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REMOTE SENSING ANALYSIS OF MANGROVE CHANGES AND EVALUATION OF ECOSYSTEM SERVICES VALUE IN SUNGAI MERBOK FOREST RESERVE, MALAYSIA

ZAILANI KHUZAIMAH

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By

ZAILANI KHUZAIMAH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

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Chairman : Professor Shattri Mansor, Ph.D
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In Malaysia and other developing countries, there is often little access to the forest area, resulting in inadequate and limited forest information. Hence, application of remote sensing technology in forestry is very valuable and has become an important element due to its capability to collect data from large areas of land and generate relevant information. In other words, remote sensing technology offers a reliable method of gathering information which is essential for forest inventory and management. Mangrove forests possess important ecosystem and socioeconomic values to human beings. Mangrove trees have the following uses: timber for construction; firewood for burning; raw material for production of charcoal; wood for fishing poles; production of pulp; and tannins for leather tanning. Around the world, mangrove forests 80, 000 and 200,000 km^2. Meanwhile, the total area of mangrove forests in Malaysia is 0.58 million ha. Despite their positive contributions, mangroves are the one of the highest degraded land of any global habitat. In fact, the socioeconomic values and ecosystem services of mangroves as natural resources are underestimated. There are no studies on the ecosystem valuations, particularly mangroves forest in Malaysia. Most of the decision making only rely on physical assessment without taking into account the loss of the ecosystem value. Therefore the main objective of this study is to develop a model to assess the impact of mangrove bio-disturbance on the literal ecosystem of mangroves using geospatial technology. In addition, variations responses in mangrove ecosystem changes during the occurrences of economic activities were investigated. SPOT 5 imageries of the year 2000 and 2010 has been used for change detection analysis. The supervised classification technique was employed in image processing for land use change detection. In order to obtain the values of socioeconomic impacts resulting from the mangrove changes, the ecosystem service valuation (ESV) model was applied. The average of land use change in every 10 years period is 12%, consist by aquaculture, forest, water body and wet land/barren land with the total area extent of 406 ha. The decrease in the economic value of mangroves was largely influenced by the decrease of 2.9% in land use change from the years 2000 to 2010 with a loss of about RM1.7 million or 3%. The total ecosystem service values in study area were reduced by 2.8% between 2000 and 2020. The massive declined in ecosystem services was largely attributable to the 17.8% loss of forest area and 19.2% loss of water body. The overall number of changes to the whole ecosystem functions at a rate of 38 % with an average of RM200,000 valuation changes dominated by deforestation and land reclamation for settlement and aquaculture. In total the main ecosystem functions of land use in the study area were loss about RM500,000 for a period of 20 years. The losses take place at spatial scales has play a crucial role in maintaining ecological balance to the coastal environment. The results showed that the total value of the existing mangrove forest ecosystem service is RM1,901,859.84. The value per unit area is about RM1,650.92 per ha. The total values of aquaculture and water bodies are RM161,33.2 and RM3,107,500 respectively. Study concluded that Sungai Merbok's Mangrove forest reserve is very important not just for coastal ecology but serves as ecosystem services, where the orientation of mangrove ecosystem is huge enough to provide essential services for the local community. Results from this study can be goes hand in hand with strategies in the context of conservation biology and sustainable forest management at the landscape levels.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

ANALISIS PENDERIAAN JARAK JAUH PERUBAHAN HUTAN PAYA BAKAU DAN PENILAIAN PERKHIDMATAN EKOSISTEM, DI HUTAN SIMPAN SUNGAI MERBOK, MALAYSIA

Oleh

ZAILANI KHUZAIMAH

Mei 2015

Pengerusi	**:**	**Profesor Shattri Mansor, Ph.D**
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Di Malaysia dan negara-negara membangun yang lain, akses yang terhad ke kawasan hutan, menyebabkan maklumat hutan yang terhad dan tidak mencukupi. Oleh itu, penggunaan teknologi remote sensing dalam bidang perhutanan adalah sangat di perlukan dan telah menjadi elemen penting kerana keupayaan untuk mengumpul data dari kawasan yang luas dan keupayaan menjana maklumat yang berkaitan. Dalam erti kata lain, teknologi remote sensing menawarkan kaedah yang berkesan dalam mengumpul maklumat yang penting untuk inventori dan pengurusan hutan. Hutan bakau mempunyai ekosistem penting dan nilai-nilai sosio-ekonomi kepada manusia. Pokok bakau menyumbang kepada penggunaan yang berikut: kayu untuk pembinaan; kayu api untuk pembakaran; bahan mentah untuk pengeluaran arang; kayu untuk tiang menangkap ikan; pengeluaran pulpa; dan tanin untuk kulit penyamakan. Di seluruh dunia, hutan bakau 80, 000 dan 200,000 km persegi. Sementara itu, jumlah kawasan hutan bakau di Malaysia adalah 0.58 juta ha. Walaupun memberikan sumbangan yang besar, hutan bakau merupakan salah satu kawasan terokaan tertinggi mana-mana habitat global. Malah, nilai-nilai sosio-ekonomi dan perkhidmatan ekosistem hutan bakau sebagai sumber asli yang dipandang ringan. Setakat ini belum ada kajian mengenai penilaian ekosistem hutan bakau di Malaysia. Kebanyakan membuat keputusan yang hanya bergantung kepada penilaian fizikal tanpa mengambil kira kerugian daripada nilai ekosistem. Oleh yang demikian, objektif utama kajian ini adalah untuk mengaplikasikan dan mengembangkan model untuk menilai kesan ganguan biologi bakau pada ekosistem literal bakau menggunakan teknologi geospatial. Di samping itu, perubahan kepada ekosistem paya bakau dan guna tanah kawasan kajian telah di analisis. SPOT 5 imej-imej bagi tahun 2000 dan 2010 telah digunakan untuk analisis pengesanan perubahan. Teknik pengelasan diselia telah digunakan dalam pemprosesan imej untuk mengesan perubahan penggunaan tanah. Dalam usaha untuk mendapatkan nilai-nilai impak sosioekonomi yang terhasil daripada perubahan bakau, model penilaian perkhidmatan ekosistem telah digunakan(ESV). Purata

perubahan penggunaan tanah dalam setiap tempoh 10 tahun adalah 12%, terdiri oleh aquakultur, hutan, air dan tanah lembap/tanah tandus dengan keluasan lebih kurang 406 ha. Penurunan nilai ekonomi bakau sebahagian besarnya dipengaruhi oleh penurunan sebanyak 2.9% pada perubahan penggunaan tanah dari tahun 2000 hingga 2010 dengan kerugian sebanyak kira-kira RM1.7 juta atau 3%. Jumlah nilai perkhidmatan ekosistem di kawasan kajian telah dikurangkan sebanyak 2.8% antara tahun 2000 dan 2020. Faktor utama kemerosotan dalam perkhidmatan ekosistem adalah sebahagian besarnya disebabkan oleh kerugian 17.8% daripada kawasan hutan dan kerugian 19.2% daripada badan air. Jumlah keseluruhan perubahan kepada fungsi ekosistem keseluruhan pada kadar 38% dengan purata RM200,000 perubahan penilaian dikuasai oleh penebangan hutan dan penambakan tanah untuk penempatan dan akuakultur. Secara keseluruhan fungsi ekosistem utama penggunaan tanah di kawasan kajian ialah kerugian kira-kira RM500,000 untuk tempoh 20 tahun. Kerugian berlaku telah memainkan peranan penting dalam mengekalkan keseimbangan ekologi alam sekitar pantai. Hasil kajian menunjukkan bahawa jumlah nilai perkhidmatan ekosistem hutan bakau yang sedia ada adalah RM1,901,859.84. Nilai per unit kawasan adalah lebih kurang RM1,650.92 per ha. Jumlah nilai kawasan akuakultur dan badan-badan air masing-masing RM161,33.2 dan RM3,107,500. Kajian membuat kesimpulan bahawa hutan simpan bakau Sungai Merbok adalah sangat penting bukan sahaja untuk ekologi pantai tetapi berfungsi sebagai perkhidmatan ekosistem, di mana orientasi ekosistem bakau cukup besar untuk menyediakan perkhidmatan penting bagi masyarakat tempatan. Hasil daripada kajian ini boleh menjadi seiring dengan strategi dalam konteks biologi pemuliharaan dan pengurusan hutan mampan di peringkat landskap.

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Approval Sheet

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LIST OF ABBREVIATIONS

AVI	Advance Vegetation Index
DEM	Digital Elevation Model
DSS	Decision Support System
ESV	Ecosystem Service Value
GIS	Geographic Information System
GPS	Global Positioning System
JUPEM	Malaysia Survey Department)
LandSat	Land Satellite
NDVI	Normalizes Different Vegetation Index
NIR	Near-InfraRed
PFE	Permanent Forest Estate
RS	Remote Sensing
SPOT	Syst’eme Probatoire d’Observation de la Terre

CHAPTER I

INTRODUCTION

1.1. General

Forests are crucial in sustaining the existence of human beings on this Earth. For example, they provide timber supply, store water, prevent landslides or debris flows, provide shelter from extreme winds and purify the air. In recent times, people have come to appreciate forests not only as a source of timber, but also as a place where Mother Nature can be enjoyed.

Malaysian tropical rainforest is among the most complicated ecosystems that exist on Earth. Its special natural heritage, which has developed over the past millions of years, is filled with vast numbers of different plant and animal species. The remarkably rich flora found in Malaysia is estimated to include at least 8,000 species of flowering plants, of which 2,500 are tree species. Therefore, there are many different rainforest formations, depending on factors such as edaphic conditions, drainage, and altitude. At an elevation of about 750 m, there are species-rich lowland and hill-dipterocarp-dominated forests in dryland areas while in wetland areas, mangrove as well as peat-swamp thrive. The upper montane rainforest can grow in areas with elevations of between 750 m and 1,500 m. The upper-hill dipterocarps are replaced by oak and laurel-dominated forest at heights above about 12,000 m.

The total land area of Peninsular Malaysia is about 13.2 mil ha; based on this figure, 5.97 mil ha or 45.3% is forested. This forested area consists of 5.67 mil ha of diptrocarp forest, and the remaining 0.2 mil ha is mangrove forest (Anon, 1992). Of the forested area, 5.25 mil ha has been reserved as Permanent Forest Estate (PFE); meanwhile, the remaining area is in the State Land Forest. Although forest stand growth models have become increasingly important for updating inventory information and projecting future forest conditions, such updating is limited because of cropland abandonment, harvesting, and urban development. The changes are extremely difficult to model; this is the major reason why satellite remote sensing data need to be fully utilised. Since the mean characteristics of forest strata change are relatively few, the major inventory problem is to estimate the amount and location of such strata.

In general, mangroves are trees and shrubs that live in saline (brackish) coastal habitats located in the tropics and subtropics. The word mangroves has three common interpretations: (1) it is commonly used to indicate the habitat and entire plant assemblage or mangal (Hogarth and Peter J., 1999), where the terms mangrove swamp and mangrove forest are seen as well; (2) it can mean all trees and large shrubs in the mangal; and (3) it sometimes points to the mangrove family of plants, the Rhizophoraceae, or at a really specific level, it is restricted to mangrove trees of the genus Rhizophora. Mangals are located in depositional coastal surroundings; the conditions are suitable for fine sediments, which usually have high organic content, to accumulate in areas away from high-energy wave action.

Mangrove can be considered a complex and unique ecosystem. It is a forest area located between land and sea. It is affected by tidal water tides twice daily depending on location and elevation. Thus, mangrove tree species are normally found between the highest and lowest tidal range. Mangrove tree species are able to adapt and live in physical environments such as those containing deep muddy alluvial soil, sandy and rocky substrates or even rugged coastal relief. Some mangrove tree species have developed numerous stilt roots to support the entire tree crown and anchorage in deep muddy soil. Meanwhile, other species develop knee-roots or flattened buttresses in order to adapt to a harsh mangrove environment. Due to its fragile and unique ecosystem, it is worthwhile to manage mangrove forests to reap their economic and aesthetic value.

Mangrove forests are estimated to cover a total area between 180,000 and 200,000 km^2 globally (Spalding et al., 1997). The total area of mangrove forest in Malaysia is 0.58 million ha; 0.10 million ha is located in Peninsular Malaysia, 0.34 million ha in Sabah and 0.14 million ha in Sarawak.

Even though conventional ground surveys are more reliable and accurate in estimating forest inventory and for mapping purpose, they are not cost-effective and efficient. This method cannot be used for updating the desired information at any short period of time. It is unable to provide timely information pertaining to the study of growth and depletion of forest resources and damage areas, which require constant monitoring. Hence, it becomes necessary to use a more advanced and sophisticated technique of remote sensing for data collection and monitoring of changes (Tomar, 1976).

New methods of mapping vegetation must be considered to meet the demand for timely and accurate information about ecosystems. These methods must consider the entire landscape, including adjacent land under separate ownership, land designated as wilderness, and other land that is often excluded from inventories and analyses. Remote sensing and GIS provide new tools that promote advanced ecosystem management. Satellite imagery is only one of the many remote sensing tools available to resource managers; nevertheless, it offers the most comprehensive perspectives among all the other tools. It allows users to view and manipulate various functions over large areas of land, such as an entire forest or region.

Remote sensing is a very handy tool to be used in forestry applications. It allows detection of forest conditions that are not visible to the human eye; this function is possible through the spectral resolution of the sensors, and the repetitive coverage and digital nature of data. There are several methods that can be used to differentiate and map forest units. When a big study area is involved, data processing can be automated; thematic mapping employs visual interpretation of images, where forestry specialists can apply their extensive experience.

The Eastern Hemisphere has mangrove biodiversity that is nearly five times higher (958 species compared with 12) than the Western Hemisphere (Tomlinson, 1986; Duke, 1992). The indo-Malesia region possesses the largest number of species, with 48 different species (Duke et al., 1998). Unfortunately, over the past half a century, huge areas of mangrove have been lost. In the case of Malaysia, the country experienced a 12% decrease in its mangrove forests from 1980 to 1990 (Chan et al., 1993); this loss was attributed to change in land use for agriculture or coastal industrialisation and development. There are also other reasons such as clearance for shrimp ponds, over-cropping for timber, alteration of water flow pattern and pollution (Ong, 1982; Farnsworth and Ellison, 1997).

1.2. Remote Sensing and Geographic Information System (GIS)

Satellite remote sensing is a widely accepted method to map bio-indicators, which among others include:

- **bio-disturbance,** indicating the degree of fragmentation due to shifting cultivation and unauthorised logging.
- **species diversity,** indicating the ecosystem integrity, habitat loss due to land use changes and forest fire occurrences.
- **terrain complexity**, whose diversity is governed by steepness, elevation and accessibility.

Satellite remote sensed data and GIS for land cover, land use and its changes are crucial to applications in several different fields, including Environment, Forestry, Hydrology, Agriculture and Geology. Precise data on the land cover in a region play a crucial role in Natural Resource Management, Planning and Monitoring programmes. Techniques for keeping track of vegetation change include intensive field sampling with plot inventories to highly detailed analysis of remotely sensed data; these methods have been found to be more cost-effective for big regions, small site assessment and analysis.

The bulk of satellite remote sensing data at different spatial, spectral, and temporal resolutions come from Satellite Imaging; it employs the suitable combination of bands to highlight the key geographical and manmade characteristics in a project for detecting changes. In fact, it is predicted that Satellite Image data will be a major contributor to a large range of global change-related application areas for vegetation and ecosystem dynamics, hazard monitoring, geology and soil analysis, land surface climatology, hydrology, land cover change, and the production of orthorectified digital elevation models (DEMs).

Satellite Imagery Analysis has the following features:

- Quick and precise overview
- Quantitative green vegetation evaluation
- Underlying soil characteristics

Satellite remote sensing is an emerging technology that can be a significant contributor to research on land cover and change detection in the future; this technology enables globally detailed assessments of several environmental and human actions to be conducted. This information will have implications for the management and policy decision-making. Satellite image data allow direct observation of the land surface at repetitive intervals. As a result, mapping of the extent of impact, monitoring and assessment are possible. In forestry characterisation to determine disturbance, GIS and remote sensing have been found to help in landscape ecology by mapping disturbance zones in ecosystem, quantifying its effect on the biodiversity and identifying land cover changes over a period of time.

1.3. Problem Statement

Mangrove forests have crucial ecosystem and socioeconomic values to human beings (Bennett and Reynolds, 1993). Mangrove trees are a source of timber for construction, firewood, charcoal, fishing poles, pulp and tanning (Hamilton and Snedaker, 1984). The mangrove forests also possess species of trees that have medicinal value (Bandaranayake, 1998). Mangrove leaves, which produce detritus, support the marine food web; it is a vital food source for shrimp and fish (Leh and Sasekumar, 1984), mollusks, crab, birds and several other animals (Macintos, 1984); the survival of these marine species in turn support the coastal fisheries (Chong et al., 1990). Mangroves provide protection and suitable habitats for breeding and serve as nursery areas for many shrimps, crabs and marine fish (Sasekumar et al., 1992; Barbier et al., 1994). In addition, mangroves play a crucial role in regulatory functions. They decrease coastal erosion and flooding, protect against salinity change and intrusion, supply and regenerate nutrients and prevent run-off (Lugo and Snedaker, 1974). The diverse flora and fauna associated with mangrove ecosystems offer opportunities for nature education, tourism and scientific research, which enhance mangrove’s social and economic values.

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. 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 (Vo et.al. 2012)

The lack of understanding of, and information on, the values of mangrove ecosystem services has generally led to their omission in public decision making. Without information on the economic value of mangrove ecosystem services that can be compared directly against the economic value of alternative public investments, the importance of mangroves as natural capital tends to be ignored.

Ecosystem services are the profits people derive from ecosystem functions as some intrinsic characteristics of the structure and processes of an ecosystem to satisfy their needs. When mangroves are accounted as part of human welfare their ecosystem services value (ESV) are actually considered as the specific price of ecosystem services. Therefore, owing to the rising concern on ecosystem degradation and the increasing need for decision- making to conserve and restore the ecosystems, comprehensive evaluations on ESV is vital to be carried out in this country.

Until this time, there are no studies or research on the ecosystem valuations, particularly mangroves forest in Malaysia , this is the first study involving the evaluation of any ecosystem in the development and exploration mangrove forests . Most of the decision makers only make physical assessment without taking into account the loss of the ecosystem value is more important in addressing climate change and ecosystem cycles safer in the future.

The value of mangrove forests in the whole world is estimated to be US$181 billion (Costanza et al., 1997). Although mangroves are of such high value, they are among the global habitats with the highest rate of depletion, with a loss of more than 1% of mangrove areas each year (Valiela et al., 2001). The major contributors to this loss of mangroves include over-exploitation, clear-cutting and pollution (Farnsworth and Allison, 1997;Alongi, 2002). In addition, wrong estimates of the ecological condition of mangroves may be harmful and reduce the functionality of mangrove forests gradually (Dahdouh-Gubas et al., 2005). In view of these issues, it is realistic to say that mangroves may completely disappear from this world if not measures are taken to conserve them (Duke et al., 2007). Therefore, rehabilitation efforts and sustainable utilisation of mangrove resources have become a global conservation priority. Since 1990, several studies have been done to estimate the values of different ecosystem services. For example, assessment of the economic value of tropical forests, evaluation of techniques for estimating the economic value of different biological resources, provision of economic incentive for biodiversity conservation, economic valuation of protected areas (Cacha, 1994) and estimation of the economic value of endangered species (Hyde and Kanel, 1994).

The land-use changes in mangrove areas have major effects on the biodiversity and ecosystem processes; however, it is a difficult task to assess the land-use impacts on such ecosystem. Coordinated conservation assessments at international, national, regional and local levels are needed for establishing an effective reserve network to prevent further depletion of biodiversity. In addition, these assessments depend very much on advanced mapping technologies and computing systems for spatial data analysis and display.

The present hardware and software for such mapping and spatial analysis are a huge setback for progress in conservation assessment and planning. The key problems are as follows: 1) Insufficient computing resources are available for biogeographers and conservation biologists to analyse the large amounts of data involved in conservation assessments; 2) bad design of data management systems for general use in manipulation of heterogeneous biogeographic data; and 3) absence of coupling among database management systems and analytical software employed in biodiversity analyses.

The losses occur at several levels (landscape, ecosystem, species, and genes), spatial scales (local to regional), and dimensions (biophysical drivers, proximal causes and social/human drives). Remote sensing and GIS serve as tools for the following purposes: to assess biodiversity, land cover change and classification index of the mangrove-landscape; to identify the relationship between the degree of disturbance and the nature of fragmentation processes in the study area; and to develop the methodology that allows integration of land cover change processes and environmental changes into decision-making. All these are done alongside the strategies specifically for conservation biology and sustainable forest management at the landscape/within community level.

In Malaysia and other developing countries, there is often limited access to the forest area, resulting in inadequate forest information. As far as forestry is concerned, remote sensing in forestry is a highly prized tool; this is because it is able to collect data for wide areas and convert it into meaningful information quickly and at a reasonable cost (Kamaruzaman, 1992). Basically, remote sensing technology provides accurate data that are vital for forest management.

During the last decade, several research studies were done to identify the possible contributions of Landsat imagery to forest mapping, inventory and other uses employing both visual and computer-aided techniques. However, much remains to be learned about the spectral characteristics of many different types of vegetation and the factors that influence the spectral response patterns measured by remote sensing systems.

In nations where forest management is not so common, the inventories are usually based on surveys of randomly sampled areas; this results in precise statistics of tree species distribution, timber volume and quality. However, this method requires a lot of time and is expensive; moreover, it does not support the production of suitable forest maps. On the other hand, satellite remote sensing can provide a synoptic view of a big region by exhibiting forest patterns. Forest mapping through remote sensing techniques can be carried out together with detailed ground surveys; this produces both precise statistics and thematic maps.

The use of remote sensing methods enables successful analysis of timber volume and forest stand structure data when supplemented with ground data. The final outputs of remote sensing supported inventories are image maps and statistics, and accurate up-to-date documentation of forest conditions.

1.4. Objectives

The general objective is to identify the socioeconomic impacts on communities due to land use change in the study area. The specific objectives that will be covered in this study are as follows:

1. To apply an ecosystem model and evaluating the impact of mangrove bio-disturbance on the ecosystem of mangroves using geospatial technology.
2. To investigate variations in the mangrove ecosystem in response to land use change during the economic activities between year 2000 and 2010 and projection in year 2020.
3. To provide useful information and solution to policy makers concerning sustainable development of mangrove resources in Sg. Merbok Forest Reserve.

1.5. Scope of the Study

This study involves the application of remote sensing data, field survey, other ancillary data and data analysis techniques in presenting the effects of land use change of the surrounding study area and extraction of the suitable parameter to estimate the ecosystem service value for each land use. The study area covers the Sg. Merbok forest reserve mainly dominated by mangrove forest, which is seriously affected by illegal logging and encroachment. Beginning January 2009, the study was conducted to investigate and estimate the impacts of those activities on the ecosystem services value and livelihood of the community. Image processing, data analysis and projection are used to describe the study outcomes.

1.6. Thesis Organisation

There are six chapters in this thesis. Chapter 1 presents the introduction with background information about forest management and economics. It also discusses the use of remote sensing technology for forest inventory and monitoring. The objectives and significance of the study are also presented. Chapter 2 comprises the literature review, which presents discussions of the concept and findings of other studies related to the application of RS technology in forest management; the economic aspect in forest management is also discussed. Chapter 3 describes the study area and the methods and materials employed in this study. The forest change detection, analysis and modelling results are shown in Chapter 4. The Ecosystem valuation models will analysis in chapter 5 with support data from chapter 4. Finally, Chapter 6 concludes the study with a summary of the major findings and directions for future research.

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