groot et al. 2012; Kumar 2010). 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.

Table 4. 1. Main types of inconsistencies

Type of inconsistency	**Specific example**
Temporal	The value of the fishery products of mangrove ecosystems in 2011 was not the same as in 2012. Therefore, selecting discount rates (trade-offs between the present and future) plays an important role and contributes to the valuation results (Ludwig et al. 2005).
Spatial/Cultural	There is a large disparity between the valuation results for fishery products in different locations. For example, the value of fishery products differs between countries – e.g., US$ 37,500/ha/year in Mexico, US$ 640/ha/year in Fiji, and US$ 1,975/ha/year in Queensland, Australia (Cabrera et al. 1998) – depending on such factors as the species composition and average catch rate. In

	addition, the willingness of people in Vietnam to pay for certain services (i.e., water filtration and pollination) might differ completely from the willingness of people in Australia to pay. Therefore, valuation depends on the distribution of wealth and cultural aspects in the society and the local livelihood.
Technical	Differences in the valuation approaches used will result in large differences in the economic value assigned, for instance, the willingness to pay and willingness to accept compensation (i.e., the amount of money a person accepts as compensation for losing) (Kumar 2010).

4.3. What remote sensing provides for the economic valuation of mangrove ecosystem services

4.3.1. Mapping mangrove cover (spatial or temporal)

Remote sensing provides useful data for mapping mangrove cover classification and has advantages for the large-scale mapping of mangrove ecosystems at a relatively low cost (Conchedda et al. 2008; Heumann 2011b; Krause et al. 2004; Kuenzer et al. 2011; Vo et al. 2013). Furthermore, remote sensing has proven to be a useful source of data for inaccessible areas. In the assessment of mangrove ecosystem services, mangrove forest cover was used as a proxy measure of ecosystem services, as forest cover has multiple linkages to the availability of provisioning services (i.e., timber, fisheries products, and tourism) and supporting, regulating, and cultural services (i.e., carbon sequestration and storm protection) (Konarska et al. 2002). For each mangrove cover type, the services provided by mangrove ecosystems are identified and assigned a monetary value based on previous studies or primary data. Therefore, mangrove cover information serves as proxy for the valuation of ecosystem services because most of the regulating, supporting, and cultural services are difficult to quantify and map (Layke et al. 2012; Maes et al. 2012). The estimated per hectare value derived from model outputs or primary data for each ecosystem is multiplied by the area of mangrove cover type to calculate the total monetary value of the ecosystem (Alongi 2002; Costanza et al. 1997a; Fujimoto 2000; Loomis et al. 2000; Mcnally et al. 2011).

4.3.2. Mapping mangrove biodiversity

Differences in the environmental properties of different surface types should lead to differences in spectral responses, which can be detected by earth observation data. Biodiversity has also been employed as a surrogate measure of ecosystems for example, a previous study (Turner et al. 2003b) found that, with the improvement of spatial and spectral resolutions, remote sensing becomes increasingly feasible for measuring certain aspects of biodiversity, such as species assemblages or the identification of individual trees. The alternative approach is the indirect remote sensing of biodiversity through reliance on such environmental parameters as proxies. For example, many species are restricted to discrete habitats, such as woodlands, grasslands, mangroves, or sea-grass beds, which can be clearly identified in remotely sensed data. By combining information regarding the known habitat requirements of species with maps of land cover derived from satellite imagery, precise estimates of potential species ranges and patterns of species richness are possible (Kuenzer et al., 2011b; Müller and Brandl, 2009; Proisy et al., 2007; Turner, et al., 2003). Species diversity can be more directly assessed by examining the relationship between the spectral radiance values recorded from remote sensors and species distribution patterns recorded from field observations (Fromard et al. 2004).

4.3.3 Limitations of remote sensing in mangrove ecosystem service valuation

As stated above, remote sensing data offer opportunities for accurately monitoring and mapping mangrove ecosystems (Heumann 2011a; Kuenzer et al. 2011; Vo et al. 2013). Some services provided by mangrove ecosystems can be delineated using remote sensing approaches, i.e., carbon sequestration, storm protection, and biomass using the leaf area index (LAI) or the Normalized Difference Vegetation Index (NDVI) as indicators. However, other services, such as fishery-related products or tourist information, can only be derived experimentally through local investigations. Indeed, fieldwork is important for the assessment of mangrove ecosystem services. Although remote sensing data have been proven to be a useful way to qualify and map mangrove ecosystems (Conchedda et al. 2008; Heumann 2011a; Krause et al. 2004; Kuenzer et al. 2011; Vo et al. 2013), it is not a complete solution for the valuation of mangrove ecosystem services. Therefore, important aspects of improving the accuracy of mangrove ecosystem service assessment using remote sensing include conducting fieldwork (household investigation) and selecting the proper spatial resolution. As noted previously (Brouwer, 2000; De Groot et al., 2012; Rönnbäck, 1999), economic valuation is context specific, which means that the economic valuation of mangrove ecosystem services is not meaningful if it is not related to the specific situation. Therefore, mangrove ecosystem service assessments derived from remote sensing and spatial analyses must be linked to the specific landscape to understand the connection between these ecosystems and local communities and to generate a meaningful valuation and reduce uncertainty.

4.4. Case study of Ca Mau: An assessment of mangrove ecosystem services based on earth observation data and a household survey

4.4.1. Study area

The Mekong Delta (MD), Vietnam, located between 8°33'–10°55'N and 104°30'–106°50'E, is one of the largest river deltas in the world, comprising an area of approximately 40,000 km^2, of which 4,000 km^2 is used for forestry (Clough et al. 2000; Evers and Benedikter 2009). The MD produces approximately 50% of the nation’s rice and contributes more than 30% of the Gross Domestic Product of Vietnam through primary products such as agricultural and aquacultural products (Evers and Benedikter 2009; Gebhardt et al. 2012). Ca Mau Province is one of the 13 Provinces of MD and was chosen as the study area for many reasons. First, Ca Mau is one of the biggest delta Provinces, hosting the largest mangrove forest areas in the MD (Figure 2). Second, Ca Mau is the Province in which the mangrove forest area has declined significantly, primarily due to the expansion of shrimp farming and ongoing population pressure (Clough et al. 2002; Johnston et al. 2000; Tong et al. 2004). Because of its high economic return, shrimp farming has been promoted to boost the national economy as a potential source of income for local communities and as a means of poverty alleviation (Corps 2007; Lebel et al. 2002). Finally, Ca Mau Province has special characteristics of the integrated mangrove-aquaculture farming system in which mangroves are planted in individual shrimp ponds at different densities (Vo et al. 2013) (Figure 4. 2).

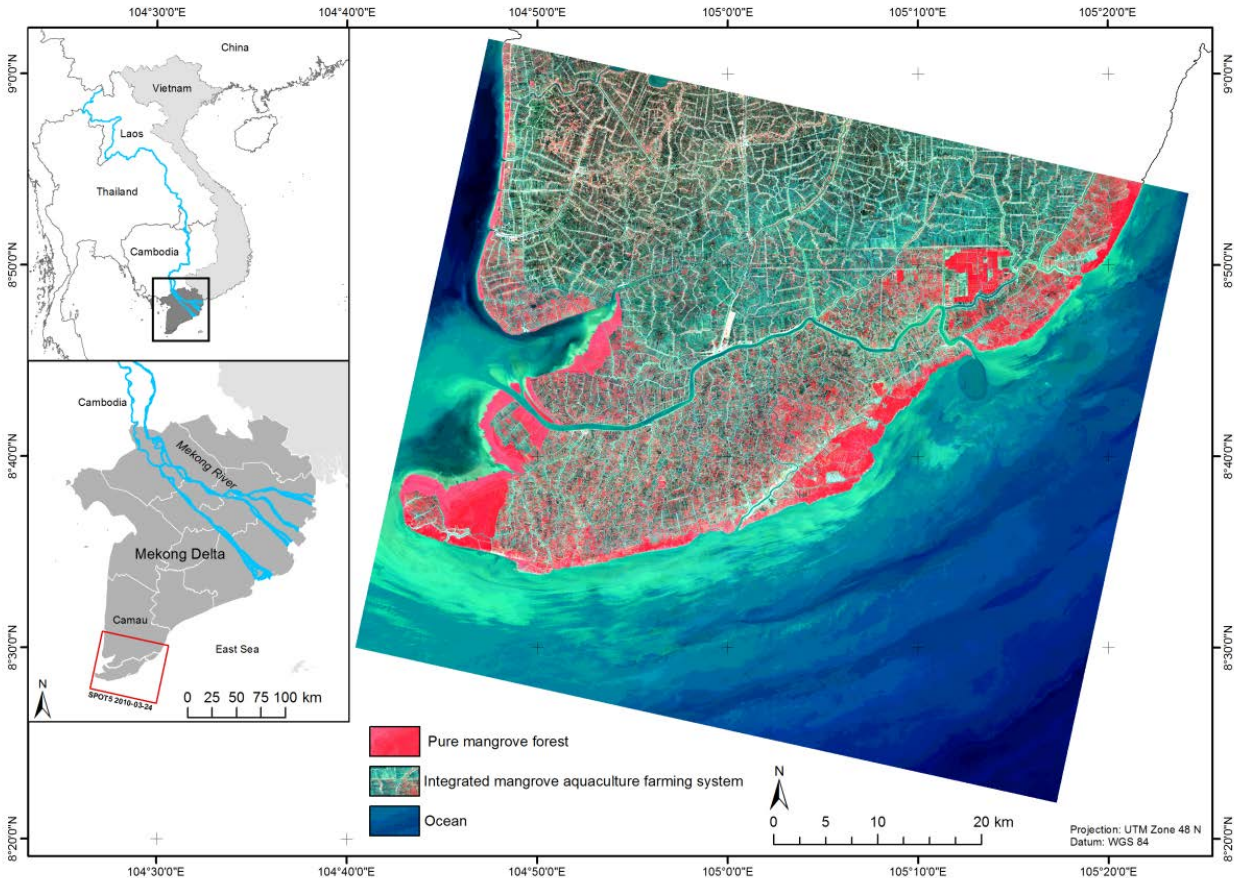

Figure 4. 2. Location of the study site in Ca Mau Province in the Mekong Delta (Source: Vo et al., 2013, modified)

4.4.2. Mangrove allocation program in Ca Mau, Mekong Delta

In the 1970s, the mangrove forest area in Ca Mau Province covered approximately 200,000 ha (Tong et al. 2004). However, the area of mangrove forest has declined significantly since then due to the overexploitation of timber for construction and charcoal and, more recently, the expansion of shrimp farming (Green et al. 1998; Kovacs et al. 2004; Lebel et al. 2002; Tong et al. 2004). According to the Vietnamese forest classification system, the mangrove forests in Ca Mau Province are classified into three different types: special-use forest, protection forest, and production forest (Government of Vietnam 2001) (Figure 4. 3). The main role of special-use forests is for nature conservation as natural reserves and national parks, protection of historical and cultural values, tourism, and environmental protection. Protection forests are maintained to protect streams and soils, prevent soil erosion, and mitigate natural disasters. Production forests have the main purpose of supplying timer and non-timber products (Figure 4. 3).

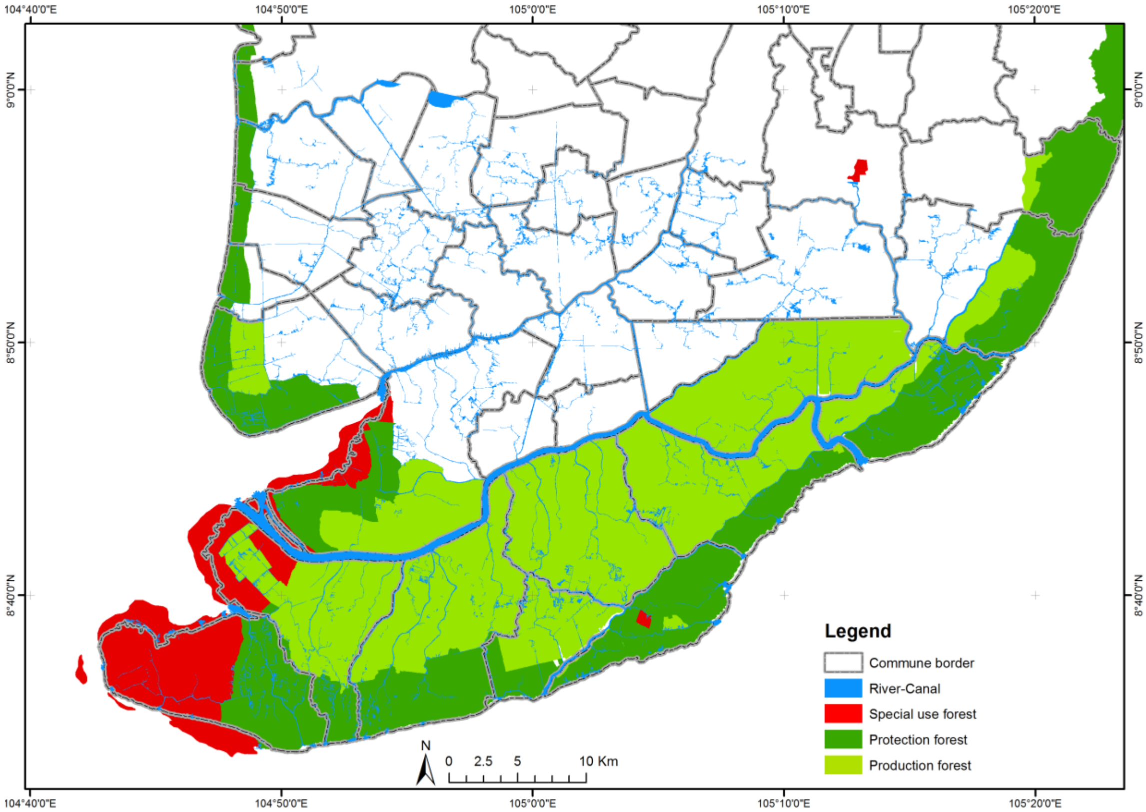

Figure 4. 3. Three different classifications of mangrove forest in Ca Mau Province (Source: Government of Vietnam, 2001)

The mangrove forest in Ca Mau Province is under the state-owned management of the provincial Department of Agriculture and Rural Development (DARD) (Thu and Populus 2007; Tong et al. 2004). Farmers lease a 20-year land-use right on forest-farm land that might be renewed provided that the farmers adequately protect 60% of the forest cover in the protection zone. For these farmers, shrimp farming and the natural fish resources caught in the tidal-operated sluice gates on the shrimp-ponds are the main sources of income (Christensen et al. 2008; Tong et al. 2004). The high income from shrimp farming compels the farmers to increase the area of aquaculture by cutting down mangroves, which results in a further increase of land being used for aquaculture and domestic purposes instead of retaining the mangrove status and complying with the 60% coverage requirement.

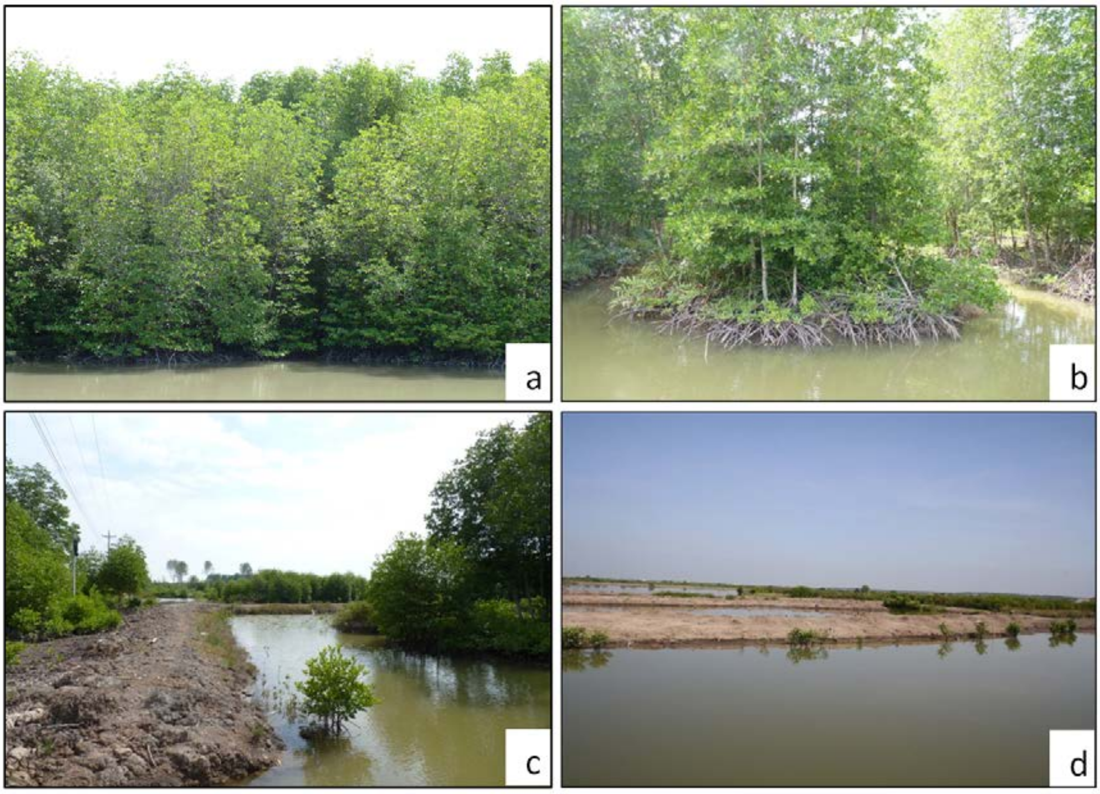

Figure 4. 4. Different mangrove cover: (a) dense mangrove forest, approximately 70%; (b) less dense mangrove forest, 50% to 70%; (c) mixed mangrove and shrimp farming, 30% to 50%; and (d) shrimp farming with less than 30% mangrove (Source: own photographs, 2010)

4.4.3. 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 local communities. The household survey includes two stages. The first stage 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 household survey. The sample size consisted of 300 randomly selected households, which was eventually reduced to 285 households after data exclusion. The survey used a semi-structured questionnaire with over 150 questions on different aspects of mangrove ecosystem services to interview local residents. The questionnaire included measures of both discrete information of land size, mangrove area, and mangrove-related income and general quantitative information on the awareness of mangrove ecosystems, mangrove forest utilization, and the perception of mangrove forest protection. All the interviewed household information was analyzed using SPSS statistics software. The market price approach was used to calculate the net benefit (i.e., fishery products and wood-related products) of the different mangrove forest densities with the following equation:

$$A = \sum \left(P_i Q_i - I_i \right)$$

where A = the net benefit (US$/ ha/year), = the product price, = the quantity, = the investment, and i = the product.

In general, measuring indirect-use values is considerably more difficult than measuring direct-use values because most indirect-use values are not traded in the market (Costanza et al. 1997a; Van Oudenhoven et al. 2012; Phuviriyakul 2007). In the present study, the valuation of indirect-use values of mangrove ecosystems (carbon sequestration and erosion control) are estimated by replacement cost (RC) and benefit transfer (BT) approaches to address the limited availability of data. RC assumes that it is possible to find surrogates for the environmental goods and services provided by mangrove ecosystems. The cost of replacing the functions or services of a mangrove ecosystem by a human-engineered system is used as a measure of the economic value of the function itself (Sundberg 2003). The BT approach is a technique for calculating the value of an ecosystem by employing an existing valuation estimate for a similar ecosystem (Navrud et al. 2007). Therefore, the economic value of carbon sequestration and erosion control of mangrove forests is calculated by using the results from previous studies performed in the same location of the present study. To address the difference in time, a gross domestic product (GDP) deflator is used to convert the values from different years to the year in which the primary data (remote sensing and household survey data) were collected (i.e., 2010). The GDP deflator is the ratio of the nominal GDP to the real GDP (Brander et al. 2012; de Groot et al. 2012; Woodward and Wui 2001) and calculates the average price of the final goods and services produced in the country.

As stated above, the mangrove forests in Ca Mau Province are subject to a special integrated mangrove-shrimp farming system in which mangrove forest and shrimp farming are mixed in each pond. However, the quantification of an accurate percentage of mangrove cover in a pond is challenging when applying pixel-based approaches, even with high-resolution data (Heumann 2011b; Tsai et al. 2011; Vo et al. 2013). To correspond to socio-economic household data, remote sensing results should be able to quantify the continuous percentage of mangrove cover in a pond. Therefore, an object-based approach is employed in this study. Object-based approaches have been applied in many investigations (Hölbling et al. 2012; Huth et al. 2012; Ranson et al. 2011; Tsai et al. 2011; Vo et al. 2013), particularly with high-resolution images; a few studies have also applied this method in field mangrove applications (Conchedda et al. 2008; Heumann 2011b; Myint et al. 2008). However, most applications related to mangrove mapping have focused on the discrete classification of mangrove and non-mangrove areas or have classified qualitative terms, such as mangrove density. When applying pixel-based approaches, the heterogeneity between the shrimp ponds (e.g., the shape, size, and forest patterns) often prevents the accurate measurement of the percentage of forest cover. To avoid this problem, Vo et al. (2013) developed a new method of quantifying mangrove forest fractions in an integrated mangrove aquaculture farming system, which was successfully applied in Ca Mau. The methodology includes several steps, including geometric and atmospheric correction, image segmentation, classification, and, finally, an accuracy assessment. A detailed description of the methodology can be found elsewhere (Vo et al. 2013). The final mangrove ecosystem service value map is a result of the multiplication of the area of each mangrove fraction by its mean value per hectare.

4.5. Results

4.5.1. Results of remote sensing classification

Estimating the total value of mangrove ecosystem services requires a classified map of different mangrove fractions. In this study, we utilized the mangrove cover classification results of Vo et al. (2013) as a basis input for calculating mangrove ecosystem services. The remote sensing data are reclassified into areas with three different percentages of mangrove cover to correspond to the socio-economic household analyses. Figure 4. 5 shows a map of six land-use types and mangrove cover fractions (aquaculture, "≤ 30% of mangrove"; mixed mangrove, "31-69% of mangrove"; and pure mangrove, "≥ 70% of mangrove"). The value of fishery-related products is estimated based on the three mangrove densities, whereas the value of erosion control and carbon sequestration is calculated based on the existence of mangrove forest.

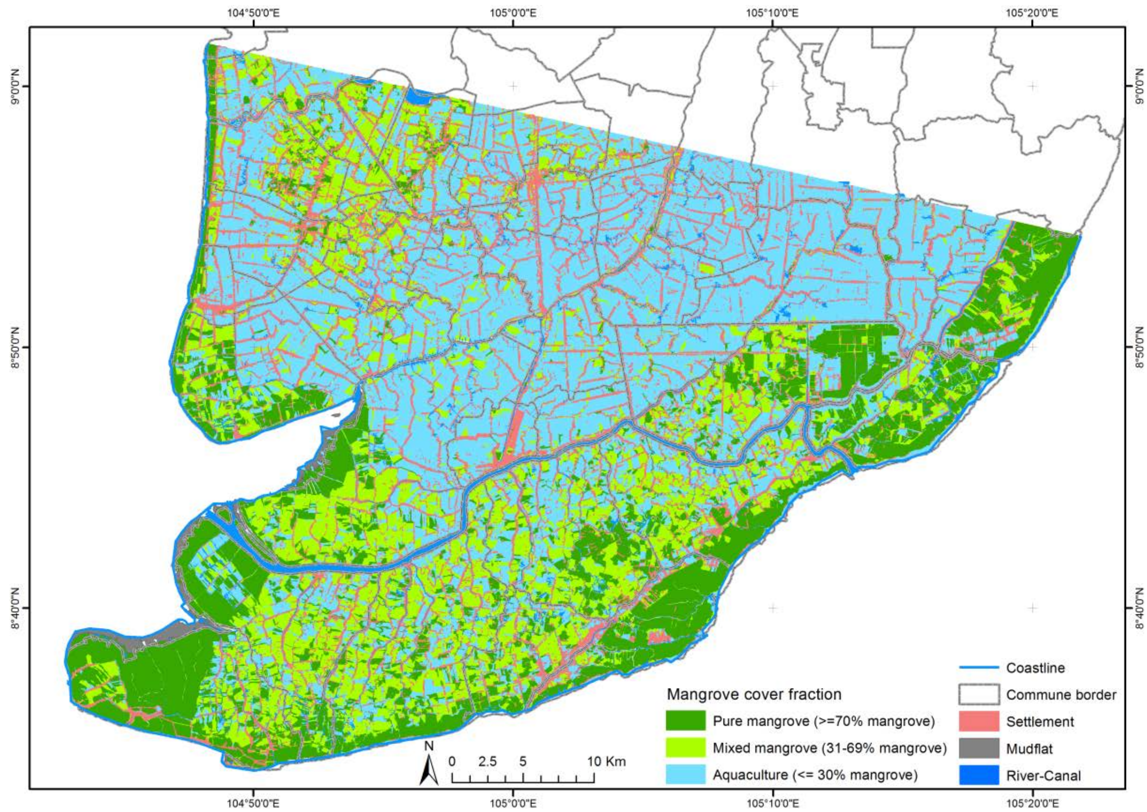

Figure 4. 5. Results of mangrove cover fractions from remote sensing

4.5.2. Results of household survey analysis

More than 90% of the interviewees were male, and the majority of respondents were within the age range of 31-50 years (55%), followed by those over 50 years old (37%). The main occupation in the area was shrimp farming (96%), which indicated that the farmers utilized their land to grow shrimp/fish/crab in an integrated mangrove-aquaculture farming system or caught natural fishery resources in tide-operated sluice gates. Although most of the interviewees had finished primary school (42%) or intermediate school (37%), nearly 4% of the households had not received school education because the area is very remote. With regard to experience in mangrove management, more than 50% stated that they had been involved in the shrimp-mangrove integrated system from 1 to 10 years, with approximately 40% of the interviewees having 11-20 years of experience (Table 4. 2).

Table 4. 2. General characteristics of the household survey

Variable		No. of Interviewees	Percentage
Age (year)	≤ 30	22	7.7
	31-50	157	55.1
	> 50	106	37.2
Sex	Male	264	92.6
	Female	21	7.4
Education Level	Primary school	121	42.6
	Intermediate school	107	37.7
	Secondary school	45	15.8
	College of university	0	0.0
	Illiterate	11	3.9
Experience in mangrove management (year)	1-10	130	50.6
	11-20	102	39.7
	21-30	23	8.9
	> 30	2	.8
Major occupation	Shrimp farmer	272	96.8
	Government officer	2	0.7
	Trader	2	0.7
	Hired laborer	1	0.4
	Unemployed	4	1.4

For the purpose of utilizing mangrove forest (multiple choices possible), the results from the household survey indicated that the mangrove forests were mainly used for fuel (firewood) and construction purposes (houses, fences, and furniture), with over 60% of households indicating these as primary uses. For the economic valuation, the utilization of these timber mangrove products could be calculated in monetary value if the farmers do not have mangrove forest on their lands. Approximately 30% of the households considered mangrove forest as a place for aqua-cultural activity (shrimp farming); this response contradicts their responses in the occupation portion of the survey (96% shrimp farming). Recreational purposes, that is, relaxing in the forest or tourism sites, have not yet been recognized as an important aspect of mangrove forests in this area (26%) (Figure 4. 6).

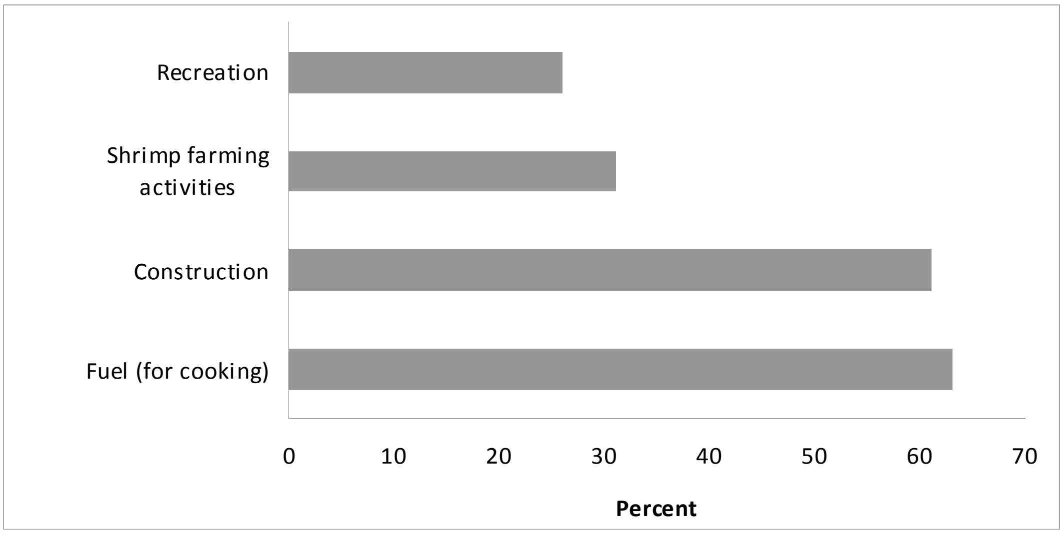

Figure 4. 6. Main utilization of the mangrove ecosystem in Ca Mau Province

The results of the household survey showed that more than 90% of the residents in Ca Mau Province utilized mangrove timber products for cooking and construction purposes (Figure 6). However, many of these individuals do not consider the mangrove forests to have economical value. Figure 4. 7 shows the results of combined questions between the economic value of mangrove forests and utilization of mangrove, indicating that even though more than 40% of the local people do not think mangrove forests have economic value, 88% used mangroves for cooking and 90% used mangroves for house construction. It is obvious that mangroves are the main source of timber for house construction and other buildings (small bridges and fences). Mangroves are also the major source of fuel, providing local communities with both firewood and charcoal for cooking. If mangrove forests did not exist on a farmer's land, he or she would have to buy these materials in the market (or use alternative fuels, such as gas or oil) to meet his or her daily needs. The economic value of these services can be estimated by asking the farmer how much money per year he or she would have to spend for those purposes (surrogate price method). The results showed that the average amount a household would have to spend is approximately US$ 300/year for firewood and approximately US$ 800 year for construction purposes.

Another way to estimate the economic value of mangrove timber is by asking the farmers how much one hectare of mangrove is worth if it is harvested; the resulting values ranged from US$ 2,300 to US$ 30,000 per hectare (with a mean value of US$ 5,700 and standard deviation of US$ 4,400). However, the profits from mangrove timber after a 20-year waiting period do not appear to be very attractive compared to the annual profit from a shrimp farming harvest. Furthermore, the farmers are unsure about the profits from mangroves, as the cost outlay is unclear to them, even though they may know the market price of mangrove wood. There is, therefore, a general distrust toward the forest management authority and profit sharing schemes, in particular. As a result, the farmers view mangroves more as a liability than a future income source (Johnston et al. 2000).

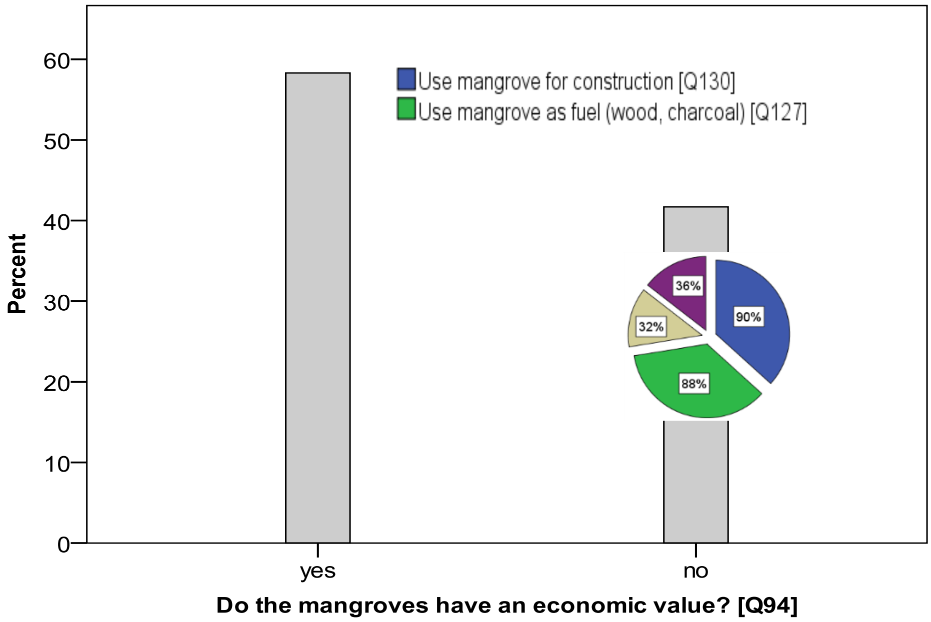

Figure 4. 7. Mangrove utilization and economic value

As stated above, the farmers in Ca Mau Province can use their land for aquacultural purposes. According to the mangrove allocation policy, however, aquaculture is not allowed to exceed 40% of the land area. The remote sensing data showed that more than a half of the region has mangrove cover less than 30% because the farmers tend to stretch the limits set by the local authorities. Indeed, the farmers engage in different shrimp farming practices depending on the percentage of mangrove cover on a farm. With the traditional method (≥70% of mangrove cover), shrimp farming in Ca Mau Province has been extensive and is based on the tidal recruitment and harvest of wild shrimp from local waterways, with little or no supplementary feeding, aeration, water pumping, or soil treatment. In contrast, industrial shrimp farming (≤ 30% of mangrove cover) requires a high investment for land preparation or shrimp seed. Therefore, the cost and benefit of the different shrimp farming methods were analyzed. The farmers were asked about their total income and investment to determine the net benefit per hectare per year.

Table 3 shows that the mean value of net benefit per hectare is highest at a mangrove cover of ≥ 70% (US$ 3,248, n=55), whereas the lowest is found at ≤ 30% (US$ 990, n=59) (Table 4. 3). The reason for this difference is that farmers tend to invest more money in aquaculture (land preparation, labor, and shrimp seeds). However, there also risks, such as outbreaks of diseases that affect shrimp, which could destroy most of the shrimp farms in Ca Mau Province (Johnston et al. 2000).

Table 4. 3. Total benefit from direct fishery products per hectare of aquaculture in US$

Mangrove percent cover	N	Mean	Std	Std. Error	Min	Max
≤ 30% mangrove cover	59	990.96	1392.11	181.23	-1184	6965
31-69% mangrove cover	162	1289.00	1299.11	102.06	-1435	10290
≥ 70% mangrove cover	55	3248.14	9539.85	1286.35	-239	72101

N, number of households; Std, standard deviation

An analysis of variance (ANOVA) was used to determine whether the mean values of the net benefit 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). The results showed significant differences among the different mangrove densities ($F(2, 273)= 4.814$, $p<0.05$) (Table 4. 4).

Table 4. 4. Result of ANOVA

	Sum of Squares	df	Mean Square	F	p-value
Between Groups	186,886,955	2	93443477	4.814	.009
Within Groups	5,298,593,763	273	19408768		

df, degrees of freedom; F, ratio of the mean square between groups and mean square within groups

Multiple comparison analyses (post-hoc test) were performed to further determine the significant differences among the mangrove covers. The results showed that the mean value of net benefit differed significantly among the groups, although the difference between ≤ 30% and 31-69% mangrove cover was not significant (sig>0.05). Thus, the net benefit of a group of households with a low mangrove cover (≤ 30%) on their land is not different from a group with an average mangrove cover (31-69%). The reason for this observation may be that the farmers invest the same amount of money for shrimp farming if they have < 70% mangrove cover on their land. Table 4. 5 provides a detailed comparison of the different mangrove densities.

Table 4. 5. Multiple comparisons between different mangrove densities

(I) Mangrove density	(J) Mangrove fraction in percentage	Mean Difference (I-J)	Std. Error	p-value
≤ 30% mangrove cover	31-69% mangrove cover	-298.042	669.903	.906
	≥ 70% mangrove cover	-2257.188*	825.741	**.025**
31-69% mangrove cover	≤ 30% mangrove cover	298.042	669.903	.906
	≥ 70% mangrove cover	-1959.146*	687.527	**.018**
≥ 70% mangrove cover	≤ 30% mangrove cover	2257.188*	825.741	**.025**
	31-69% mangrove cover	1959.146*	687.527	**.018**

* The mean difference is significant at the 0.05 level.

Bio/geophysical data from adjacent Provinces in the MD were used to conduct the valuation on the indirect-use value of the mangrove ecosystem. The environmental and climate conditions of these sites are similar, which allows the assumption that the functions of the mangrove ecosystem are similar. However, the value utilized in this study can only reflect the data available in the literature; therefore, our valuation results represent only a subset of the total economic value of the mangrove ecosystem in Ca Mau Province.

Concerning indirect use, many studies have shown that mangrove forests play an important role in stabilizing coastlines, functioning as natural barriers, dissipating the destructive energy of waves, and reducing the impact of hurricanes, cyclones, tsunamis, and storm surges (Brander et al. 2012; Hussain and Badola 2010; Rönnbäck et al. 2007). A multiple response analysis was used to investigate which services are important to the local communities. The results indicated that most of the interviewees agreed that mangroves provide barriers for storm protection (95%) and prevent coastal erosion (59%). Accordingly, we expected a negative relationship between the distance to the coast and erosion control service. A clear trend showed that the farmers who live close to the coastline (≤ 1 km) assign greater value to the erosion prevention function of mangroves in comparison to those located farther way (>4 km). Storm protection is important to the majority of the local communities (>80% agreement) and appeared to be independent of distance to the coastline (Figure 4. 8).

The most widely used approach for assessing the economic value of indirect-use value, such as coastal protection or erosion prevention, is the replacement cost approach, which derives the value of constructing man-made alternatives with the same protective function for the shoreline (Brander et al. 2012; Navrud et al. 2007). The present study applies the replacement cost method for the economic valuation of the protection functions of mangroves. In 2010, a pilot project was initiated to build a sea dike at one of the most eroded sites in Ca Mau Province (the same site of the current study); the total cost for constructing a 1-km dike (concrete embankment) along the coast was estimated at approximately US$ 470,000 (VNS 2010). Based on the household survey analysis, weighting factors are applied according to the agreement between the distance to the coastline and agreement on erosion control by mangrove forest (Table 4. 6).

Table 4. 6. Weighting factor and total economic value of erosion control

Distance to the coast	Weighting*	Length (km)	Value/km (US$)	Total value (US$)
≤ 1000 m	1	171	470,000	80,370,000
>1000 m-4000 m	0.5	171	470,000	40,185,000
>4000 m	0.2	171	470,000	16,074,000

*the weighting factor is assigned based on the results of the household survey analyses.

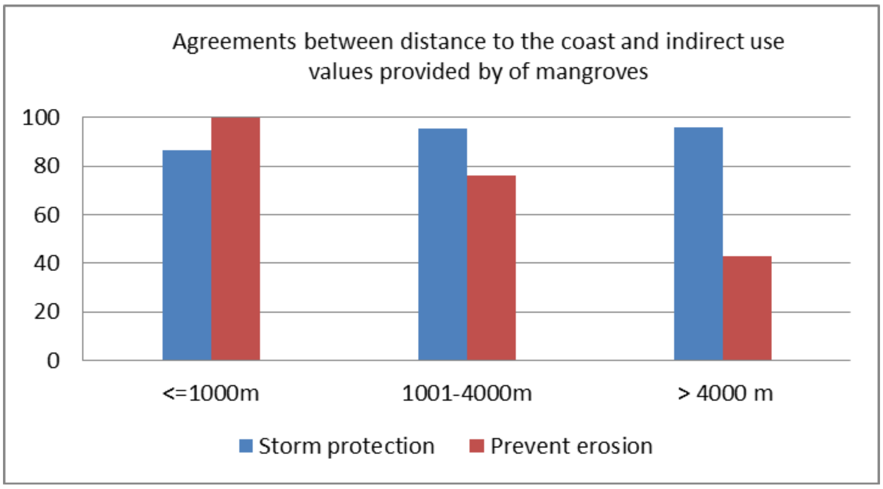

Figure 4. 8. Agreement between the distance to the coast and protection functions of mangroves

Three zones are generated according to the Department of Agriculture and Rural Development of Ca Mau Province (DARD). The first zone is called the “Full Protection

Zone" for coastal protection purposes along the coast; it covers a band approximately 1000 m wide along the coastline. The other zone is called the "Buffer Zone" for controlled economic activities and forest protection (60% forestry and 40% shrimp farming), ranging from 1000 m to approximately 4000 m from the coastline and the inland zone, where the land is mostly used for aquaculture (Figure 4. 9)

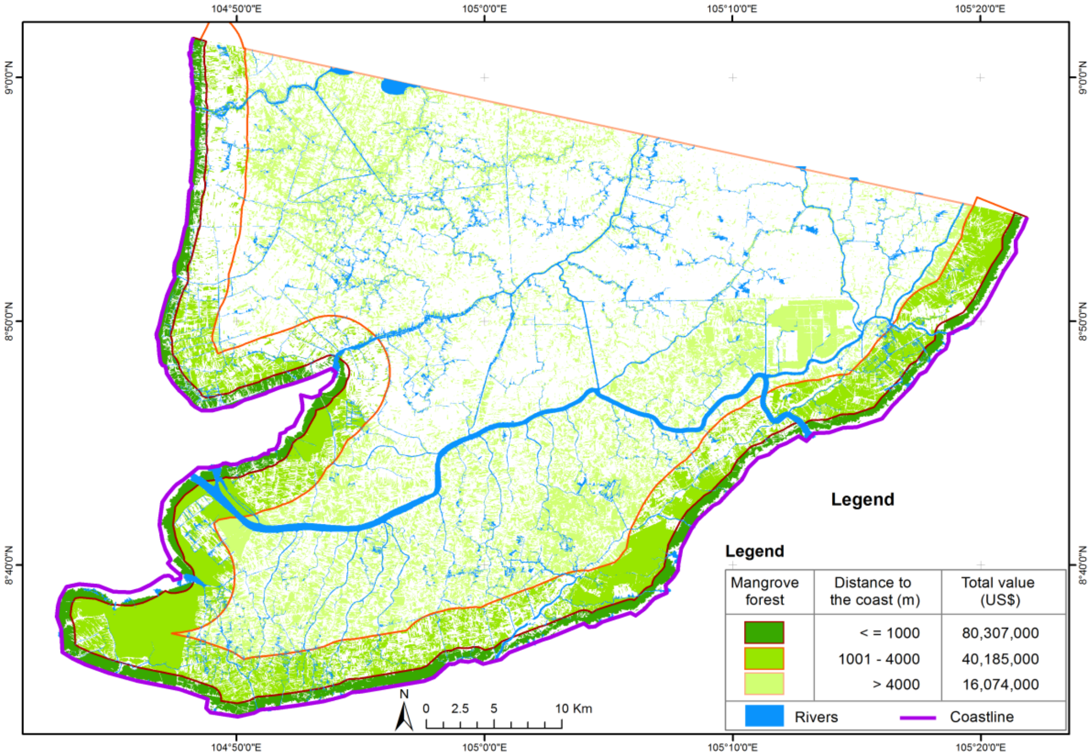

Figure 4. 9. Distance to the coast and value of erosion control of mangrove forests

Mangrove forests are known as a high-productivity ecosystem with the ability to absorb a significant amount of carbon (Fujimoto 2000; Tue et al. 2012). A recent study of the carbon sequestration rate of a *Rhizophora apiculata* forest plantation in Ca Mau Province was performed by Mcnally et al. (2011) and showed that the carbon sequestration rate depends on the age of the forest, with an average approximately 25.85 tons/ha. In the present study, the value of carbon sequestration is calculated as the product of the carbon sequestration rates in the site being valued and the global price of carbon taken from a source, such as the WB reports (US$ 24/ton in 2010). The value of carbon sequestration is calculated by the area of mangrove multiplied by the price of carbon (US$/ton).

4.5.3. Final value map of mangrove ecosystem services

A summary of the estimates of the total economic value of mangrove ecosystem services in Ca Mau is presented in Table 4. 7. The total economic value of four selected ecosystem services provided by mangrove forests in this area is estimated at approximately US$ 600 million for 2010, with approximately US$ 3,000/ha/year. The value of mangrove timber is estimated at US$ 400 million, comprising 68% of the total value of Ca Mau's ecosystem service. The value of erosion control contributed to the area, at more than US$ 136 million/year, accounts for 22% of the total value of Ca Mau's ecosystem service. Carbon sequestration was assigned a value of US$ 46 million/year, amounting to 7.3% of the total value of the ecosystem services in Ca Mau, and the value of fishery-related products is estimated at approximately US$ 17 million, contributing to 2.8% of the total value of the region.

Table 4. 7. Summary of the total economic value of mangrove ecosystem services in Ca Mau Province in 2010

Ecosystem service	Based on		Mean value (US$/ha/yr)	Value	**Sum**
Fisheries	Mangrove cover in ponds (%)	≤ 30%	991	5913,297	17,720,222
		31-69%	1,289	3,966,253	
		≥ 70%	3,248	7,840,672	
Erosion control	Distance to the coastline (m)	1,000	7,904	80,307,000	136,566,000
		3,000	1,651	40,185,000	
		4,000	450	16,074,000	
Carbon sequestration	Mangrove area (ha)	73,994	620	45,876,280	45,876,280
Timber	Mangrove area (ha)	73,994	5,700	421,770,246	421,770,246
				Total value of Ca Mau in 2010 (US$)	**621,932,748**
				Total area (ha)	**187,533**
				Mean value/US$/ha/year	**3,316**

Figure 4. 10 shows the spatial distribution of the total economic value of mangrove ecosystem services in Ca Mau Province. There is a considerable variability in the ecosystem

service values delivered by the different mangrove densities and distance to the coast. On a per hectare basis, the mangroves located close to the coast are estimated to provide the highest value (US$ 4,001-10,000/ha/year), followed by the less dense mangroves (US$ 2,001- 4,000/ha/year). The area with the lowest value is located inland, sites where mangrove coverage is low and that have a small value for erosion control and carbon sequestration (US$ <1,000/ha/year).

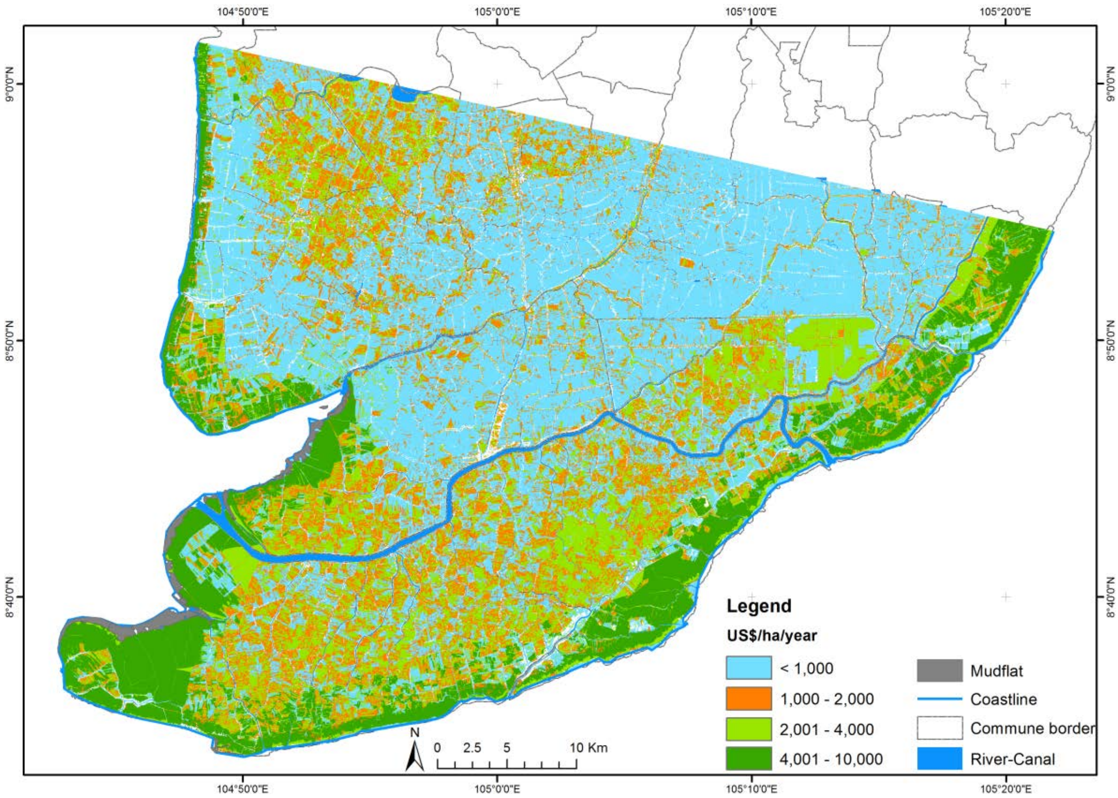

Figure 4. 10. Ecosystem service values in Ca Mau Province; an overview of direct-use values and indirect-use values

4.6. Discussion and conclusion

The total benefits provided by the mangrove ecosystem in Ca Mau Province are immense. Although cultural, biodiversity, tourism, and water filtration values were not considered, the total annual economic value provided by the mangrove forests in this area is worth millions of US dollars, indicating that the society benefits will be lost if the mangrove forests are destroyed or will remain if these forests are maintained.

Our initial estimates of the value of mangrove ecosystem services using a combined approach of remote sensing and household survey analyses have shown that these benefits are a significant contributor to the local communities in Ca Mau Province. A higher percentage of mangrove cover (equal to or greater than 70%) in an integrated mangrove-shrimp farming system represents by far the most valuable factor contributing to a famer's net benefits. Mangrove forests located near the coast are more valuable in terms of erosion control and storm protection compared to inland mangroves. Other services, such as biodiversity and tourism, are not considered in this study due to the absence of primary data. Utilizing remote sensing and spatial analyses allows us to determine the specific locations of the most valuable mangrove densities in addition to the value of the mangrove ecosystem services as a whole. Figure 10 illustrates that dense mangrove forests, mostly located in coastal areas, are very valuable. Such knowledge plays an important role in the decision-making process. The value, US$ 1.25 million, is comparable to the GDP of Ca Mau Province in 2010 (Goverment of Vietnam 2011). The total value of mangrove ecosystem services is estimated at US$ 600 million/year, significantly greater than the GDP of the Province.

However, to make this total value comparable to others, we compare our result with a recent result from a meta-analysis of mangroves in Southeast Asia by Brander et al. (2012). Using value estimates from 130 different studies and standardized to the value of 2007, the authors found that the mean value of mangrove was US$ 4,185/ha/year. This mean value consisted of many ecosystem services provided by mangroves, such as coastal protection, water quality, fisheries, and fuel wood. The mean value founded by Brander et al. (2012) is notably higher than our mean value (US$ 3,000/ha/year) because we selected only four ecosystem services that are highly relevant to the local communities in Ca Mau Province.

Future research directions on the valuation of mangrove ecosystem services should include more primary data from original research (mangrove species, mangrove ages, and populations), and other areas should be tested to determine whether this approach is transferable and consistent. Although this study used the most accurate data from remote sensing classification, the value of carbon sequestration may be different if the mangrove species and age of trees are taken into account. It will also be necessary to determine the condition of the trees and changes over time, which also affects to the total value of mangrove ecosystems.

The approach followed in this study represents a first attempt to estimate the economic value of mangrove ecosystem services using a combined approach of remote sensing and household survey data. Remote sensing data are used for the quantification of the mangrove cover in a highly structured environment, such as the integrated aquaculture-mangrove farming system of Ca Mau Province, using an object-based approach; the result of the household investigation is based on different mangrove covers to determine the direct-use value of mangrove. Spatial analysis is used to generate the final value map of mangrove ecosystems as a whole and is useful for assigning weighting factors of some of the indirect uses provided by the mangrove ecosystem. For example, we found that the value of erosion control is more valuable if the mangroves are located near the coastline and vice versa.

As noted in section 2, the results of the valuation of ecosystem services depend on the context-specific, socio-economic circumstances of the study area. The estimated value of mangrove ecosystem services is meaningful to raise awareness of the benefits provided by mangroves to local authorities in their decision-making processes. In addition, the results showed that the mean value of fishery-related products is much higher when the mangrove cover in ponds increases. This information could be used to increase the understanding of the local farmers to the mangrove ecosystem, many of whom (40%) believe that mangrove forests have no economic value at all.

The importance of mangrove ecosystem services to local communities has cultural and ecological dimensions in addition to economic aspects. Revealing the important of such aspects in monetary terms is an important way to raise awareness of mangrove ecosystems among local communities and policy makers. Information on the monetary valuation of mangrove ecosystems can be used as a communication tool to ensure better informed, more balanced decisions concerning trade-offs in land-use planning. Finally, our particular case study provides knowledge on the monetary value of different mangrove densities in an integrated mangrove-shrimp farming system in Ca Mau Province, contributing to the Ecosystem Service Value Database established in 2008 (Van der Ploeg et al. 2010).

Chapter V Conclusions

The aim of this research was to investigate a new approach combining remote sensing data and socio-economic analyses to quantify the economic value of mangrove ecosystems. Emphasis was placed on high spatial resolution imagery suitable for mapping and quantifying mangrove-shrimp integrated system like those found in Ca Mau Province, Mekong Delta, Vietnam. In summary, the important conclusions drawn from this study have been described as follows:

A review of previous studies in Chapter 2 found that there are a number of valuation methods for mangrove ecosystems. Provisioning services are regularly valued through direct market approaches, while regulating services are mostly valued using replacement cost or avoided cost approaches. The choices of the most appropriate valuation approach for a given service depends on the purpose of the valuation and the socio-economic and environmental circumstances. However, due to the differences of socio-economic context, mangrove ecosystem services valuations should be site-specific. Ecosystem functions and its services need to be standardized due to the interaction between them. The geographical and temporal specificity of any service valuation limits the extrapolation of current values to different landscapes.

The object-based classification approach using SPOT5 data in Chapter 3 found that the method was more accurate in estimating percentage of mangrove cover in a mangrove-shrimp integrated farming system compared to a pixel-based approach. The approach followed in this chapter represents a first effort to quantitatively calculate mangrove densities at the "pond level" without utilizing information on cadastral maps. The results are of great value to natural resource managers in terms of mangrove inventory mapping and guidelines related to mangrove fractions in the respective areas. However, the image segmentation is influenced by physically visible natural boundaries such as the shrimp pond dikes. Therefore the inclusion of additional information in the image segmentation process, such as cadastral maps, is essential for improving the accuracy of the classification.

A case study of estimating the economic values of mangrove ecosystems in Ca Mau Province using combined approach in Chapter 4 found that remote sensing was an important input data for the estimation of mangrove ecosystem values. The result of the household investigation based on different mangrove covers determined the direct-use values of mangrove forests. Spatial analysis is used to generate the final value map of mangrove ecosystems as a whole and is useful for assigning weighting factors of some of the indirect-use values provided by the mangrove ecosystem, such as carbon sequestration and erosion protection of coastal areas. The total estimated value was approximately US$ 600 million in 2010 (average value US$ 3,000/ha/year) which is significantly greater than the GDP of the province. The results of this monetary valuation are important in the policy debate regarding exploitation versus sustainable use of mangrove. Expressing the value of mangrove ecosystem services in monetary units provides additional information for helping decision makers by giving approximations of the values of mangrove ecosystems involved in the trade-off analysis. On the other hand, the economic value of mangrove forests could be used to raise awareness of local communities on the important of mangrove ecosystems. As shown in the analysis of economic values of mangroves in chapter 4, even though more than 40% of the farmers do not consider mangrove forests to have economic value, 88% used mangroves for cooking and 90% used mangroves for house construction. It is obvious that mangroves are the main source of timber for house construction and other buildings. Mangroves are also the major source of fuel, providing local communities with both firewood and charcoal for cooking. If mangrove forests did not exist on a farmer's land, he or she would have to buy these materials in the market (or use alternative fuels, such as gas or oil) to meet his or her daily needs. Therefore, environmental education should be undertaken in order to increase an awareness of local people on the economic values of mangrove, even though they get it for free.

Based on the findings of this research, the following research areas for the economic valuation of mangrove ecosystems should be addressed: **1)** Given the limitations of segmentation without utilizing auxiliary information on ownership boundaries, the object-based approach should be enhanced by using additional information on cadastral maps. In addition, radar or hyper-spectral data should be incorporated in order to discriminate mangrove species-structure, which contributes to the total value of mangrove ecosystem. A research on combination of SPOT5 optical data and TerraSAR-X should be investigated for quantifying percentages of mangrove in the Mekong Delta. In addition, with this proposed approach, it is possible to monitor compliance with environmental laws and regulations. For example, in this area, aquaculture is not allowed to exceed 40% of the area in the farmer's land. However, farmers tend to stretch the limits by expanding aquaculture area and the compliance of the forest manager’s tasks is not examined. Recently, organic shrimp farming has been applied in this region to solve the contradiction between economic and ecological interests. In order to get organic certification from an organic production company (farmers can sell shrimp with highest prices, and have sustainable incomes), the shrimp farmers have to fulfill certain conditions. At least half of the area used for aquaculture has to be covered by mangrove forests. Independent organizations could monitor whether the regulations are being adhered to by using this proposed approach.

2) More primary research on culture, biodiversity, and water filtration of mangroves should be carried out in order to fully understand the total value of mangrove ecosystem. Although this study used the most accurate data from remote sensing classification, the value of carbon sequestration may be different if the mangrove species and age of trees are taken into account. It will also be necessary to determine the condition of the trees and changes over time, which also affects to the total value of mangrove ecosystems. **3)** This approach should be tested in other areas in the Mekong Delta to determine whether this approach is transferable and consistent.

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Erklärung

Hiermit erkläre ich, dass ich die vorliegende Dissertation, abgesehen von der Beratung durch meine akademischen Lehrer, selbstständig verfasst habe unter keine weiteren Quellen und Hilfsmittel als die hier angegebenen verwendet habe. Diese Arbeit hat weder ganz, noch in Teilen, bereits an anderer Stelle einer Prüfungskommission zur Erlangung des Doktorgrades vorgelegen. Ich erkläre, dass die vorliegende Arbeit gemäß der Grundsätze zur Sicherung gutter wissenschaftlicher Praxis der Deutschen Forschungsgemeinschaft erstellt wurde.

Kiel, 24th May, 2013

Vo Quoc Tuan

Curriculum Vitae

Name: VO, Quoc Tuan
Date of birth: 28.February.1978
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Address: Can Tho University
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Professional Work experience

08/2009 – Present	**German Remote Sensing Data Center, DLR, Germany,** PhD researcher. Research in the field of economic evaluation of mangrove ecosystem services using combined approaches of remote sensing data and socio-economic data. Getting involved in the development of remote sensing products within WISDOM project-(work package 6000); data processing for mangrove mapping; development of mangrove classification schemes for mangrove forest classification.
03/2008 - 07/2008	**Can Tho University, Vietnam,** College of Agriculture and Applied Biology, Department of Soil Science and Land Management, Researcher in the field of remote sensing and cadastral mapping; Supervision of undergraduate students in the field of remote sensing applications, GIS, land management, environment assessment and cadastral mapping.
02/2006 – 02/2008	**Seoul National University, South Korea,** Department of Agricultural Economics and Rural Development, Regional Information Major; Master of Art in Economics; participation in Remote Sensing of Environment, Geographic Information Systems, Data Mining, Management Information System with high grades.
10/2001 – 02/2006	**Can Tho University, Vietnam,** College of Agriculture and Applied Biology, Department of Soil Science and Land Management, Researcher and Teaching assistance in the field of GIS and

	Remote Sensing. Supervision of undergraduate students in the field of remote sensing applications, GIS, land management, environment assessment and cadastral mapping.
09/1997 – 09/2001	**Can Tho University, Vietnam,** College of Agriculture and Applied Biology, Department of Soil Science and Land Management, Bachelor of Land Management (with good ranking).

Computer Skills

Good skills	Good skills in Remote Sensing Software Tools: Erdas Imagine, eCognition, ENVI+ GIS application in spatial analysis (ArcGIS). SPSS. Mapinfo
Familiar with	Data mining, R.

Languages

English:	Good at speaking and writing, daily communication in English, used to present and negotiate.
Vietnamese:	Mother tongue

Training

2012	ESA Earth Observation Summer School on Earth System Monitoring and Modelling (in English, ESA, Rome, Italy)
2011	Integrated Assessment of Ecosystem Services: From Theory to Practice (in English, in Amsterdam and Wagenigen, the Netherland)
	Radar Remote Sensing (in English, U.S. Geological Survey, Can Tho University, Vietnam)
2010	Advanced Remote Sensing for Mapping, Monitoring & Management the Environment. (in English, ISPRS, Vietnam)
2009	Soil and Water Assessment Tool – SWAT (in English, Nong Lam University, Vietnam)
2004	Geographic Information System (in English, AIT, Vietnam)

	Remote Sensing (in English, AIT, Vietnam)
	GIS Application in Land Resource and Land Use Studies (in English, Can Tho University)
2001	Computer-Based Analysis of Agricultural Polices (in English, University of Economics, HCMC)

Publications

2013	**Vo QT**, C. Kuenzer, N. Oppelt, **2013**. How remote sensing supports mangrove ecosystem services valuation – case study Ca Mau province, Vietnam. Ecosystem Services (Submitted)
	C. Kuenzer and **Vo QT**. **2013.** What are Can Gio's Mangroves worth? Assessing Ecosystem Service Values of Can Gio Mangrove Biosphere Reserve: combining Earth Observation and Household Survey based Analyses. *Applied Geography* (in review).
	Vo QT., Oppelt, N., and C. Kuenzer, **2013**: Remote Sensing in Mapping Mangrove Ecosystems - An Object-based Approach *Remote Sensing* 5(1), 183-201
2012	**Vo QT**, C Kuenzer, QM Vo, F Moder, N Oppelt, **2012**: Review of valuation methods for mangrove ecosystem services. *Ecological Indicators* 23, 431-446
	Kuenzer, C., Campbell, I., Roch, M., Leinenkugel, P., **Vo, QT.**, and S. Dech, **2012**: Understanding the Impacts of Hydropower Development in the context of Upstream-Downstream Relations in the Mekong River Basin. Accepted for publication in *Sustainability Science*
	J Huth, C Kuenzer, T Wehrmann, S Gebhardt, **Vo QT**, S Dech, **2012**: Land cover and land use classification with TWOPAC: towards automated processing for pixel-and object-based image classification. *Remote Sensing* 4 (9), 2530-2553
2011	Claudia Kuenzer, Andrea Bluemel, Steffen Gebhardt, **Vo QT** and S. Dech, **2011**: Remote Sensing of Mangrove Ecosystems- A review. *Remote Sensing* 3 (5), 878-928

2008	Yoo, Chul Woo; Kim, Misuk; Choe, Young Chan; and **Vo QT 2008 :** Factors Motivating Software Piracy in Vietnam. AMCIS proceedings.
	Vo, QT., Vo Quang Minh. **2008**. A methodology framework for soil peat volume simulation overtime at Vo Doi-Camau. *Soil Science*
2003	**Vo, QT.**, Vo Quang Minh, **2003**. Application of Geo-statistics and GIS in spatial distribution monitoring of soil pH and Organic in Cai Lay District, Tien giang province. *Scientific Journal of Cantho University.*

Conference Contributions

2013	**Vo, QT.**, N. Oppelt., C, Kuenzer 2013. Quantifying Mangrove Ecosystem Services based on Remote Sensing and Household Surveys. Proceedings of the 35th International Symposium on Remote Sensing of Environment, 22-26 April, 2013, Beijing, China
2012	**Vo, QT**., Kuenzer, C., Vo, QM., and N. Oppelt, 2012: Mangrove Ecosystem Services in the Mekong Delta: Combining Socio-Economic Household Surveying with Remote Sensing based Analyses. Proceedings of the 32dn International Geographical Congress, 26-30 August, Cologne, Germany
2011	**Vo, QT**. and C. Kuenzer, 2011: Assessment of Mangrove Ecosystem Services in the Mekong delta, Vietnam, based on Remote Sensing and Household Surveying. Proceedings of the 32nd Asian Remote Sensing Conference, ARSC, 03-07 October, Taipei, Taiwan
2010	**Vo, QT**., Gebhardt, S., Vo, QM., Huth, J., and C. Kuenzer, 2010: How remote sensing supports economic evaluation of mangrove ecosystems, Proceedings of the 31st Asian Remote Sensing Conference, 01-05 November, Hanoi, Vietnam