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# Serviços de ecossistemas em Moçambique: uma avaliação biofísica e monetária entre 2005 e 2025

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A thesis submitted in partial fulfillment of the requirements for the degree of Doctor in Information Management

November, 2017

**NOVA Information Management School**
Universidade Nova de Lisboa

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# Serviços de ecossistemas em Moçambique: uma avaliação biofísica e monetária entre 2005 e 2025

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**Abstract**

Land cover change has been negatively affecting the provision of ecosystem services (ES) to satisfy the increasingly global demand of goods. ES valuation assessments may provide relevant information to policy makers about natural capital, being one potentially effective way of achieving sustainability. In this work GlobCover land cover data was utilized to identify Mozambique's biomes between 2005 and 2009. A benefit transfer approach was used to estimate the values of the services delivered by the ecosystems. With this dissertation we intend to contribute to a better understanding of the value of ES provision and its contribution for wellbeing in Mozambique, and create the conditions for better maintaining these services. For that reason, we develop three studies about ES assessment; we start with the assessment of changes in ecosystem service monetary values in Mozambique between 2005 and 2009 (Chapter 2). Then we study multiple ES using ES indicators, including biodiversity, from 2005 to 2025 (Chapter 3). Finally, a prediction of ES monetary value for 2025 is presented (Chapter 4). This set of studies may contribute to the development of policy instruments and assist decision policies affecting ES provision and trade-offs in Mozambique. Additionally, they can also be used to call for the importance of considering ES in national well-being accounting, and for going beyond GDP as a national welfare measure and policy goal.

**Key-words:** Biomes; Land Use/Land Cover Change; Benefit Transfer; Ecosystem Services Valuation; GlobCover, InVEST; Land Change Modeler; Africa; Natural capital

## Resumo

A mudança do uso e da cobertura do solo tem afetado negativamente a provisão de serviços de ecossistemas (SE). As avaliações de SE podem prevenir de forma eficaz essa tendência e preservar o capital natural (CN). Neste trabalho, utilizámos os dados de uso e cobertura do solo GlobCover estudar as alterações nos biomas de Moçambique entre 2005 e 2009. A valorização económica dos SE fornecidos pelos biomas foi feita através do método de transferência de benefício. Com esta dissertação, pretendemos contribuir para uma melhor compreensão do valor da provisão de ES e sua contribuição para o bem-estar em Moçambique, a fim de criar condições para uma melhor manutenção desses serviços. Por essa razão, desenvolvemos três estudos sobre a avaliação de SE; começamos com avaliação das mudanças nos valores monetários do serviço dos ecossistemas em Moçambique entre 2005 e 2009 (Capítulo 2). Depois, estudamos os múltiplos SE usando cinco indicadores, incluindo a biodiversidade de 2005 a 2025 (Capitulo 3). Finalmente, estudamos a previsão do valor monetário do SE para 2025 (Capítulo 4). Esses estudos podem contribuir para o desenvolvimento e monitoramento de instrumentos de política que considerem provisão de SE. Estes também pode contribuir com uma metodologia que pode ser útil para monitorar SE e auxiliar políticas de decisão que afetam a provisão e as compensações de SE. Além disso, também podem ser usados para chamar a atenção da sua importância para que SE sejam considerados na contabilidade nacional de bem-estar e para ir além do PIB como medida nacional de bem-estar e objetivo político.


**Palavras-chave**: Biomas; Uso do solo / mudança de cobertura do solo; Transferência de Benefícios; Avaliação de serviços de ecossistemas; GlobCover, InVEST, Land Change Modeler, África, capital natural.

**Lista de publicações resultantes desta tese**

Artigos publicados:

Título: *Ecosystem services and biodiversity trends in Mozambique as a consequence of land cover change*

Jornal: *International Journal of Biodiversity Science, Ecosystem Services & Management* da Taylor and Francis. Este jornal é um Q2 no Scopus.

Link: http://www.tandfonline.com/doi/full/10.1080/21513732.2017.1349836

Título: *Assessment of changes in ecosystem service monetary values in Mozambique*

Jornal: *Environmental Development* da Elsevier. Este jornal é um Q1 no Scopus.

Link: http://www.sciencedirect.com/science/article/pii/S2211464517301653

Artigo submetido:

Título: Avaliação dos serviços de ecossistemas em Moçambique entre 2005 e 2025.

## Agradecimentos

Agradeço a Deus, pela vida.

Ao Prof. Pedro Cabral, supervisor desta tese, pela sua permanente disponibilidade, para ajudar, suportar, guiar e contribuir com ideias valiosas que deram corpo e qualidade a este estudo. Meu muito obrigado.

Aos Prof. Marco Painho, Prof. Tiago Oliveira, Profª Cristina Marreiros, e Prof. Leonardo Vanneschi por me terem orientado na fase inicial desta jornada.

A Ângela Rodrigues e Gabriela Augusto, por terem trabalhado comigo no terceiro capítulo desta tese, Obrigado'.

Um especial agradecimento a minha família Joaquina e Claudo, esposa e filho respectivamente, pela paciência, cuidados, suporte e motivação que me deram durante todas etapas desta tese.

Obrigado a todos.

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## 1) Introdução

O capital natural (CN) é constituído pelos elementos da Natureza que fornecem um fluxo de benefícios a longo prazo para os indivíduos e para a sociedade como um todo (Costanza, d'Arge, et al., 1997; Zhongyuan & Hua, 2011). Estes benefícios são conhecidos por serviços de ecossistema (SE) e são fundamentais para o bem-estar da humanidade (Costanza et al., 2014; Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, & Suttonkk, 1997; Daily, 1997; Mooney et al., 2005; Sander et al., 2016).

A história moderna do conceito de SE começa nos finais da década de 70 (Gómez-Baggethun, de Groot, Lomas, & Montes, 2010), com um enquadramento prático das funções benéficas do ecossistema como serviços, tendo em vista o aumento do interesse público na conservação da biodiversidade (Ehrlich PR, 1981; Rudolf S. de Groot, 1987; Westman, 1977). Na década de 90, o interesse pelo estudo dos SE cresceu ao ponto de ser incorporado na literatura (Costanza & Daly, 1992; Daly, 1997) e a sua utilização na avaliação global do CN (Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, & Suttonkk, 1997). Após a publicação dos resultados do Millenium Assessment (Millenium Assessment, 2003), que teve seu foco nos benefícios que a humanidade pode obter directa ou indirectamente dos ecossistemas, a literatura sobre SE cresceu de uma forma exponencial (Fisher, Turner, & Morling, 2009). A partir deste momento vários actores e projectos passaram a lidar com a classificação, quantificação, mapeamento e a avaliação dos SE com o intuito de integrar o conceito nos processos de tomada de decisão (Hermann, Schleifer, & Wrbka, 2011). Neste processo, várias definições foram usadas para caracterizar os SE, tendo-se destacado três principais abordagens. Para Daily (1997), SE são as condições e processos pelos quais os ecossistemas naturais e as espécies que as compõem, suportam a vida humana. Ainda no mesmo ano, Costanza et al., (1997), dizem que SE são os benefícios que a humanidade obtém, directa ou indirectamente, das funções dos ecossistemas. Por último, o MEA (2005) considera SE como benefícios que a humanidade obtém dos ecossistemas. A ambiguidade deste conceito torna difícil desenvolver uma plataforma coerente para tomada de decisão (Wallace, 2007).

Existem muitas formas de classificar os SE de acordo com propósito do seu uso (Hermann et al., 2011). Daí, vários cientistas (Costanza, d'Arge, et al., 1997; R. de Groot et al., 2012; R.S. de Groot, Alkemade, Braat, Hein, & Willemen, 2010) e projectos como o CICES (CICES, 2017), OpenNESS (Openness, 2017), TEEB (TEEB, 2017) surgiram com objectivo de criar um sistema de classificação dos SE para facilitar a sua compreensão comparabilidade entre diferentes plataformas. O projecto Europeu OpenNESS (2012-2017) visa traduzir os conceitos

NC e SE em estruturas operacionais que fornecem soluções testadas, práticas e personalizadas para integrar a ES na gestão do solo, da água e da cidade e na tomada de decisões apresentando vários casos de estudo europeus (Openness, 2017). O projecto CICES foi preparado para ajudar a medir, contabilizar e avaliar os SE. Este tem sido amplamente utilizado na pesquisa de SE para a concepção de indicadores, mapeamento e para avaliação (Haines-Young, 2016). O CICES tende a ser uma classificação mais compreensível e abrangente que a classificação definida pelo MA e TEEB(CICES, 2017). Este subdivide os SE em 5 níveis hierárquicos (Sessão, Divisão, Grupo, Classe e Tipos de Classe (CICES, 2017). O maior destaque da sua aplicação foi como base do estudo alemão TEEB (Deutschland, 2014) (Naturkapital Deutschland - TEEB DE, 2014), bem como a avaliação nacional alemã do ecossistema, NEA-D (Albert et al., 2014). Para Spangenberg, von Haaren, & Settele, (2014), o modelo cascata é uma estrutura geral muito útil para classificar diferentes etapas de geração e alocação de SE e a respectiva atribuição de valores monetários e não-monetários aos produtos ou SE providenciados. Vários autores como (Brink et al., 2016; Diehl, Burkhard, & Jacob, 2015; Fu, Wang, Xu, Yan, & Li, 2014; Honrado et al., 2013; Liquete, Zulian, Delgado, Stips, & Maes, 2013; Maes et al., 2012; Mononen et al., 2015; Nahuelhual et al., 2015; Primmer et al., 2015; Saarikoski et al., 2015; Spangenberg, von Haaren, & Settele, 2014b; Tolvanen et al., 2014), usaram o modelo cascata para avaliar os SE em diferentes locais.

Devido à procura crescente de terras para o desenvolvimento de actividades agrícolas, florestais e urbanização, a capacidade dos SE em suportarem as necessidades humanas está a ser reduzida drasticamente (Halpern et al., 2008; Kareiva, Tallis, Ricketts, Daily, & Polasky, 2011b). Para reverter esta situação, vários estudos sobre a avaliação dos SE têm sido realizados a nível mundial (Costanza et al., 2014; Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, & Suttonkk, 1997; R. de Groot et al., 2012) e a nível nacional/regional (D'Amato, Rekola, Li, & Toppinen, 2016; Joshi & Negi, 2011; Perez-Verdin et al., 2016) com vista a contribuir-se com informação detalhada para os decisores, auxiliando-os na definição de políticas de planeamento que visem a gestão e preservação dos ecossistemas.

Em África existem poucos estudos sobre o valor, biofísico e monetário, dos SE como consequência da mudança de uso e ocupação do solo (Dawson & Martin, 2015; Kindu, Schneider, Teketay, & Knoke, 2016b). A principal razão desta falta de estudos deve-se, em boa parte, à ausência de dados (Leh, Matlock, Cummings, & Nalley, 2013). A escassez destes estudos constitui um problema importante porque este continente encontra-se num processo significativo de mudanças de uso e cobertura do solo com um impacto importante na provisão dos SE (Kindu, Schneider, Teketay, & Knoke, 2016a; Niquisse & Cabral, 2017; Niquisse, Cabral, Rodrigues, & Augusto, 2017; Power et al., 2010).

Especificamente para Moçambique, diversos estudos analisaram os SE a nível local e regional. Por exemplo, Wong et al. (2005) apresentaram uma revisão preliminar dos SE e respectivos determinantes e constituintes do bem-estar para Moçambique. Fallis (2013) reportou que o Chibuto (distrito da província de Gaza no sudoeste de Moçambique) é largamente utilizado como um agroecossistema com agricultura, pastagem e recolha de fibra. Nunes e Ghermandi (2015) realizaram um estudo sobre a avaliação e compreensão dos SE marinhos do canal nortenho de Moçambique. Mudaca et al. (2015) estudaram os factores que influenciam a decisão dos agregados familiares em participarem no programa de pagamento de SE numa comunidade localizada na província de Sofala. Concluímos, portanto, que estudos sobre SE em Moçambique são raros e nenhum deles providenciou até ao momento deste estudo uma avaliação monetária a nível nacional e/ou provincial nem as suas mudanças como consequência da alteração do uso e cobertura do solo. A falta destes estudos pode constituir um importante obstáculo na manutenção da provisão dos SE.

### 1.1. Hipóteses

As hipóteses subjacentes à realização deste estudo são:

- A falta de estudos detalhados sobre os SE em Moçambique, faz com que estes não sejam valorizados nem tomados em conta em processos de planeamento;
- A alteração do uso e cobertura do solo tem impactos biofísicos e económicos no nível de provisão dos SE.

### 1.2. Objectivos

Este estudo pretende superar a evidente falha de informação sobre SE em Moçambique que tem dificultado ou mesmo impossibilitado a tomada de decisões na gestão e preservação do CN. Assim, este estudo tem como principal objectivo realizar a primeira avaliação monetária e biofísica dos SE e analisar os impactos da alteração do uso e cobertura do solo nos SE em Moçambique, entre os anos 2005 e 2025. Especificamente, pretende-se realizar:

i) Uma avaliação monetária dos SE e das suas mudanças em Moçambique entre 2005 e 2009;
ii) Avaliar os SE ao nível biofísico em Moçambique entre 2005 e 2009;

iii) Projectar as tendências dos SE e da biodiversidade, em termos biofísicos e monetários, como consequência da alteração do uso e cobertura do solo até ao ano 2025.

### 1.3. Metodologia

A metodologia aplicada nesta pesquisa é apresentada na Figure 1.1 e explicada em seguida.

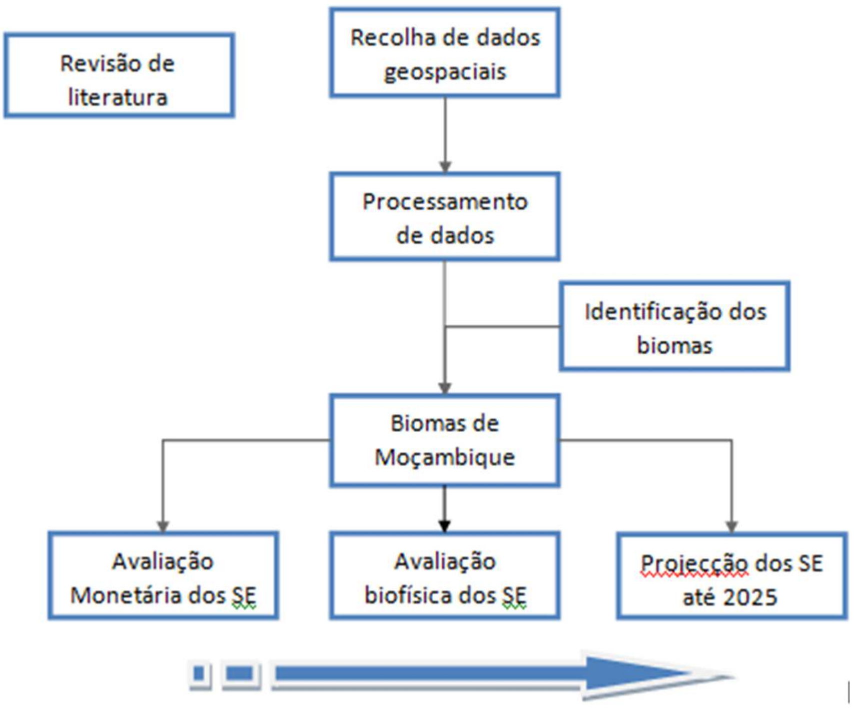


*Figure 1-1 Esquema do procedimento metodológico*

#### 1.3.1. Revisão de literatura

A revisão de literatura, transversal a todo estudo, foi realizada com objectivo de conhecer o estado de arte sobre os SE a nível global e a nível nacional. Esta permitiu identificar as principais áreas que ainda carecem de estudos para uma melhor tomada de decisão e na definição de políticas e estratégias nacionais de gestão e conservação dos SE existentes. A revisão de literatura foi também, necessária na definição de todos os aspectos metodológicos do estudo que envolveram a recolha de dados e a utilização de técnicas de modelação.

### 1.3.2. Processamento de dados

***Recolha de dados espaciais***

Neste estudo, foram utilizados os mapas de uso e cobertura do solo de Moçambique do período entre 2004 e 2006 (aqui designado 2005) e 2009 extraídos do projecto *GlobCover* (http://due.esrin.esa.int/page_globcover.php). Foram, também utilizados diversos dados obtidos junto do CENACARTA e em diversas fontes internacionais. Todos os dados utilizados nesta pesquisa são de acesso livre.

***Equivalência de uso e cobertura do solo em Biomas***

Para a conversão das classes de uso e cobertura do solo do projecto GlobCover em bioma correspondente, foi utilizado o estudo de Bai et al., (2014). Estas classes foram convertidas em biomas com base no estudo de Costanza et al., (2014). Foram identificados sete biomas: *Floresta, Pradaria/Pastagens, Zonas húmidas, Deserto, Urbano, Lagos/Rios, e Zonas cultivadas.*

### 1.3.3. Avaliação dos SE

***Avaliação monetária***

A atribuição de valores económicos aos biomas de Moçambique foi feita a partir do método da transferência de benefício (Chen et al., 2014; Farber et al., 2006). Esta técnica consiste em utilizar a avaliação de estudos ou dados existentes para estimar o valor dos SE numa área similar (Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, Suttonkk, et al., 1997). Esta técnica é usada comummente quando há insuficiência de recursos e/ou tempo para realizar a recolha detalhada de dados no campo (Wilson & Hoehn, 2006), como é o caso do presente estudo.

***Avaliação biofísica***

Tendo em conta a disponibilidade dos dados para a avaliação biofísica dos SE foram usados os seguintes indicadores de SE: produção de água, qualidade da água, retenção de sedimentos, sequestro de carbono e biodiversidade. Estes indicadores foram usados com sucesso noutros estudos de SE (Yang Bai, Zheng, Ouyang, Zhuang, & Jiang, 2012; Bhagabati et al., 2012; Cabral, Feger, Levrel, Chambolle, & Basque, 2016; Leh et al., 2013). Foi usado o software InVEST (*Integrated Valuation of Ecosystem Services and Trade-offs*) (Tallis et al., 2015) para mapear e quantificar os indicadores de SE.

***Projecção***

Para obtermos as estimativas dos valores dos biomas para o ano 2025 foi utilizado um modelo de alteração do uso e cobertura do solo - o Land Change Modeler disponível no programa IDRISI Selva (Eastman 2012). Este modelo usa as mudanças históricas dos biomas entre 2005 e 2009 para projetar os biomas para o ano 2025 de uma forma espacialmente explícita. O processo de modelação incluiu o uso de cadeias de Markov que determinaram a probabilidade de cada célula mudar para outra classe entre 2005 e 2009. Os potenciais de transição, que correspondem a mapas de probabilidade para cada célula transitar de bioma, foram modelados com recurso a uma rede neuronal.

### 1.4. Organização da tese

Este documento encontra-se organizado em 5 capítulos. O primeiro capítulo corresponde à Introdução e o último capítulo (Capítulo 5) às conclusões. Os capítulos 2, 3 e 4 correspondem, respectivamente, a 3 artigos académicos:

- O primeiro artigo realiza a primeira avaliação monetária dos SE em Moçambique entre 205 e 2009. Este artigo foi aceite para publicação no jornal *Environmental Development* da Elsevier. Este jornal é um Q1 no Scopus.
- O segundo artigo faz a primeira avaliação biofísica dos SE em Moçambique entre 2009 e 2025 e foi publicado no *International Journal of Biodiversity Science, Ecosystem Services & Management* da Taylor and Francis. Este jornal é um Q2 no Scopus.
- O terceiro artigo, em revisão, faz uma projecção dos valores monetários dos SE para 2025.

## 2) Assessment of changes in ecosystem service monetary values in Mozambique

### 2.1. Introduction

Ecosystems provide a wide range of benefits to society known as ecosystem services (ES), which are constituents of well-being (Millenium Assessment, 2003). However, changes in ecosystems in a global context of increasing demand for agricultural land, forest plantations, and industrial and urban areas are compromising their ability to support mankind (Halpern et al., 2008; Kareiva et al., 2011b). By ignoring the benefits provided by nature, mankind puts itself at danger by degrading ES beyond the limits of sustainability (Millenium Assessment, 2003). One factor having an important impact on the provision of ES is land cover change (Lawler et al., 2014; MEA, 2005b) and the effective management of the locations responsible for maintaining ES has been considered essential to prevent their further decline (Cabral et al., 2016; Egoh et al., 2007; Leh et al., 2013; Portela & Rademacher, 2001).

Considerable efforts have been made to draw attention to the importance of preserving natural capital, and also to providing useful information for decision making through economic valuation of ES (Kindu et al., 2016b; Sander et al., 2016). To this end, several research works have been carried out at global (Costanza et al., 2014; Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, Suttonkk, et al., 1997; R. de Groot et al., 2012), and/or national and/or regional levels (D'Amato et al., 2016; Joshi & Negi, 2011; Perez-Verdin et al., 2016). Some of these valuation studies also include spatially explicit approaches which provide information on those locations responsible for ES provision (Frélichová et al., 2014; Kremer & Hamstead, 2016; Kubiszewski, Costanza, Dorji, Thoennes, & Tshering, 2013; La Notte, Maes, Grizzetti, Bouraoui, & Zulian, 2012; Liu, Costanza, Troy, & D 'aagostino, 2010).

Globally, the ES value in 2011 was estimated at US $125 trillion/yr for 2007 $US (Costanza et al., 2014). According to these authors, between 1997 and 2011 the ES value fell by US $4.3-20.2 trillion/yr as a result of land changes. Losses in ES value at national and regional levels have also been reported (Crespin & Simonetti, 2016; Zhiliang Wang, Wang, Zhang, Lu, & Ren, 2015). For Africa there are very few studies about ES valuation as a consequence of land cover change (Dawson & Martin, 2015; Kindu et al., 2016b). The main reason for such a scarcity of studies is the absence of data (Leh et al., 2013). The lack of such studies is an important problem because Africa is undergoing significant land changes with important impacts on the provision of ES (Kindu et al., 2016b; Power et al., 2010). Specifically in Mozambique, previous works have analyzed single ES at local or regional levels. Wong et al.

(2005) provided a preliminary review of ES threats by region in Mozambique. These authors found that Gaza, Manica, Nampula, Sofala and Tete had all the analyzed ES and well-being constituents being threatened. Fallis (2013) reported that the Chibuto district (province of Gaza in south-western Mozambique) largely served as an agro-ecosystem with agricultural, grazing, and fiber collection. More recently, Nunes and Ghermandi (2015) carried out a study dealing with the understanding and valuation of marine ES for the Northern Mozambique Channel. These authors found that just the Northern Mozambique Channel contributes 5% of national Gross Domestic Product (GDP) in small island states. Mudaca et al. (2015) show that economic benefits, social inclusion, and forest conservation are the factors influencing household's decisions to participate in the Payments for Ecosystem Services (PES) program in a Community located in Sofala province. Niquisse et al. (2017) studied the trends of ES and biodiversity biophysical values in Mozambique as a consequence of land cover change. These authors found a moderate increase in climate regulating service between 2005 and 2009, and a decrease in projected water quality (nutrient retention) and biodiversity to the year 2025. Hence studies about ES in Mozambique are rare when compared to other locations, and to our knowledge none of them has provided a monetary valuation at national and/or province levels and/or its changes. The lack of such studies may constitute an important obstacle for maintaining ES provisioning which could be achieved through several available policy instruments in Mozambique when targeting specific or several ES (Table 2.1).

*Table 2-1: Policy instruments available in Mozambique related to ES analysed in this study*

| **Biome** | **Ecosystem service(s)** | **Policy instrument** |
|---|---|---|
| Cropland Grass/Rangeland | Food | National Agriculture Investment Plan (República de Moçambique, 2013) |
| | | Action Plan for Poverty Reduction (República de Moçambique, 2011) |
| Forest | Biodiversity protection | National Strategy for the Sustainable Development of Mozambique (MICOA, 2007) |
| | Food | National Agriculture Investment Plan (República de Moçambique, 2013) |
| | | Action Plan for Poverty Reduction (República de Moçambique, 2011) |
| | Raw materials | National strategy for forests (RCM, 2015) |
| | | Strategy for the Mangrove Protection (República de Moçambique, 2015a) |
| Wetlands | Food | National Agriculture Investment Plan (República de Moçambique, 2013) |
| | | Action Plan for Poverty Reduction (República de Moçambique, 2011) |
| | Raw material | National Strategy for Forests (RCM, 2015) |
| | | Strategy for the Mangrove Protection (República de Moçambique, 2015a) |
| | Water | National Strategy for Hydrological Resources Management (República de Moçambique, 2007) |
| Desert | Raw material | National Plan for Fighting Desertification (RCM, 2014) |
| Lakes / Rivers | Recreation | Strategic Plan for Tourism Development in Mozambique (República de Moçambique, 2004) |

In line with the national TEEB (*The Economics of Ecosystems and Biodiversity*) assessments (TEEB, 2010), this study seeks to provide the first monetary assessment of ES for Mozambique. Freely available data was used to assess the ES value for Mozambique and its provinces, between years 2005 and 2009, using a spatially explicit approach. Knowing ES value and its spatial dynamics at national and province levels calls for the importance of considering ES in national well-being accounting and for going beyond GDP as a national welfare measure and policy goal.

## 2.2. Methods

### 2.2.1. Study area

Mozambique, officially the Republic of Mozambique, is located in Southeast Africa and comprises a land surface of about 800,000 $km^2$ (Figure 2.1). Mozambique has a diverse landscape ranging from coastal plains to savanna, and woodlands to mountains. There are numerous rivers flowing from west to east into the Indian Ocean, with the Zambezi and Limpopo being the two largest. Mozambique is divided into 11 provinces and shares borders with six countries. It is separated from Madagascar by the Mozambique Channel to the east. Mozambique had about 27.22 million inhabitants in 2014 (World Bank, 2016). The capital and largest city is Maputo with 1,241,702 inhabitants (INE, 2015). This country became independent from Portugal in 1975, followed by a civil war which ended in 1992. The first democratic elections took place in 1994 and the country has enjoyed political stability since then (Brouwer & Falcão, 2004). Mozambique's GDP was $14{,}807 \times 10^{\wedge 6}$ US$ in 2015 (World Bank, 2016). Mozambique ranked 180 out of 188 countries in the most recent Human Development Index (UNDP, 2015).

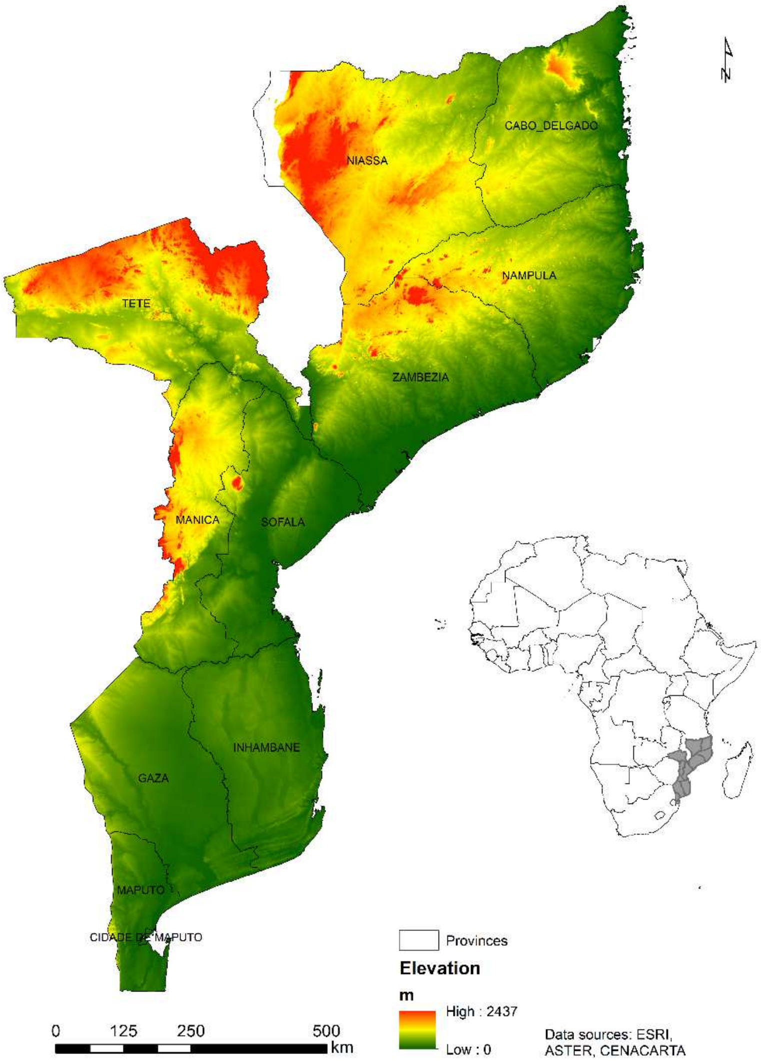


*Figure 2-1: Study area*

### 2.2.2. Data collection and processing

Land cover maps of Mozambique for the period of 2004-2006 (hereinafter referred to as 2005) and 2009 from ESA/ESA GlobCover Project (http://due.esrin.esa.int/page_globcover.php) were used in this study. These were the only two available reference years for these datasets, which differentiate 19 classes of land cover (Table A.1, Annex 1). This product was derived from data acquired by the ENVISAT MERIS sensor with 300m of spatial resolution (GlobCover, 2015). The overall accuracy, weighted by the area proportions of the various land cover classes, is 73% (Defourny et al., 2009). Additional data for administrative boundaries were obtained from the National Center of Cartography (http://www.cenacarta.com).

Biomes are "the World´s major communities classified according to the predominant vegetation and characterized by adaptations of organisms to that particular environment" (Simon et al., 1996). There are many ways to categorize the biomes according to different criteria, such as climate, habitat, animal and plant adaptation, biodiversity, and human activity (WWF, 2016). To identify the biomes in Mozambique, the land cover classes from GlobCover dataset were assigned to the corresponding biome (Annex 1). GlobCover classes were converted into a simplified land cover scheme (Yan Bai et al., 2014). These classes were then matched to biomes (Costanza et al., 2014). This procedure resulted in seven biomes for Mozambique: Forest, Grass/Rangeland, Wetland, Desert, Urban, Lakes/Rivers, and Cropland (Fig. 2).

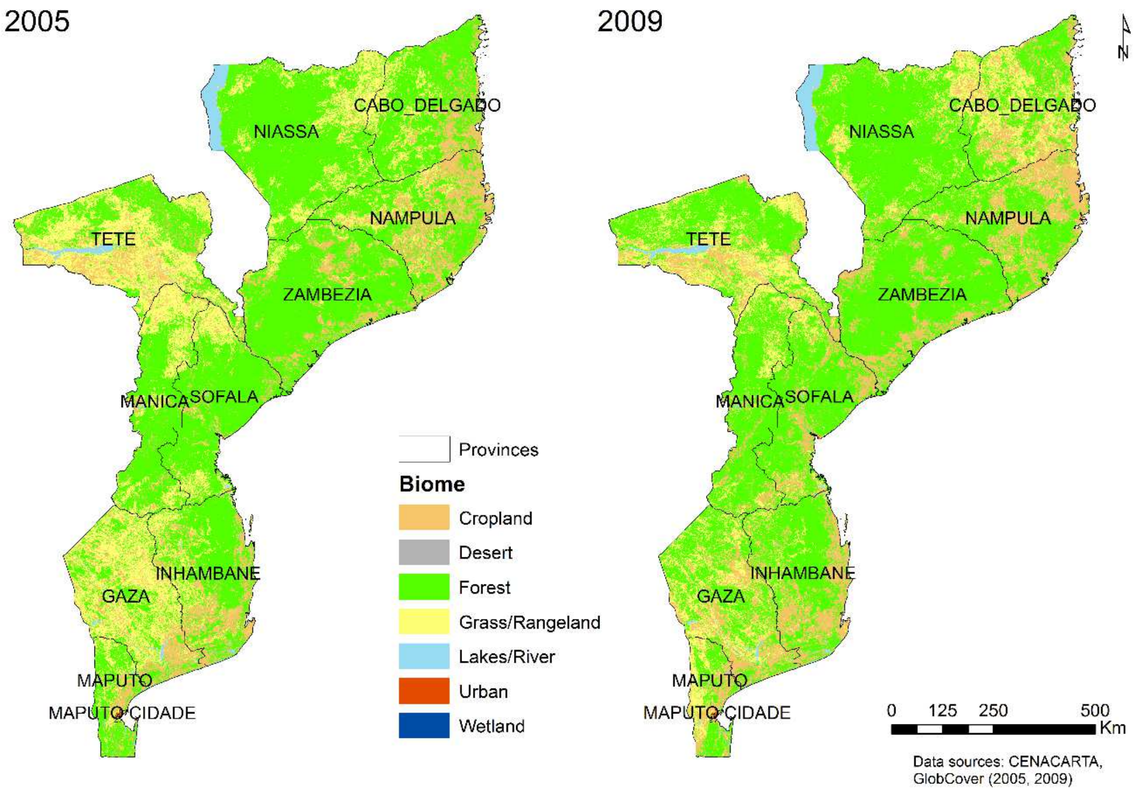


*Figure 2-2: Biomes of Mozambique in 2005 and in 2009*

### 2.2.3. Assignment of ecosystem service values to biomes

Several economic valuation methods have been applied to determine the value of ES, such as the simulated market approach (Guy Garrod and Kenneth G, 1999), the surrogate market approach (Wu, Ye, Qi, & Zhang, 2013) and the benefit transfer method (Chen et al., 2014; Farber et al., 2006). The last has been used to estimate value of ES of global biomes and their changes (Costanza et al., 2014; Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, Suttonkk, et al., 1997). In this study a benefit transfer method was used to estimate the ES value of Mozambique. This technique consists of utilizing existing valuation studies or data to estimate the ES value in a similar location (Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, Suttonkk, et al., 1997). It is commonly used when there are insufficient resources and/or time to carry out detailed on-the-ground data collection (Wilson & Hoehn, 2006), as is the case of the present study.

The valuation of the ES of each biome identified was carried out using the values obtained in the Ecosystem Services Valuation Database (ESVD) (Van der Ploeg & de Groot, 2010), made available by the Ecosystem Services Partnership (ESP – http://www.es-partnership.org). ES studies available in the ESVD for the existing biomes in Mozambique or in locations at similar latitudes were the ones selected for this study (Table 2.2). All ES value estimates were converted into 2009 US$/ha/yr to match the date of the last GlobCover dataset. The Urban biome was not considered for ES valuation because there was not any study comparable to Mozambican urban areas, including the revised urban coefficient reported in Costanza et al. (2014) which was considered highly overestimated (Yi, Güneralp, Filippi, Kreuter, & Güneralp, 2017). In any event, the total urban area of Mozambique was 17,163ha in 2009, representing only about 0.02% of the total area. Thus, the impact of this biome in total ES value was relatively low. Some of the values in Table 2.2 concern only one ES for each biome (e.g. Cropland, Grass/Rangeland, Desert, and Lakes/River) while others represent multiple ES per biome (Tropical Forest, and Wetland). In this last case, all the values were summed to determine the ES value for these biomes. In the cases in which the values were in different currencies (e.g. Tropical Forest and Grass/Rangeland), the ES coefficients were converted into 2009 US$.

The total value of the ES (ES value) was estimated using (Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, Suttonkk, et al., 1997) (1):

$$\text{ES value} = \sum(A_k \times VC_k) \qquad (1)$$

where A is the area (ha), and VC the value coefficient in ($/ha/year) for each land cover category k. The changes in ES value were obtained by calculating the difference between the estimated values for each year (Kreuter, Harris, Matlock, & Lacey, 2001).

*Table 2-2: Biomes and correspondent ES value coefficients ($/ha/year)*

| **Biome** | **ES coefficients ($/ha/yr)** | **Country** | **Ecosystem services** | **Source** |
|---|---|---|---|---|
| Cropland | 77.6 | Tanzania | Food | (Turpie, 2000) |
| Tropical Forest | 11.95 (sum of all ES values and conversion from RAND to US$ in 2009) | South Africa | Raw materials, Food, Biodiversity protection, Pollination | (Mike H. Allsopp, Willem J. de Lange, 2003) |
| Grass/Rangeland | 185 (conversion from PULA to US$ in 2009) | Botswana | Food | (J. Barnes, 2002) |
| Wetland | 98.3 (sum of all ES values) | Malawi | Food, Raw material and Water | (Schuijt, 2002) |
| Desert | 166 (sum of all ES values) | Kenya | Raw material | (Mogaka, 2007) |
| Lakes/River | 1,205.4 (sum of all ES values) | Kenya | Recreation | (Mogaka, 2007) |

## 2.3. Results

### 2.3.1. Changes in biomes' areas between 2005 and 2009

The area of the biomes, as well as gains and losses in each category between 2005 and 2009, are shown in Table 2.3. Forest was the biome that accounted for most of the Mozambican territory (59.57% and 61.13% of total area in, respectively, 2005 and 2009). This biome increased 2.6% during this time period. The greatest changes were in the Grass/Rangeland (-26.7%) and Cropland biomes (26.6%). These biomes represented, respectively, 16.49%, and 21.5% of total area of Mozambique in 2009. The Grass/Rangeland biome lost 3,732,984ha to the Cropland and 6,016,653ha to the Forest. On the other hand, the Cropland lost 4,513,455ha to the Forest and 1,419,066ha to the Grass/Rangeland. Although the Desert was a small proportion of Mozambique, this biome also increased substantially between 2005 and 2009 (39.9%).

*Table 2-3: Changes in biome's surface area (ha) between 2005 and 2009. Cells indicate the amount of area contributed to each biome in 2009 (columns) from the 2005 biome's (rows)*

| | 2009 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Class | Cropland | Forest | Grass/Rangeland | Wetlands | Urban | Desert | Lakes/River | Total ha | % |
| 2005 | Cropland | 7,349,436 | 4,513,455 | 1,419,066 | 243 | 0 | 1,089 | 0 | 13,283,289 | 16.98 |
| | Forest | 5,718,177 | 37,266,831 | 3,608,100 | 666 | 0 | 261 | 0 | 46,594,035 | 59.57 |
| | Grass/Rangeland | 3,732,984 | 6,016,653 | 7,847,829 | 414 | 0 | 2,178 | 0 | 17,600,058 | 22.50 |
| | Wetlands | 216 | 468 | 81 | 2,952 | 0 | 0 | 0 | 3,717 | 0.00 |
| | Urban | 243 | 126 | 234 | 0 | 17,163 | 0 | 0 | 17,766 | 0.02 |
| | Desert | 144 | 27 | 1,836 | 0 | 0 | 2,871 | 0 | 4,878 | 0.01 |
| | Lakes/River | 13,842 | 18,738 | 24,273 | 0 | 0 | 423 | 655,209 | 712,485 | 0.91 |
| | Total ha | 16,815,042 | 47,816,298 | 12,901,419 | 4,275 | 17,163 | 6,822 | 655,209 | 78,216,228 | |
| | % | 21.50 | 61.13 | 16.49 | 0.01 | 0.02 | 0.01 | 0.84 | | |
| | ∆ % 2005-2009 | 26.6 | 2.6 | -26.7 | 15.0 | -3.4 | 39.9 | -8.0 | | |

### 2.3.2. **Changes in ES value between 2005 and 2009**

The estimated total value of ES in 2005 was US$ 5,703.6x10^6. In 2009, this value was US $5,054.4x10^6, representing a decrease of US $649.2x10^6 (-11.4%) (Table 4). The biome with the highest ES value in 2009 was the Grass/Rangeland (US$ 2,386.8 x10^6), i.e. 47.2% of total ES value of the country (Fig. 3). Overall there was an average yearly decrease of -2.3% in Mozambique's ES value. The biomes that considerably increased their ES value were the Desert (39.9%), the Cropland (26.6%) and the Wetlands (15%). In contrast, the Grass/Rangeland (-26.7%) significantly decreased its ES value during the study period. The remaining biomes, i.e. Forest and Lakes/River, had changes in ES value of less than 10% between 2005 and 2009.

*Table 2-4: Total ecosystem service value (in US$/ha/yr, 2009 price levels) estimated for each biome in Mozambique using regional coefficients, and the overall change between 2005 and 2009*

| Biome | ESV value (US$*10^6) 2005 | ES value % 2005 | ES value (US$*10^6) 2009 | ES value % 2009 | ∆ ES value (US$*10^6) 2005-2009 | Average Annual Change (US$*10^6) | Annual Change (%) | ∆ ES value (%) 2005-2009 |
|---|---|---|---|---|---|---|---|---|
| Cropland | 1,030.8 | 18.07 | 1,304.8 | 25.82 | 274.1 | 68.5 | 6.6 | 26.6 |
| Forest | 556.8 | 9.76 | 571.4 | 11.31 | 14.6 | 3.7 | 0.7 | 2.6 |
| Grass/Rangeland | 3,256.0 | 57.09 | 2,386.8 | 47.22 | -869.2 | -217.3 | -6.7 | -26.7 |
| Wetlands | 0.4 | 0.01 | 0.4 | 0.01 | 0.1 | 0.0 | 3.8 | 15.0 |
| Desert | 0.8 | 0.01 | 1.1 | 0.02 | 0.3 | 0.1 | 10.0 | 39.9 |
| Lakes/River | 858.8 | 15.06 | 789.8 | 15.63 | -69.0 | -17.3 | -2.0 | -8.0 |
| Total | 5,703.6 | 100 | 5,054.4 | 100 | -649.2 | -162.3 | -2.8 | -11.4 |

### 2.3.3. **Changes in ES value by province**

According to Table 2.5, all the provinces decreased their ES value between 2005 and 2009, with Gaza (-16.6%) and Sofala (-15.9%) the ones decreasing the most. Cabo-Delgado was the province that decreased the least (-4.3%). Niassa was the province with the highest ES value in 2009 (US$ 837.5x10^6). However, this province lost -10.6% of its ES value since 2005, i.e. US$ -99.35x10^6. Gaza was the province that contributed most to ES value loss with US$ -101.0x10^6. Maps of Fig. 3 depict ES value in Mozambique using a 300m spatial resolution cell. These maps were built by associating the ES value in $/ha/yr to each biome.

*Table 2-5: Total ecosystem service value (ES value in US$//ha/yr, 2009 price levels) estimated for each province in Mozambique using regional coefficients, and the overall change between 2005 and 2009*

| Province | ESV($/ha/yr)*10^6 2005 | ESV($/ha/yr)*10^6 2009 | ∆ 2005-2009 ($/ha/yr) | ∆ 2005-2009 (%) |
|---|---|---|---|---|
| Cabo-Delgado | 546.1 | 522.6 | -23.5 | -4.3 |
| Gaza | 609.5 | 508.5 | -101.0 | -16.6 |
| Inhambane | 464.6 | 402.7 | -61.8 | -13.3 |
| Manica | 481.8 | 415.6 | -66.2 | -13.7 |
| Maputo | 170.5 | 156.2 | -14.2 | -8.3 |

| | | | | |
|---|---|---|---|---|
| Nampula | 486.9 | 444.1 | -42.9 | -8.8 |
| Niassa | 936.6 | 837.4 | -99.3 | -10.6 |
| Sofala | 492.6 | 414.5 | -78.1 | -15.9 |
| Tete | 830.3 | 732.6 | -97.7 | -11.8 |
| Zambeze | 683.9 | 619.5 | -64.5 | -9.4 |
| Cidade de Maputo | 0.7 | 0.6 | -0.1 | -11.7 |
| Total | 5703.6 | 5054.3 | -649.3 | -11.4 |
| | | | | |

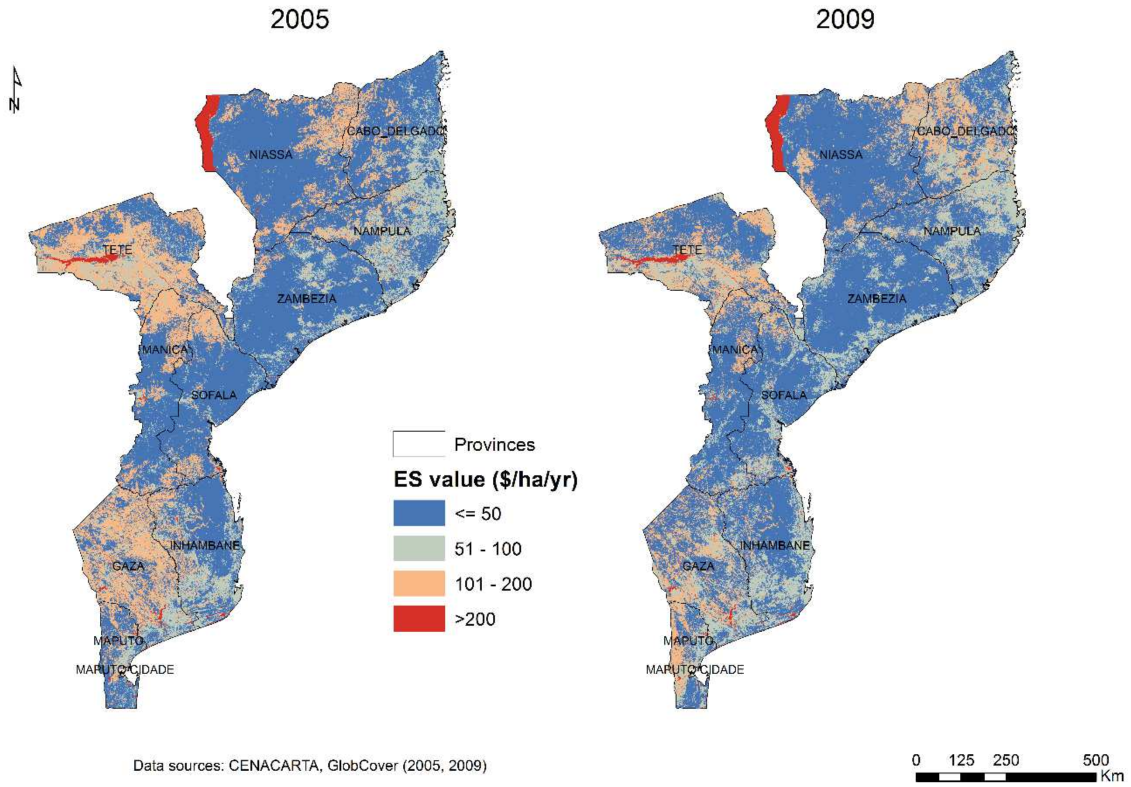


*Figure 2-3: ES value in 2005 and 2009 (in US$/ha/yr, 2009 price levels)*

In Table 2.6, it is possible to see the changes of ES value (%) per biome at province level between 2005 and 2009. A significant increase in the Cropland biome was noticed in the provinces Niassa (148.2%), and Sofala (166.7%). With the exceptions of Cabo-Delgado (88.9%) and Maputo (34.8%), the Grass/Rangeland biome decreased in all of the provinces, ranging from -53.1% in Zambeze to -27.5% in Niassa. It is worth noting that the increase of Grass/Rangeland in Cabo Delgado and Maputo provinces was coincident with an important increase in the Cropland biome for both provinces (45.9% and 51.9%, respectively). The Forest biome supported the increase of these biomes (-32.9% and -92.9%, respectively). The greatest (and only) decrease in the Wetland biome was verified in Sofala (-2.6%). Tete was the only province that increased the Wetland surface area (30.2%). All other provinces had no changes in this biome. Manica had a very significant increase in the Desert biome (1900%). This biome has increased in almost every provinces except Niassa (-100%), Tete (0%) and Cidade de Maputo (-16.7%). Finally, the Lakes/Rivers biome has decreased in all the provinces, ranging from -0.7% in Niassa to -22.9% in Cabo Delgado.

*Table 2-6: Changes of ES value (%) per biome at province level between 2005 and 2009*

| Province | Cropland (%) | Forest (%) | Grass/ Rangeland (%) | Wetland (%) | Desert (%) | Lakes/River (%) |
|---|---|---|---|---|---|---|
| Cabo-Delgado | 45.9 | -32.9 | 88.9 | 0.0 | 55.6 | -22.9 |
| Gaza | 20.6 | 51.9 | -42.3 | 0.0 | 23.9 | -9.1 |
| Inhambane | 23.0 | 2.8 | -50.4 | 0.0 | 44.0 | -8.3 |
| Manica | 57.6 | 12.0 | -42.8 | 0.0 | 1900.0 | -9.4 |
| Maputo | 51.9 | -92.9 | 34.8 | 0.0 | 35.0 | -5.4 |
| Nampula | -0.7 | 9.6 | -30.3 | 0.0 | 46.4 | -14.3 |
| Niassa | 148.2 | 2.8 | -27.5 | 0.0 | -100.0 | -0.7 |
| Sofala | 166.7 | -10.0 | -45.3 | -2.6 | 78.3 | -11.0 |
| Tete | -5.8 | 45.7 | -31.6 | 30.2 | 0.0 | -2.8 |
| Zambeze | 20.7 | -0.9 | -53.1 | 0.0 | 11.2 | -9.9 |
| Cidade de Maputo | 55.9 | -23.3 | -32.5 | 0.0 | -16.7 | -17.5 |

Fig. 4 shows the provinces which have changed their ES value above and below the mean using a standard deviation classification scheme. The yellow color denotes the provinces for which the change in ES value was close to the mean between 2005 and 2009 (between -0.5 and 0.5 standard deviations). Light brown (-1.5 to 0.5 standard deviations) and dark brown (<1.5 standard deviations) colors represent the provinces which have changed their ES value below the mean. Turquoise and (0.5 to 1.5 standard deviations) and dark turquoise (>1.5 standard deviations) colors represent the provinces which have changed their ES value above the mean.

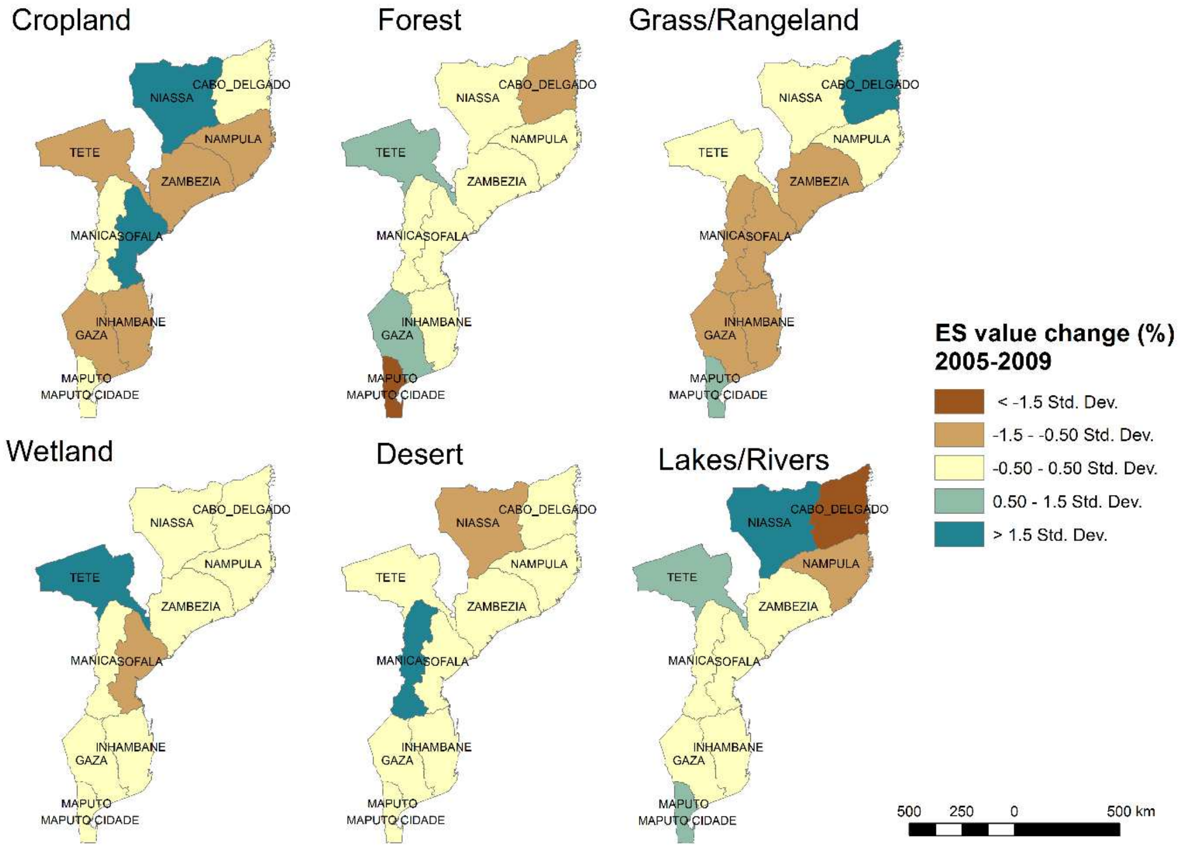


*Figure 2-4: Changes of ES value (%) per biome using standard deviations at province level between 2005 and 2009*

## 2.4. Discussion

### 2.4.1. Changes of ES value in Mozambique as a consequence of land cover change

In this study the services provided by the Cropland and Grass/Rangeland concern only food from agriculture. However, the ES value for Cropland is 77.6 US$/ha/year whereas the Grass/Rangeland is valued at 185 US$/ha/year, which is negatively affecting the total ES value for Mozambique. The Grass/Rangeland biome lost area and value mostly to Forest and Cropland (Table 2.3). It is likely that in the long term, Cropland's ES value will continue growing due to the need for food production to meet the needs of the country's increasing population (World Bank, 2016). This conversion has an important impact on ES provided by Forest and Grass/Rangelands as well, as these are the biomes that supported the growth of Cropland (Table 2.3). The conversion of Grass/Rangeland biome to Forest is a positive factor regarding the provision of several ES, such as flood regulation, which is a serious problem in Mozambique. Floods were very intensive from 2007 to 2009, when several rivers rose dramatically (República de Moçambique, 2008; UNISDRI, 2015).

Forests provide services such as raw materials, food, biodiversity protection and pollination services. However, the time period valued in this study witnessed a near equal conversion of the Forest biome to Cropland. According to FAO (2013), the main farming system in Mozambique is rain-fed subsistence farming with low levels of productivity due to the lack of conditions, including technology, market accessibility, storing infrastructure, and agricultural organization (Woodhouse, 2014). Therefore, to increase production, small farms increase agricultural land by converting other biomes into Cropland, mainly Grass/Rangeland because it is much easier for them to prepare the land. The changes in ES value of the other biomes were little, or irrelevant, if considering their proportional area, i.e. less than 1% of total area of Mozambique (Wetlands, Desert, Lakes/River). From this group of biomes the Desert increased its ES value significantly (39.9%). This value was very high in Manica (1900%). Despite the proportional low value of this biome, this should be considered carefully because severe desertification is a serious problem in Mozambique (República de Moçambique, 2015b).

At province level, the total ES value changed negatively in all case. However, changes in biomes were different in both magnitude and location. Manica, Sofala, and Niassa were the provinces with the greatest increase in ES value in Cropland. As mentioned above, the Cropland increased in order to increase the food production as agriculture is considered the key factor for reducing poverty in the country (Cunguara, Garrett, Donovan, & Cássimo, 2013). Cidade de Maputo also had an important increase in Cropland (55.9%). This province hosts the capital and the most populated city of Mozambique: Maputo. However, it is important to note that the increase of Cropland led to the decline of ES value of other biomes, i.e. Grass/Rangeland, Forest and Lakes/Rivers, which provide important ES.

### 2.4.2. Limitations and uncertainties

The benefit transfer method has been widely used in ES valuation studies (Bateman, Mace, Fezzi, Atkinson, & Turner, 2011; Boyd & Wainger, 2003; Chen et al., 2014; Costanza et al., 2014; Gaodi, Lin, & Chunxia, 2010; Kubiszewski et al., 2013; Liu et al., 2010; Maes et al., 2012; Troy & Wilson, 2006). However, this method has several shortcomings, such as being prone to errors resulting from the lack of correspondence between the estimate of ES value per hectare to all areas having the same land-cover or habitat type (Plummer, 2009). The ES analyzed in this study are limited to the ones available in the ESVD (Annex 1). However, knowing that each biome may deliver multiple ES necessarily makes our ES value estimates undervalued. For instance, the Tropical Forest delivers relevant services such as erosion protection, water service, gas regulation, etc. However, the study selected in the ESVD to value this biome in Mozambique valued only raw materials, food, biodiversity protection, and pollination services. Also, the ES analyzed per biome were valued all together making it impossible any kind of individualization regarding each specific service. Consequently, an analysis on how much each single service changed between the two dates was not provided. Additionally, assuming constant ES value or lack of measurements, and poorly representative sizes of study sites are also potentially important problems when extrapolating ES values (Eigenbrod et al., 2010; Frélichová et al., 2014).

In this study the biomes and corresponding ES values came from studies applied to different regions, scales, and time, also constituting a source of uncertainty. These studies may also contain biased data due to biophysical and socio-economic conditions different from our study area making them unsuitable for the benefit transfer method application (Wilson & Hoehn, 2006). Finally, the ecological pattern, quality, and processes have strong influences on ES value (W. Wang et al., 2014; Zang et al., 2017). However, in our study, changes in ES value ignore these factors as only the changes of ecosystem areas are considered.

Land cover data availability was also an important limitation in this study. The most recent data available were from 2005 and 2009, which is quite old considering Mozambique's increasing performance in economic activity (World Bank, 2016). The spatial resolution of the land cover data is coarse and may lead to generalization problems. For instance, small area sizes of wetlands, which have their own typical ES, may be generalized to other land cover types. Additionally, the accuracy value (73%) of GlobCover is below the minimum level of interpretation accuracy in the identification of land use and land cover categories from remote sensing data which should be at least 85% (Anderson, Hardy, Roach, & Witmer, 1976). Finally, the conversion of the land cover classes from GlobCover to biomes is also a source of uncertainty due to the transitional characteristics of some of the land cover classes.

Despite all these limitations, and knowing that the evaluation of ES using primary data is costly forcing researchers to work with proxies (Eigenbrod et al., 2010), this studied tried to minimize them. Still, it was not possible to eliminate all of the problems in our assessment considering the available resources. Follow-up studies for more accurate ecosystem service assessment, which will include the use of tools such as InVEST (H Tallis et al., 2014), are necessary to reduce the impact of these errors.

### 2.5. Conclusions

This study contributes to ES science by providing the first monetary evaluation of ES and changes as a result of land cover change in Mozambique between 2005 and 2009. Spatial planning decisions benefit from the incorporation of the effects on ES (Geneletti, 2011). The measurement of the ES value with the benefit transfer method at the province level provided an innovative perspective and a better understanding of the different regional ES value dynamics, which are closely linked to the economic development of the country.

The findings can help policy-makers to optimize Mozambique's land use structure to maximize total ES value. For instance, with this type of information, trade-offs in ES resulting from alternative land use policies can be assessed and used in the definition of land planning policies. The existing policy instruments (Table 2.1) should be jointly coordinated for targeting specific or several ES with the aim of achieving sustainability in the country. With this study, at province level, it is possible to inform policy makers regarding the responsibility of each province in ES provisioning for Mozambique (Table 2.6). The policy makers now have the tools to know how each province is performing regarding ES provisioning (Fig. 4). This will enable them to develop specific efforts for the underperforming provinces. An effort to include sustainability goals based on ES on the existing policy instruments (Table 2.1) is still lacking and it must be pursued by the Mozambican authorities.

It is important to note that not all the services provided by the biomes were assessed, such as climate regulation provided by the Forest biome that could also be linked to specific policy instruments (e.g. the National Strategy for Climate Change Adaptation and Mitigation (República de Moçambique, 2015b)). Thus, this study's results can be considered only as a preliminary ES assessment with the aim of raising awareness of policy makers about the importance of ES.

Although some suitable studies exist in the ESVD to apply the benefit transfer method, there is a lack of updated valuation studies, both biophysical and monetary, for Africa and, particularly, for Mozambique. Thus, there is a strong need to improve the number of ES valuation studies for this important continent and, most specifically, for Eastern African countries that are undergoing significant land changes. Nevertheless, for an initial assessment, the data and methodology can be very useful as a basis for future ES valuation studies in Mozambique aiming at the preservation of ES provisioning.

Mozambique's total ES value was estimated at 5,054.4x10$^{\wedge 6}$ US$ for the year 2009, representing a variation of -11.4% since 2005. However, considering that the ES value for the year 2009 was about half of the GDP for the year 2009 (10,910x10$^{\wedge 6}$ US $), one might conclude that the ES value of Mozambique is substantial. Additionally, the results of this study can also be used to raise awareness about the importance of preserving ES to improve human-wellbeing in Mozambique, and for going beyond GDP as a national welfare measure and policy goal. Future research should focus on multi-ES that exist in the country, which are not yet studied and/or valued, with the objective of updating the ES value estimates presented in this study.

## 3) Ecosystem services and biodiversity trends in Mozambique as a consequence of land cover change

### 3.1. Introduction

Ecosystem services (ES) are the benefits that people derive from nature and these are essential for human well-being (Costanza et al., 2014; Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, & Suttonkk, 1997; Daily, 1997; Mooney et al., 2005). However, their ability to support mankind is being threatened by the increasing demand of land for agriculture, forest, industrial, and urban areas (Halpern et al., 2008; Kareiva et al., 2011b). Considerable efforts have been carried out to draw attention to the importance of preserving natural capital, and also to providing useful information for decision making through biophysical (Yang Bai et al., 2012; Leh et al., 2013) and economic valuation studies of ES (Frélichová et al., 2014; Kindu et al., 2016b; Kubiszewski et al., 2013; Sander et al., 2016). ES mapping tools and quantitative biophysical and economic indicators make ES values visible thereby helping to assess the tradeoffs associated with these interactions (Burkhard, Crossman, Nedkov, Petz, & Alkemade, 2013; Maes et al., 2012; Heather Tallis & Polasky, 2009, 2011). To this end, several national ecosystem assessments have been carried out under the Millennium Ecosystem Assessment framework (Millenium Assessment, 2003). However, these are context-specific, and insufficiently harmonized to inform European policies (Schröter et al., 2016). For instance, the Portuguese national ecosystem assessment (Pereira, Domingos, Vicente, & Proença, 2009) is composed of several dispersed case studies, and does not include a national assessment at country level. Thus, there is need for national ecosystem assessments that provide a valuation of multiple ecosystem services in biophysical and/or economic terms.

One possible way of carrying out regional and national assessments is to study the impact of land cover change (LCC) on the provision of multiple ES (Feger, Cabral, Basque, Levrel, & Chambolle, 2015; Leh et al., 2013; Tolessa, Senbeta, & Kidane, 2017). The effective management of LCC has been considered crucial to design policies able to ensure ES supply (Martínez-Harms & Balvanera, 2012; Mascarenhas, Ramos, Haase, & Santos, 2015; Nelson et al., 2009; Portela & Rademacher, 2001; Swetnam et al., 2011). It has also been demonstrated that to better understand the impact of planning policies it is important to have decision support-tools based on system diagnosis and simulation of scenarios (Costanza & Ruth, 1998; Kareiva, Tallis, Ricketts, Daily, & Polasky, 2011a; Kubiszewski, Costanza, Anderson, & Sutton, 2017; Maes et al., 2012; Olsson, Folke, & Berkes, 2004).

Studies about the impact of LCC on ES have been carried out all over the world (Feger et al., 2015; Polasky, Nelson, Pennington, & Johnson, 2011; Zongming Wang et al., 2015). For Africa, these studies are rare, possibly due to the lack of data (Abram et al., 2014; Dawson & Martin, 2015; Kindu et al., 2016b; Leh et al., 2013; Wangai, Burkhard, & Müller, 2016). This constitutes an important problem because this continent is undergoing significant LCC with important impacts on the supply of ES (Kindu et al., 2016b; Leh et al., 2013; Power et al., 2010). Specifically for Mozambique, earlier works have analyzed ES at national, regional, and local levels (Mudaca et al., 2015b; Nagabhatla, Saimone, Juizo, & Masiyandima, 2008; P. Nunes & Ghermandi, 2015; von Maltitz, Gasparatos, Fabricius, Morris, & Willis, 2016; C. Wong, Roy, & Duraiappah, 2005). However, none has provided a biophysical assessment of ES at national and/or province levels nor their changes as a consequence of LCC. As a result, it is still difficult to understand ES trends and dynamics in Mozambique, complicating the task of preserving natural capital. The lack of such studies may constitute an important obstacle for designing policies aiming to maintain ES supply.

In order to provide more precise information about the state of ES in Mozambique, we use a spatially explicit modeling tool - the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) (H Tallis et al., 2014) - that uses ecological production functions and economic valuation as inputs (in this study, we perform only a biophysical assessment). InVEST is a free and open model, has low data requirements, and has demonstrated its usefulness in different study areas (Cabral et al., 2016; Delphin, Escobedo, Abd-Elrahman, & Cropper, 2013; Geneletti, 2013; Goldstein et al., 2012; Jiang, Li, Wang, & Zhang, 2016; Leh et al., 2013; Nelson et al., 2009; Posner, Verutes, Koh, Denu, & Ricketts, 2016). Thus, the main goal of this study is to assess the impact of LCC on multiple ES and biodiversity of this country. The assessment is focused on “landscape services”, i.e., the capacity of a landscape to provide goods and services to society (Lamarque, Quétier, & Lavorel, 2011). We use “ecosystem service indicators” to model the likely trends in ES, as these represent “quantitative spatially differentiated metrics or maps related to supply of, or demand for, ecosystem services” (EPA, 2009). The specific objectives of this exploratory and awareness raising study are:

(i) To identify and describe the trends of ES and biodiversity in Mozambique as a consequence of LCC between 2005 and 2009 using open data;

(ii) To estimate future LCC for year 2025, and the impact on Mozambique’s ES and biodiversity.

With this study we expect to shed light on issues regarding the assessment of ES at the country level, and to discuss how this approach can provide useful information for planning.

## 3.2. Materials and methods

### 3.2.1. Study area

Mozambique, officially the Republic of Mozambique, is located in southeast Africa and comprises a land surface of about 800,000 km$^2$ (Figure 3.1). This country is naturally endowed with a diverse landscape including coastal plains, savannah, woodlands, and mountains. There are many rivers flowing from west to east into the Indian Ocean, with the Zambezi and Limpopo being the two largest. Mozambique is divided into 11 provinces, and shares borders with six countries. The country had about 27.98 million inhabitants in 2015 (World Bank, 2016). This represents an increase of 37.4% in total population since the last census in 2007 (INE, 2007) (Table 3.1). The capital and largest city is Maputo, with 1.24 million inhabitants (projected population) (INE, 2015). Mozambique´s Gross Domestic Product (GDP) was US $14,807 billion in 2015 (World Bank, 2016). The country ranked 180 out of 188 countries in the Human Development Index for year 2015 (UNDP, 2015).


*Figure 3-1: Mozambique provinces, dams, and numbered hydrological basins.*

*Table 3-1: Mozambique's population in year 2007 (INE 2007)*

| Province | 2007 | Inhab. / Sq Km | Area (Sq Km) |
|---|---|---|---|
| Cabo Delgado | 1,683,681 | 21 | 78,778 |
| Gaza | 1,362,174 | 18 | 75,334 |
| Inhambane | 1,444,282 | 21 | 68,775 |
| Manica | 1,400,415 | 22 | 62,272 |
| Maputo-Província | 1,098,846 | 47 | 23,258 |
| Maputo-Cidade | 1,271,569 | 3667 | 347 |
| Nampula | 3,861,347 | 49 | 79,010 |
| Niassa | 1,055,482 | 8 | 129,798 |
| Sofala | 1,715,557 | 25 | 67,753 |
| Tete | 1,593,258 | 16 | 100,662 |
| Zambézia | 3,880,184 | 37 | 103,478 |
| Total | 20,366,795 | 26 | 789,466 |

Drought is a serious problem, especially in the Southern provinces of the country, with devastating consequences, such as the loss of crops and cattle, and famine. According to SETSAN (SETSAN, 2016) approximately 2.3 million people are expected to be food insecure between October and March 2017. Mozambique, has also been identified as especially vulnerable to flooding due to the occurrence of tropical storms (Cardona et al., 2012; Chemane, Motta, & Achimo, 1997; Nicholls & Tol, 2006). Mozambique has one of the longest African coastlines, approximately 2,700km, with a high level of exposure of coastal populations to climate hazards and erosion (around 60% of the population live in the coastal areas) (INE, 2016a; República de Moçambique, 2015a, 2015b). This exposure is being amplified by the increase of people and associated infrastructures (EEA, 2006; Martins, Pires, & Cabral, 2012), and by the expected increase in coastal flooding and sea level rise (IPCC, 2014).

### 3.2.2. Data and methods

The overall methodology followed in this paper is shown in Figure 3.2 and explained further below.

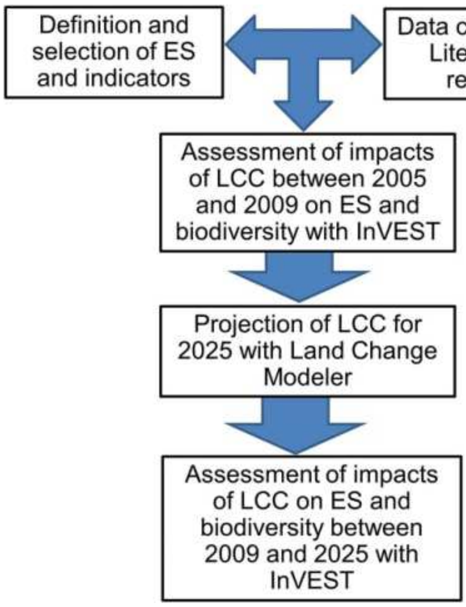


*Figure 3-2: Flowchart of the methodology used in the study.*

This study deals only with ES supply and does not specifically examine the ES demand. However, considering that 80% of the population depends on agriculture production (FAO, 2012), it is reasonable to assume that ES indicators related with the sustainability of food production are in high demand. Water provision and quality are also ES of utmost importance in Mozambique, as almost half of the population does not have access to treated water for domestic use (INE, 2016b). Earlier research has demonstrated a positive relationship between well-being and the biodiversity richness (Dallimer et al., 2012), and the preservation of biodiversity is equally important for Mozambicans. Finally, climate regulation is an important global ES (Gómez-Baggethun & Barton, 2013). Therefore, and considering the data availability, the selected ES indicators for modelling included water yield, water quality, sediment retention, carbon storage, and biodiversity. These indicators have been used successfully in other studies (Yang Bai et al., 2012; Bhagabati et al., 2012; Cabral et al., 2016; Leh et al., 2013). Table 3.2 shows the ES and respective ES indicators (units) used in the current study. We used the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) tool (H Tallis et al., 2014) to quantify and map ES indicators. ESRI ArcGIS (ESRI, 2014) was the software used to process, analyze, and map all of the geographical data used in the study.

*Table 3-2: Ecosystem services and biodiversity indicators used in this study.*

| **Ecosystem services** | **Ecosystem service indicator, units** |
|---|---|
| Water yield | Water yield, $m^3$/ha/year |
| Water quality | Nutrient retention (nitrogen), kg/ha/year |

| | |
|---|---|
| Erosion regulation | Sediment retention, t/ha/year |
| Climate regulation | Carbon stored, t/ha/year |
| Biodiversity | Habitat quality score [0–1]/year |

### *3.2.2.1. Land cover data*

The land cover maps of Mozambique for years 2005 and 2009 used in this study are from ESA/ESA GlobCover Project (http://due.esrin.esa.int/page_globcover.php). These datasets differentiate 19 classes of land cover (Table 3.3), and are derived from data acquired by the ENVISAT MERIS sensor, with 300m of spatial resolution (GlobCover, 2015). The overall accuracy is 73% (Defourny et al., 2009). Additional data for administrative boundaries were obtained from the National Center of Cartography (CENACARTA) (http://www.cenacarta.com).

*Table 3-3: Land cover classes from GlobCover Project and legend reclassification.*

| Code | Land use land cover category | Simplified legend (Bai et al. 2014) |
|---|---|---|
| 14 | Rainfed croplands | Cropland |
| 20 | Mosaic cropland (50–70%) /vegetation (grassland/shrubland/forest) (20–50%) | Cropland |
| 30 | Mosaic vegetation (grassland/shrubland/forest) (50–70%) /cropland (20–50%) | Cropland |
| 40 | Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m) | Forest |
| 50 | Closed (>40%) broadleaved deciduous forest (>5m) | Forest |
| 60 | Open (15–40%) broadleaved deciduous forest/woodland (>5m) | Forest |
| 90 | Open (15–40%) needle-leaved deciduous or evergreen forest (>5m) | Forest |
| 100 | Closed to open (>15%) mixed broadleaved and needle-leaved forest (>5m) | Forest |
| 110 | Mosaic forest or shrubland (50–70%) /grassland (20–50%) | Shrubland |
| 120 | Mosaic grassland (50–70%) /forest or shrubland (20–50%) | Grassland |
| 130 | Closed to open (>15%) (broadleaved or needle-leaved, evergreen or deciduous) shrubland (<5m) | Shrubland |
| 140 | Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses) | Grassland |
| 150 | Sparse (<15%) vegetation | Grassland |
| 160 | Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) – Fresh or brackish water | Wetland |
| 170 | Closed (>40%) broadleaved forest or shrubland permanently flooded – Saline or brackish water | Wetland |

| | | |
|---|---|---|
| 180 | Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil – Fresh, brackish, or saline water | Wetland |
| 190 | Artificial surfaces and associated areas (Urban areas >50%) | Urban |
| 200 | Bare areas | Desert |
| 210 | Water bodies | Water |

#### *3.2.2.2. ES indicators*

All of the ES indicators were calculated using a 300m spatial resolution. All spatial datasets had or were converted into a common World Geodetic System 84 Universal Transverse Mercator projection.

**Water yield**

Water yield is the amount of water running off the landscape (Langbein & Iseri, 1995). The Water Yield InVEST model is based on the Budyko curve and annual average precipitation (H Tallis et al., 2014). The hydrologic basins, available at the CENACARTA website, are based on the 30 meter digital elevation model (DEM) from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). We parameterized this InVEST model using average annual precipitation (Hijmans, Cameron, Parra, Jones, & Jarvis, 2005), annual reference evapotranspiration (Trabucco & Zomer, 2009), soil characteristics (FAO, IIASA, ISRIC, ISSCAS, & JRC, 2012), watersheds from CENACARTA, and land cover (ESA, 2015) to calculate the average water yield. We report water yield in $m^3$/ha/year. Pixel values were aggregated by province using a GIS operation (zonal statistics) available in the ArcGIS software. Annex S.1 provides the biophysical values used to parameterize the InVEST water yield model (Leh et al., 2013; Leh, Matlock, Cummings, & Nalley, 2016).

**Water quality**

The InVEST nutrient retention model evaluates land cover effects on water quality (H Tallis et al., 2014). The average annual quantity of nutrients exported from each land cover cell is determined using values found in the literature for nitrogen (N) export coefficients (H Tallis et al., 2014). The nutrient load is obtained by routing water along flow paths based on slope (H Tallis et al., 2014). Finally, the nutrient load quantity retained by the landscape is calculated using the nutrient retaining capacity of each type of land cover (H Tallis et al., 2014). We parameterized this InVEST model using a digital elevation model (DEM) (NASA, 2012), annual reference evapotranspiration (Trabucco & Zomer, 2009), soil characteristics (FAO et al., 2012), watersheds from CENACARTA, and land cover (ESA, 2015). We report nutrient retention (nitrogen) in kg/ha/year. Pixel values with mean nutrient retention were aggregated by province using a GIS operation (zonal statistics) available in the ArcGIS software. Annex S.1 provides the biophysical values used to parameterize the InVEST nutrient retention model (Leh et al., 2013, 2016).

**Erosion regulation**

Soil erosion can be caused by rain and runoff. Harmful effects of erosion include (Lal, 1998; Mann, Tolbert, & Cushman, 2002): the reduction of water quality, reduction of soil ability to store water and nutrients, reduction of agronomic productivity, damage in infrastructures, and siltation. The sediment retention InVEST model (H Tallis et al., 2014) was used to determine the ability of the landscape to retain sediments in a watershed as a function of rainfall (Hijmans et al., 2005), soil characteristics (FAO et al., 2012), and topography (NASA, 2012). The model uses the Universal Soil Loss Equation (USLE) (Wischmeier, 1978) to calculate the potential soil loss of each type of land use and land cover (1):

$$\mathrm{USLE} = \mathrm{R} * \mathrm{K} * \mathrm{LS} * \mathrm{C} * \mathrm{P} \qquad (1)$$

where USLE is the potential average annual soil loss, R is the rainfall erosivity factor, K is the soil erodibility factor, LS is the slope length and steepness factor, C is the land use and land cover management factor, and P is the supporting practice factor (Wischmeier, 1978). The sediment retention corresponds to the difference between potential soil loss (USLE) of the landscape and the maximum potential soil loss assuming a bare landscape. The rainfall erosivity (R) is a climatic factor strongly related to soil loss, and was obtained using (Roose, 1996) (2):

$$\mathrm{R} = 0.5 * P + 0.05 \qquad (2)$$

where R is rain erosivity and $P$ is the average annual precipitation (mm) (Hijmans et al., 2005). We report sediment retention in t/ha/year. Pixel values with mean sediment retention were aggregated by province using a GIS operation (zonal statistics) available in the ArcGIS software. Annex S.1 are provides the biophysical values used to parameterize the InVEST sediment retention model (Leh et al., 2013, 2016).

**Climate regulation**

Carbon storage is an important global climate regulating service (Gómez-Baggethun & Barton, 2013). Estimates of the carbon stored by the vegetation for each land cover class with values found in literature (Leh et al., 2013) were used in the InVEST carbon model (H Tallis et al., 2014). The carbon stored by Mozambique's landscape is reported in t/ha/year and was aggregated by province using a GIS operation (zonal statistics) available in the ArcGIS software. Annex S.2 are provides the biophysical values used to parameterize the InVEST carbon model (Leh et al., 2013, 2016).

**Biodiversity**

Biodiversity is not considered an ES despite being associated with functional services that provide ES, such as soil fertility, pest control, pollination, water yield, and water quality (Hassan, Scholes, & Ash, 2005; Lavorel et al., 2015; Newbold et al., 2015). The InVEST habitat quality model uses information on land cover and threats to biodiversity to produce habitat quality maps (H Tallis et al., 2015). Habitat quality is the ability of the ecosystem to provide appropriate conditions for individual and population persistence and depends on four factors (H Tallis et al., 2015): (i) the relative impact of each threat; (ii) distance between habitat and the threat source; (iii) level of legal / institutional / social / physical protection from disturbance in each cell; and (iv) the relative sensitivity of each habitat type to each threat on the landscape. We modeled biodiversity using the approach described by Leh et al. (2013). These authors considered "disturbed" and "undisturbed" land cover category as "non-habitat" and "habitat" areas, respectively. The habitat quality score ranges from 0 (non-habitat land cover classes) to 1 (perfect habitat land cover classes). The habitat degradation sources (roads, urban areas, and agriculture areas) were weighted and given a maximum distance of degradation influence (Leh et al., 2013). The habitat quality of Mozambique is reported as an average of pixel scores resulting from the model ranging from 0 to 1. These values are aggregated to provide estimates by province using a GIS operation (zonal statistics) available in the ArcGIS software. Annex S.3 provides the biophysical values used to parameterize the InVEST habitat quality model (Leh et al., 2013, 2016).

#### 3.2.2.3. Projection of land cover for year 2025

LCC were projected for year 2025 using the Land Change Modeler available in IDRISI Selva software (Eastman, 2012). This model uses the historical changes from 2005 to 2009 land cover maps to project future land cover for year 2025. The land change demand was obtained through the use of Markov chains that determined the probability of a pixel changing to another class between year 2005 and 2009. The transition potentials correspond to suitability maps for each land cover transition, and express the likelihood that land will transition in the future using a multi-layer perceptron neural network. During this process, a collection of potential transition maps is created using driver variables that were transformed using a natural log. Only the transitions with more than 100,000 cells were retained for the modeling exercise for the sake of simplicity, and because we are interested only in the major transitions. As we had only two time moments for the land cover, it was not possible to assess the quality of the model projection output. We assumed a *Business as usual* (BAU) case scenario, in which the historical trend of LCC between 2005 and 2009 was used to project 2025 land cover without any planning restrictions. The resulting land cover map was used to obtain the ecosystem service indicators described in Section 2.2.2 for the year 2025.

#### 3.2.2.4. ES changes

After calculating the ES of each type for each year in Mozambique, changes were calculated as (3):

$$ESC_x = \left[\frac{ES_{t+1x} - ES_{tx}}{ES_{tx}}\right] * 100 \qquad (3)$$

where $ESC_x$ is the ES change index for delivering ES of type *x*, $ES_{tx}$ is the baseline situation for delivering ES of type *x* at time t, and $ES_{t+1x}$ is the situation for delivering ES of type *x* at time t+1.

## 3.3. Results

### 3.3.1. Land changes in Mozambique between 2005 and 2009

After reclassifying GlobCover classes using a simplified land use and land cover legend (Yan Bai et al., 2014) (Table 3.3), we observe an important increase in the cropland between 2005 and 2009 (27%) (Table 3.4). This class, the second major type of land cover in the country, increased its proportion in the landscape from 17% to 22%. It is likely that in the long term cropland will continue to grow due to the need for food production to address the increasing population of the country (World Bank, 2016). This will have an important impact on ES provided mostly by shrubland and grasslands, as these are the land covers that will most likely change into cropland. According to (FAO, 2013), the main farming system in Mozambique is rain-fed subsistence farming with low levels of productivity due to the lack of conditions, including technology, market accessibility, storing infrastructure and agricultural organization (Woodhouse, 2014). Therefore, to increase production small farmers increase agricultural land by converting other land covers into cropland, mainly grassland and shrubland, because it is much easier for them to prepare the land. Conversely, the shrubland, which is the third largest type of land cover, has decreased sharply, from 21% in 2005 to 15% in 2009. Forest is the largest land cover class and has remained practically unchanged between the two dates (60% in 2005 and 62% in 2009). The other classes represented altogether, approximately, less than 2% of Mozambique's total area. From these, it is worth noting that the water bodies fell 9%, between 2005 and 2009.

*Table 3-4: Land cover changes between 2005 and 2009 (C: Cropland; F: Forest; S: Shrubland; G: Grassland; W: Wetland; U: Urban; D: Desert; WB: Water Bodies).*

| | **2009** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2005** | **Class** | **C** | **F** | **S** | **G** | **W** | **U** | **D** | **WB** | **Total ha** | **%** | **Var (%) 05–09** |
| 2005 | C | 7,216,749 | 4,500,738 | 1,455,930 | 92,466 | 450 | 63 | 1089 | 11,367 | 13,278,852 | 17.14 | 27 |
| | F | 5,760,801 | 36,935,244 | 3,634,830 | 227,880 | 828 | 45 | 396 | 26,955 | 46,586,979 | 60.14 | 3 |
| | S | 3,398,499 | 6,070,653 | 6,203,430 | 330,714 | 378 | 126 | 54 | 9171 | 16,013,025 | 20.67 | –28 |
| | G | 402,345 | 248,076 | 282,798 | 620,046 | 27 | 99 | 2034 | 12,717 | 1,568,142 | 2.02 | –17 |
| | W | 549 | 729 | 27 | 99 | 2484 | 0 | 0 | 72 | 3960 | 0.01 | 13 |
| | U | 225 | 108 | 99 | 153 | 0 | 10,872 | 0 | 36 | 11,493 | 0.01 | –2 |
| | D | 189 | 0 | 27 | 1764 | 0 | 0 | 2538 | 171 | 4689 | 0.01 | 40 |
| | WB | 30,879 | 45,900 | 11,889 | 32,202 | 315 | 36 | 450 | 580,149 | 701,820 | 0.91 | –9 |
| | Total ha | 16,810,236 | 47,801,448 | 11,589,030 | 1,305,324 | 4482 | 11,241 | 6561 | 640,638 | 77,467,140 | | |
| | % | 21.7 | 61.71 | 14.96 | 1.69 | 0.01 | 0.01 | 0.01 | 0.83 | | | |

### 3.3.2. Impact of land changes in ecosystem services between 2005 and 2009

Figure 3.3 shows ES changes between 2005 and 2009 in Mozambique. There was an increase in climate regulating service (carbon storage) (7.4%), which is consistent with the increase in forest (2%) and wetland (13%) classes. However, water quality (nitrogen retention) (-8.6%), and biodiversity (-5.5%) decreased as a result of LCC in Mozambique. Both water yield (-1.6%) and erosion regulation (-0.2%, sediment retention) had variations too small to be considered significant considering data and modeling uncertainties.

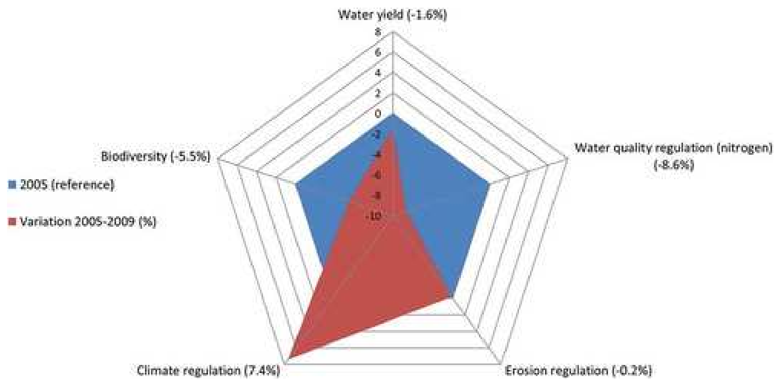


*Figure 3-3: Ecosystem service changes (%) in Mozambique (2005–2009).*

Table 3.5 shows the changes (%) in ES per province. Maputo city is by far the province with the poorest performance in all the ES. All ES fell considerably in this province as a result of LCC (changes between -86.3% and -96.8%). This may be associated with the urbanization process necessary to accommodate an increasing number of people living in the country's capital and environs (INE, 2015), and also with the increase of cropland necessary to support food needs (FAO, 2013). Maputo and Maputo city were the only provinces in which all ES decreased. All the other provinces had mixed performances, with positive and negative evolutions in the level of ES provision translating different LCC dynamics.

*Table 3-5: Ecosystem service changes (%) by province (2005–2009).*

| Province | Water yield | Water quality(N retention) | Erosion regulation | Biodiversity | Climate regulation |
|---|---|---|---|---|---|
| Cabo Delgado | 1.5 | 4.3 | –2.9 | –10.4 | –23.7 |
| Gaza | –4.8 | –22.2 | 0.6 | –5.8 | 24.2 |
| Inhambane | –0.6 | –10.1 | –1.5 | –8.4 | 12.4 |
| Manica | –2.9 | –10.9 | –1.2 | –5.2 | 25.2 |
| Maputo | –0.8 | –2.1 | –5.4 | –13.4 | –11.3 |
| Maputo City | –94.6 | –96.2 | –86.3 | –96.8 | –93.3 |
| Nampula | –1.3 | –7.0 | 0.5 | 0.2 | 6.8 |
| Niassa | –2.8 | –6.5 | –0.5 | –3.7 | 4.8 |
| Sofala | –0.7 | –6.7 | –2.7 | –15.5 | 4.1 |
| Tete | –5.5 | –13.6 | 2.7 | 1.4 | 32.7 |
| Zambezia | –1.0 | –1.6 | –0.4 | –4.0 | 6.4 |

Figure 3.4 shows the variation of ES for all the provinces using year 2005 as reference. Orange to red colors represent an increasing decline in the ES between 2005 and 2009, while light green to dark green represent an increasing improvement in ES. Maputo city is always red color, indicating a degradation of more than 30% in all ES. The water quality regulating service has also decreased strongly in the Gaza province (-22.2%). Sofala had the second poorest

performance after Maputo city in biodiversity (-15.5%). Cabo Delgado also had a notable decrease in the climate regulating service as a consequence of LCC (-23.7%).

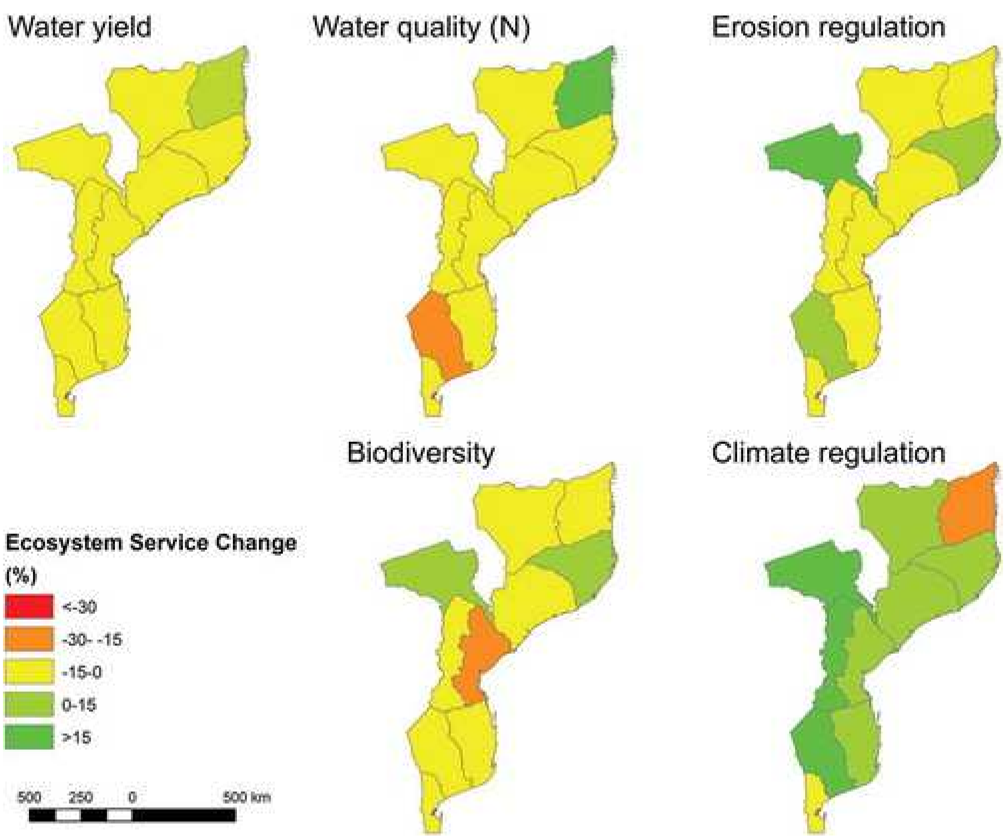


*Figure 3-4: Ecosystem service changes (%) by province (2005–2009).*

### 3.3.3. Modelled land change trends and impacts on ES for 2025

Figure 3.5 reports the major trends in land cover modeled for 2025. Cropland is expected to remain stable (-0.6% between 2009 and 2025). Forest will continue to grow (3.1% between 2009 and 2025). This growth will mainly reflect the replacement of cropland by this class. Finally, shrubland will continue to fall (-12.1% between 2009 and 2025). In this case, both forest and cropland will contribute similarly to the decline of this class. Figure 3.6 shows the variation (%) of the ES indicator levels from 2005 to 2025 (index 100 in 2005).

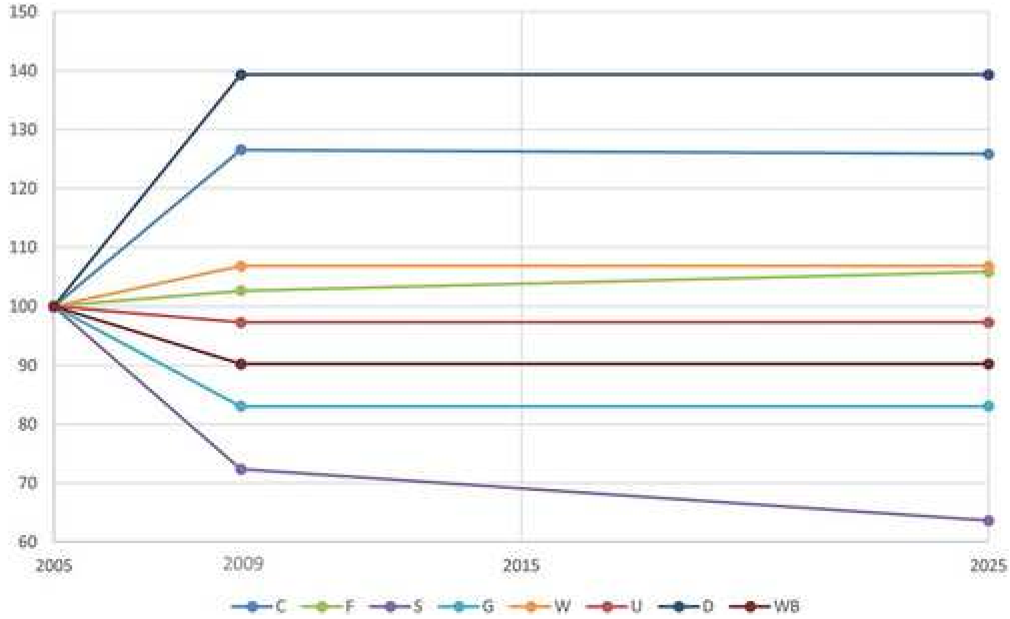


*Figure 3-5: Land cover changes between 2009 and 2025 (C: Cropland; F: Forest; S: Shrubland; G: Grassland; W: Wetland; U: Urban; D: Desert; WB: Water Bodies) (index 100 in 2009).*

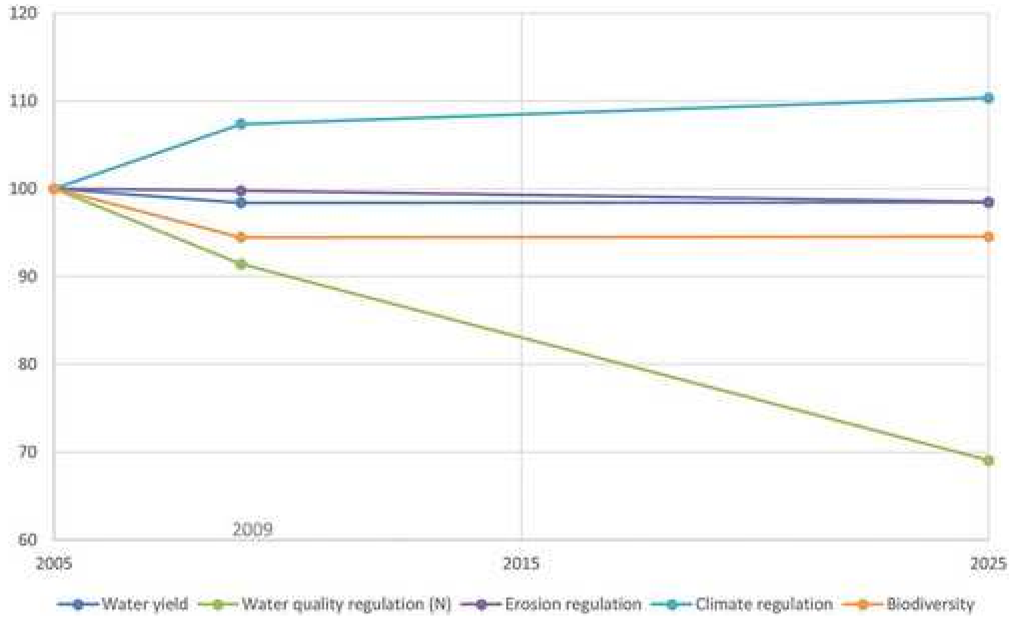


*Figure 3-6: Ecosystem service trends between 2005 and 2009 and 2025 projection results (index 100 in 2005).*

Results show that the climate regulating service is expected to increase 10.3% in Mozambique, confirming the trend seen between 2005 and 2009. However, water quality regulating service (nitrogen retention) is expected to fall sharply (-30.9%). All the other services will fall less than 6%. The reduction of nitrogen retention by the landscape can be explained by the increase of cropland (Martínez et al., 2009).

There was a slight reduction in water yield from 2005 to 2009 (-1.56%) at the country level, and this service is expected to be stable for 2025. However, a detailed analysis at the province level (Figure 3.7) shows that the provinces in the South of the country will be affected by a decrease in this service from 2009 to 2025.

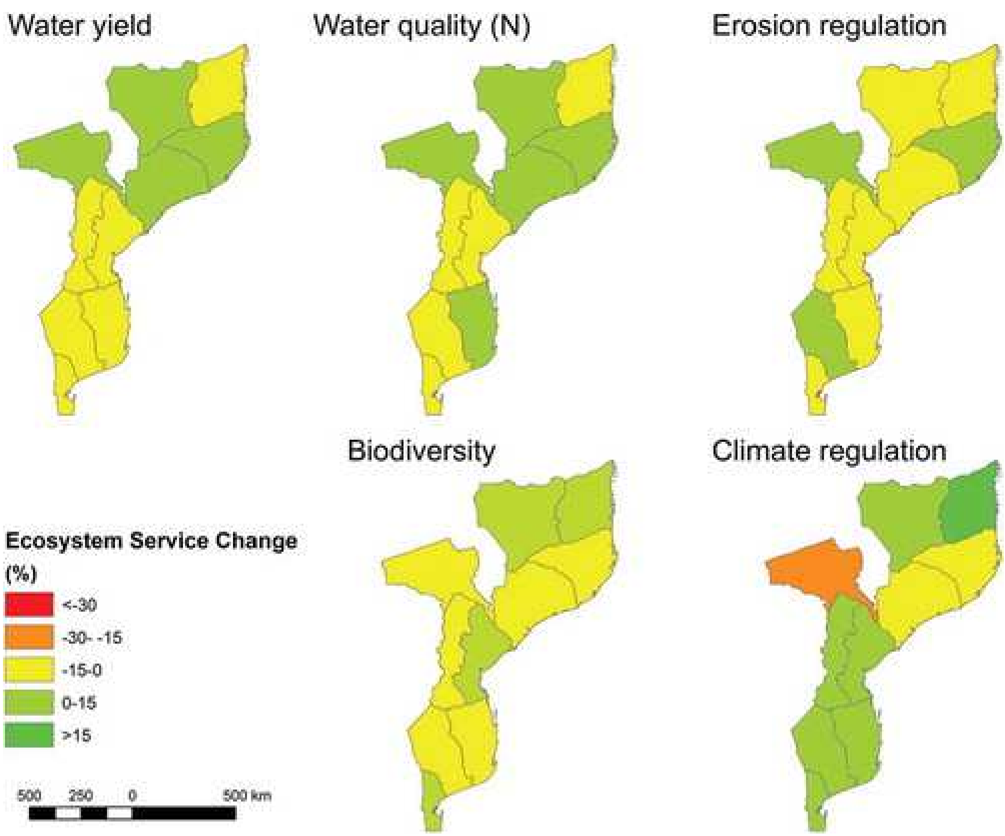


*Figure 3-7: Ecosystem service changes (%) between 2009 and 2025 by province.*

Another important result at the province level, and contradictory with the performance of the service at national level, is the decrease in the climate regulating service in the province of Tete (-16.3%), from 2009 to 2025. This province is undergoing substantial LCC due to the increasing demand for agricultural lands (26.5% increase in the agriculture class, between 2005 and 2009).

Overall, biodiversity fell -5.5% between 2005 and 2009, and is likely to remain stable from 2009 to 2025. A decrease of biodiversity is usually associated with an increase in agriculture activities (McLaughlin & Mineau, 1995). This decrease may be explained by the increase of agroforestry and other economic activities, which have caused the loss of suitable habitats for many species during the time period studied. The loss of biodiversity may severely jeopardize several ES and functions (Newbold et al., 2015).

## 3.4. Discussion

### 3.4.1. ES trends in Mozambique as a result of LCC

We provide the first ES and biodiversity assessment for Mozambique. In addition to earlier studies, which have used InVEST for mapping past changes in multiple ES and biodiversity in Africa, we also analyze future changes in ES and biodiversity as a consequence of LCC, at country and province levels. To overcome the lack of land cover data for Africa, and for Mozambique in particular, we employed a land change model to estimate future LCC, and quantified the impact on ES and biodiversity. The land change model allowed for an innovative perspective on the ES and biodiversity trends for this country, and to understand how each of the provinces was, and is expected to be, performing regarding each ES and biodiversity in the future.

### 3.4.2. LCC main impacts on ES and policy implications

At national level, the main problems identified by our study were the observed negative trends in the water quality service and biodiversity.

The projected decrease in the water quality service in Mozambique for year 2025 should be closely monitored, as two main coastal ecosystems depend greatly on water quality: mangroves and coral reefs. Both of these habitats have been widely acknowledged as important factors in the protection of coastlines worldwide (Cabral et al., 2017). The mangrove trees occupy an area of approximately 350,000ha (Barbosa, Cuambe, & Bandeira, 2001), and their ability to protect population and infrastructures from storms and cyclones has been reported in several studies (e.g., Barbier, 2016; Das and Crépin, 2013). Moreover, mangroves are themselves an important ecosystem for the subsistence of coastal communities, by providing rich fishing grounds, wood, medicine, coastal erosion protection, thereby contributing to the country's economic development (Barbosa et al. 2001). At the same time, the coral reefs on Mozambique's coast range from 413 to 570km$^2$ (Carissa Wong, Roy, & Duraiappah, 2005a), and are known to dissipate wave energy and assist in the prevention of sea storm effects on habitats and infrastructures of nearby coasts (Costa, Araújo, Araújo, & Siegle, 2016; van Zanten, van Beukering, & Wagtendonk, 2014). Coral reefs are also one of the major attractions for Mozambique's developing coastal tourism industry (Motta, Pereira, Gonçalves, Ridgway, & Schleyer, 2002). Knowing that Mozambique is likely to be severely affected by climate change and rising sea level (República de Moçambique, 2015b), the degradation of mangrove and coral habitats will likely increase coastal vulnerability, magnifying the effects of climate hazards and erosion, including the loss of lives (Cabral et al., 2017; UNISDR, 2016). These findings may have important policy implications for Mozambique. Our results may be linked to the national strategy for mangrove protection (República de Moçambique, 2015a), and to the strategy and action plan for the Integrated Coastal Zone Management (ICZM) of Mozambique, which is currently being developed (República de Moçambique, 2016). Our study offers relevant information to be considered in these plans because the increase of nutrients in the water increases the mortality of mangroves (Lovelock, Ball, Martin, & C. Feller, 2009), and negatively affects coral physiology and ecosystem functioning (D'Angelo & Wiedenmann, 2014). Knowing that about 60% of the population lives in coastal areas (INE, 2016a), our study confirms and reinforces the need for such strategies to preserve the important services provided by coastal habitats.

Regarding biodiversity, our results are worrying at national level despite the existence of planning instruments aimed at preservation of the country's environment and biodiversity (MICOA, 2007, 2014). Our findings call for the reinforcement of policies aimed at preserving biodiversity as it is positively connected to human well-being, and other functional services that provide ES (Dallimer et al., 2012; Hassan et al., 2005; Lavorel et al., 2015; Newbold et al., 2015).

At province level, our results allow the prioritization of individual services locally. By looking at the provinces individually, one can see which ES require more attention regarding the maintenance of ES levels. For instance, Maputo City clearly stands out from the other provinces as being the one with the poorest performance in all ES. Although this province represents a very small portion of the territory, it is the most densely populated one. An individual analysis of the other provinces will also allow deriving conclusions about which ES should be targeted for intervention by planners.

### 3.4.3. Limitations

Important aspects to consider when dealing with ecosystem assessments, and which are often overlooked by actors and researchers, are scale (Grêt-Regamey et al., 2014; Zhang, Holzapfel, & Yuan, 2013) and data and modeling uncertainties (Hamel & Bryant, 2017; Hou, Burkhard, & Müller, 2013). The scale of analysis has a variable impact on the results of ES studies (Raudsepp-Hearne & Peterson, 2016). It limits the type of ES possible to analyze, and also influences estimates of ES values (Grêt-Regamey et al., 2014; Zhang et al., 2013). The possible management interventions, including those for the area analyzed in this study, should always incorporate the effects of scale when targeting ecological processes sustaining ES generation (Lindborg et al., 2017). Regarding data and modeling uncertainties, and although techniques and strategies exist to minimize this problem, their implementation is not always possible due to the lack of data and/or modeling limitations (Hamel & Bryant, 2017; Hou et al., 2013). Thus, these ES assessment results should also be carefully interpreted concerning scale, data and modeling uncertainties.

The InVEST models were not assessed comparing the model outputs with real data or observations. Unfortunately, we had no access to datasets to validate the model results and, for this reason a sensitivity analysis was not carried out. Like all models, those used herein have several limitations, which are documented in the InVEST manual (H Tallis et al., 2015). For instance, the carbon model is very simplified and does not consider full carbon cycle (H Tallis et al., 2015). The same is true of the water model, which does not account for the whole hydrologic cycle (H Tallis et al., 2015). However, the advantage of the InVEST tool is to provide a set of open source models ready to use and available for anyone wishing to do multiple ES assessments in GIS environments. It is also important to note that we have measured only the potential of the ecosystem to provide such ES. More detailed analysis is required to study the relationship between land management practices, ES provision, and ES use by people.
The spatial resolution of the land cover data was coarse, leading to generalization problems. This is problematic in small but important areas such as wetlands, which have their own typical ES, and may be generalized to other land cover types. Additionally, the low level of accuracy of GlobCover (73%) is below the minimum level of interpretation accuracy in the identification of land use and land cover categories from remote sensing data, which should be at least 85% (Anderson et al., 1976). Another important aspect we had to deal with was the different characteristics of the data, such as disparate collection dates, and/or different scales. The coherent integration of these different datasets demanded a considerable effort. However, it required no additional data than those already available at national scale, which was very important for such a large study area. The quality and reliability of results can be improved when more accurate, updated, and detailed data become available. This work thus also calls for more recent and better land cover data for Africa in general and, in particular, for Mozambique. However, having access to better data will change only the suite of services to be analyzed if more human resources are available to carry out local and more detailed studies.

Finally, this study would have benefitted from stakeholder participation. This would help selecting a suite of ES that could better correspond to an effective demand of ecosystem services, and not to the authors' view regarding this subject. For example, other ES could have been analyzed, such as water quality related to pesticides and contaminants. Additionally, the discussion about the communication and/or adjustment of specific ES indicators, and scenario building, would enrich this approach, fitting better the information needs for effective spatial planning. Future works will include the development of alternative scenarios with economic valuation, and tradeoff analysis to better understand the impact of different planning options on ES.

### 3.5. Conclusions

This exploratory and awareness-raising study assessed the impact of LCC on multiple ES and biodiversity, using a spatiotemporal approach enabling a new perspective on the functions and uses of the natural environments of Mozambique. The estimates here presented point out the responsibility of the 11 provinces belonging to this territory in their capacities to maintain ES and biodiversity. This type of spatiotemporal diagnosis may help the provinces regarding their contribution to provide non-market ES. These indicators should help to carry out trade-offs considering the natural capital in addition to classic economic approaches. Beyond the completion of this study, which will also include scenario and ES valuation, the challenge will be to continue to work on the usefulness of this assessment and the way it can effectively influence decision-making activities, contributing to the maintenance of ecosystem functioning in Mozambique.

## 4) Avaliação dos serviços de ecossistemas em Moçambique entre 2005 e 2025

### 4.1. Introdução

Os ecossistemas fornecem uma larga escala de benefícios à sociedade conhecidos por serviços de ecossistemas (SE) (Millenium Assessment, 2003). No entanto, as mudanças nos ecossistemas num contexto global de crescente procura de terras para a agricultura, plantação de florestas e áreas urbanas estão a comprometer as suas capacidades em suportarem o bem-estar humano (Halpern et al., 2008; Kareiva et al., 2011b). Ao serem ignorados os benefícios que a Natureza proporciona, a humanidade coloca-se em perigo degradando os SE para além do limite da sustentabilidade (Millenium Assessment, 2003). Um factor com um impacto importante na provisão dos SE é a mudança de uso e cobertura do solo (Lawler et al., 2014). A gestão efectiva dos locais responsáveis pela manutenção dos SE têm sido considerados essenciais para prevenir o seu declínio (Cabral et al., 2016; Leh et al., 2013).

Esforços consideráveis têm sido realizados no sentido de se chamar a atenção para a preservação do CN, e também para se obterem informações úteis para tomada de decisão através da avaliação económica dos SE (Kindu et al., 2016b; Sander et al., 2016). Para esse fim, vários estudos têm sido realizados a nível mundial (Costanza et al., 2014; Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, & Suttonkk, 1997; R. de Groot et al., 2012), e/ou a nível nacional/regional (D'Amato et al., 2016; Joshi & Negi, 2011; Perez-Verdin et al., 2016). Alguns destes estudos de avaliação incluíram também abordagens espaciais explícitas (Kremer & Hamstead, 2016; Kubiszewski et al., 2013).

Globalmente, em 2011, o valor dos SE foi estimado em 125 triliões/ano de dólares americanos (USD) (assumindo mudanças nos biomas) e 145 triliões/ano USD (sem assumir a mudança de áreas dos biomas), tomando como referência o valor do USD em 2007 (Costanza et al., 2014). De acordo com estes autores, entre 1997 e 2011, o valor dos SE decresceu 4.3 – 20.2 triliões/ano de USD como resultado da mudança do uso e cobertura do solo. A perda de valor de SE a nível nacional e regional têm também sido reportados (Crespin & Simonetti, 2016; Zhiliang Wang et al., 2015). Em África existem poucos estudos sobre o valor dos SE como consequência da mudança de uso e cobertura do solo (Dawson & Martin, 2015; Kindu et al., 2016b). A principal razão desta falta de estudos deve-se em boa parte à ausência de dados (Leh et al., 2013). A escassez destes estudos constitui um problema importante porque a África encontra-se num processo significativo de mudanças de uso e cobertura do solo com um impacto importante na provisão dos SE (Kindu et al., 2016b; Power et al., 2010). Para Moçambique em particular, diversos estudos analisaram os SE a nível local e regional. Por exemplo, Wong et al. (2005) apresentaram uma revisão preliminar dos SE e respectivos determinantes e constituintes do bem-estar para Moçambique. Fallis (2013) descobriu que o Chibuto (distrito da província de Gaza no sudoeste de Moçambique) é largamente usado como um agroecossistema com agricultura, pastagem e recolha de fibra. Recentemente, Nunes e Ghermandi (2015) realizaram um estudo sobre a avaliação e compreensão dos SE marinhos do canal nortenho de Moçambique. Mudaca et al. (2015) estudaram os factores que influenciam a decisão dos agregados familiares em participarem no programa de pagamento de SE numa comunidade localizada na província de Sofala. Niquisse et al. (2017) estudaram as tendências dos SE e da biodiversidade em Moçambique como consequência da mudança do uso e cobertura do solo. Concluímos, portanto, que estudos sobre SE em Moçambique são raros e nenhum deles providenciou ainda uma avaliação monetária a nível nacional e/ou provincial nem as suas mudanças. A falta destes estudos pode ser um importante obstáculo na manutenção da provisão dos SE.

Em linha com as avaliações nacionais do *The Economics of Ecosystems and Biodiversity* (TEEB) (TEEB, 2010), este estudo realiza uma avaliação dos SE para Moçambique e das suas alterações como consequência do uso e cobertura do solo. Para tal, utilizaremos dados disponibilizados gratuitamente para avaliar os SE em Moçambique e nas suas províncias nos anos 2005, 2009 e 2025 usando uma abordagem espacialmente explícita. Conhecendo o valor dos SE e a sua dinâmica espacial a nível nacional e provincial, tornará possível considerar os SE na contabilidade nacional do bem-estar e ir para além do PIB como medida nacional de bem-estar e objetivo político.

### 4.2. Área de estudo

Moçambique situa-se no sudeste de África e possui uma área cerca de 800,000 km$^2$ (Figure 4.1). Este país possui uma paisagem diversificada que vai desde as planícies costeiras à savana, e da floresta à montanha. Existem muitos rios correndo do oeste para este até ao oceano Índico, sendo o Zambeze e o Limpopo os maiores rios do país. Moçambique encontra-se dividido em 11 províncias e faz fronteira com 6 países. A este, faz fronteira com Madagáscar através do canal de Moçambique. O país tem cerca de 28.83 milhões de habitantes (World Bank, 2016). A maior cidade e capital do país é cidade de Maputo com cerca de 1.2 milhões de habitantes (INE, 2015). O PIB era de 14807x10$^{\wedge 6}$ USD em 2015 (World Bank, 2016). Este país encontra-se na posição 180 de 188 países no mais recente Índice de Desenvolvimento Humano (UNDP, 2015).


*Figure 4-1: Área de estudo*

## 4.3. Métodos

Neste estudo, foram utilizados os mapas de uso e cobertura do solo de Moçambique do período entre 2004 e 2006 (aqui designado 2005) e 2009 do projecto *GlobCover* (http://due.esrin.esa.int/page_globcover.php). Estes são os únicos anos de referência disponíveis para estes dados e que diferenciam 19 classes de uso e cobertura do solo (Tabela 1). Estes dados foram obtidos a partir do satélite *ENVISAT MERIS* que conta com um sensor com 300m de resolução espacial (GlobCover, 2015). A precisão geral, ponderada pelas proporções das várias áreas das classes de uso e cobertura do solo é de 73% (Defourny et al., 2009). Adicionalmente foram obtidos dados da divisão administrativa de Moçambique no Centro Nacional de Cartografia (http://www.cenacarta.com).

*Table 4-1: Classes de uso e cobertura do solo do projecto GlobCover e o bioma correspondente (Yan Bai et al., 2014; Costanza et al., 2014).*

| Código | Classe de uso e cobertura do solo | Bioma |
|---|---|---|
| 14 | Zonas cultivadas de sequeiro | Zonas cultivadas |
| 20 | Mosaicos de zonas cultivadas (50-70%) / vegetação (pastagens/vegetação arbustiva/floresta) (20-50%) | Zonas cultivadas |
| 30 | Mosaicos de vegetação (pastagens/vegetação arbustiva/floresta) (50-70%) / Zonas cultivadas (20-50%) | Zonas cultivadas |

| | | |
|---|---|---|
| 40 | Floresta de folhas verdes largas ou semi-decídua (>5m) cerrada a aberta (>15%) | Zonas cultivadas |
| 50 | Floresta decídua de folhas largas (>5m) cerrada (>40%) | Floresta |
| 60 | Bosque/Floresta de folhas largas decídua (>5m) aberta (15-40%) | Floresta |
| 90 | Floresta verde ou de folhas agulha decídua (>5m) aberta (15-40%) | Floresta |
| 100 | Floresta mista de folhas agulha e de folha larga (>5m) cerrada a aberta (>15%) | Floresta |
| 110 | Mosaicos de floresta ou vegetação arbustiva (50-70%) / pastagens (20-50%) | Pradaria/Pastagens |
| 120 | Mosaicos de pastagens (50-70%) / floresta ou vegetação arbustiva (20-50%) | Pradaria/Pastagens |
| 130 | Vegetação arbustiva (<5m) (folhas largas ou de agulhas, de folhas verdes ou decíduas) cerrada a aberta (>15%) | Pradaria/Pastagens |
| 140 | Vegetação herbácea (pastagens, savanas ou líquenes/musgos) cerrada a aberta (>15%) | Pradaria/Pastagens |
| 150 | Vegetação dispersa (<15%) | Pradaria/Pastagens |
| 160 | Floresta de folha larga cerrada a aberta (>15%) em solo regularmente inundado (semipermanente ou temporariamente) – Água fresca ou salobra | Zonas húmidas |
| 170 | Floresta de folha larga ou mato cerrada (>40%) em solo permanentemente inundado ou alagado – Água salobra ou salgada | Zonas húmidas |
| 180 | Pastagens ou vegetação arborizada cerrada a aberto (>15%) em solo regularmente inundado ou alagado – Água fresca, salobra ou salgada | Zonas húmidas |
| 190 | Superfícies artificializadas e zonas associadas (áreas urbanas >50%) | Urbano |
| 200 | Solo nú | Deserto |
| 210 | Corpos de água | Água |

Os biomas são unidades biológicas classificadas de acordo com a vegetação dominante e caracterizadas pela adaptação dos organismos àquele ambiente particular (Campbell, 1996). Existem várias formas de caracterizar os biomas de acordo com diferentes critérios como, por exemplo, o clima, o habitat, a adaptação de plantas e animais, a biodiversidade e as actividades humanas (WWF, 2016). Para a identificação dos biomas em Moçambique foram usadas as classes de uso e cobertura do solo dos dados GlobCover e a sua correspondência de acordo (Yan Bai et al., 2014; Costanza et al., 2014). Foram identificados sete biomas, como resultado da conversão descrita na tabela 1: *Floresta, Pradaria/Pastagens, Zonas húmidas, Deserto, Urbano, Lagos/Rios, e Zonas cultivadas* (Figure 4.2).

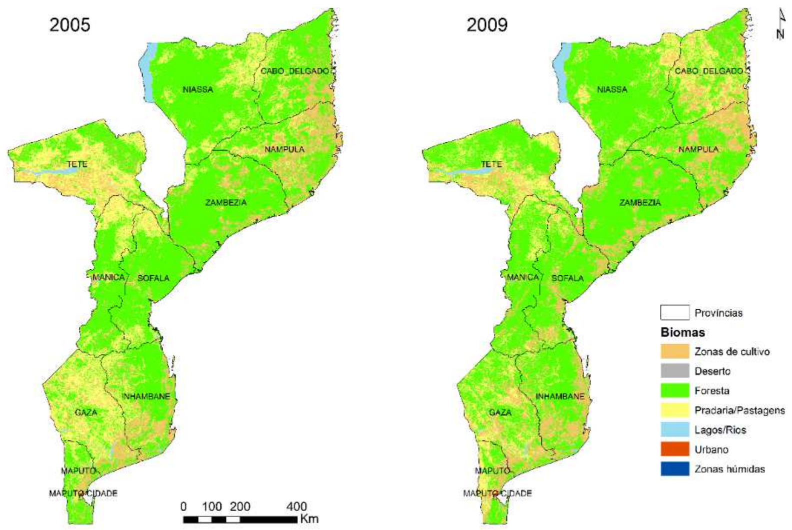


*Figure 4-2: Biomas de Moçambique em 2005 e em 2009*

Diversos métodos de avaliação económica têm sido usados para determinar o valor dos SE, tais como a abordagem de mercado simulada (Guy Garrod and Kenneth G, 1999), a abordagem de mercado substituta (Wu et al., 2013), ou o método da transferência de benefício (Chen et al., 2014; Farber et al., 2006). Este último tem sido usado para estimar o valor dos SE dos biomas globais e as suas mudanças (Costanza et al., 2014; Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, Suttonkk, et al., 1997). Assim, neste estudo optámos por usar este método para estimar o valor dos SE de Moçambique. Esta técnica consiste em utilizar a avaliação de estudos ou dados existentes para estimar o valor dos SE numa área similar (Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, Suttonkk, et al., 1997) e é usada quando há insuficiência de recursos e/ou tempo para realizar a recolha detalhada de dados no campo (Wilson & Hoehn, 2006), como é o caso do presente estudo.

A avaliação dos SE de cada bioma identificado foi realizado com base nos valores obtidos na *Ecosystem Services Valuation Database* (ESVD), disponibilizada pela *Ecosystem Services Partnership* (ESP – http://www.es-partnership.org). Foram selecionados os estudos que avaliaram SE similares aos disponíveis em Moçambique e em áreas com latitude aproximadas. Todos os valores de SE foram convertidos USD/ha/ano usando o ano de 2009 como referência. O valor total dos SE foram estimados usando a equação (Costanza, Arge, Groot, Farberk, Grasso, Hannon, Limburg, Naeem, Neill, Paruelo, Raskin, Suttonkk, et al., 1997) (1):

$$VSE = \sum(A_k \times VC_k) \qquad (1)$$

Onde VSE é o valor estimado de SE, A é a área em ha, e VC o valor do coeficiente em (USD/ha/ano) para cada classe de uso e cobertura do solo k. As mudanças do VSE são obtidas através do cálculo da diferença entre os valores estimados para cada ano (Kreuter et al., 2001).

Para obtermos as estimativas dos valores dos biomas para o ano 2025 foi utilizado um modelo de alteração do uso e cobertura do solo - o Land Change Modeler disponível no IDRISI Selva (Eastman 2012). Este modelo usa as mudanças históricas dos biomas entre 2005 e 2009 para projetar os biomas para o ano 2025 de uma forma espacialmente explícita. O processo de modelação incluiu o uso de cadeias de Markov que determinaram a probabilidade de cada célula mudar para outra classe entre 2005 e 2009. Os potenciais de transição, que correspondem a mapas de probabilidade para cada célula transitar de bioma, foram modelados com recurso a uma rede neuronal. Durante este processo, uma colecção de mapas de transição foi criada usando variáveis determinantes (*drivers*) que foram transformadas usando um logaritmo natural. Estas variáveis consideraram apenas a dependência espacial (por exemplo, uma célula tem maior aptidão a mudar para floresta quanto mais próximo esta estiver de células do tipo floresta). Somente as transições com mais de 100000 células foram mantidas para o exercício de modelação por uma questão de simplicidade, e porque nos interessava apenas modelar as principais transições. Como apenas tínhamos dois momentos temporais para os dados de uso e cobertura do solo (2005 e 2009), não nos foi possível avaliar a qualidade da projecção do modelo. Foi assumido um cenário tendencial, no qual a tendência histórica de alteração dos biomas entre 2005 e 2009 foi usada para projectar os biomas para 2025 sem restrições de planeamento. O mapa dos biomas resultante foi utilizado para calcular os valores de SE.

### 4.4. Resultados

A Floresta era o bioma que representava a maior parte do território moçambicano (59.57% e 61.13% da área total, respectivamente, 2005 e 2009). Este bioma cresceu cerca de 2.6% neste período de tempo. As maiores mudanças foram dos biomas de Pradaria/Pastagens (-26.7%) e Zonas cultivadas (26.6%). Estes biomas representavam 16.49%, e 21.5% respectivamente, da área total em 2009. O bioma da Pradaria/Pastagens 3732984ha para Agricultura e 6016653ha para Floresta. Por outro lado, as Zonas cultivadas perderam 4513455ha para Floresta e 1419066ha para Pradaria/Pastagens. Embora o Deserto representasse uma pequena percentagem, este bioma também aumentou substancialmente entre 2005 e 2009 (39.9%).

A estimativa dos biomas para o ano de 2025, tomando o ano de 2005 como referência (índice 100), é apresentada na Figure 4.3. Nota-se a manutenção da tendência de crescimento das Zonas cultivadas e das Florestas, i.e. um aumento de 9.1% e 2% entre 2009 e 2025, respectivamente. A tendência de decrescimento importante da Pradaria/Pastagens (-19.4% entre 2009 e 2025) é também mantida. Os outros biomas mantêm para o ano de 2025 valores semelhantes aos que tinham no ano de 2009 pois apenas foram modeladas as transições com mais de 100000 células.

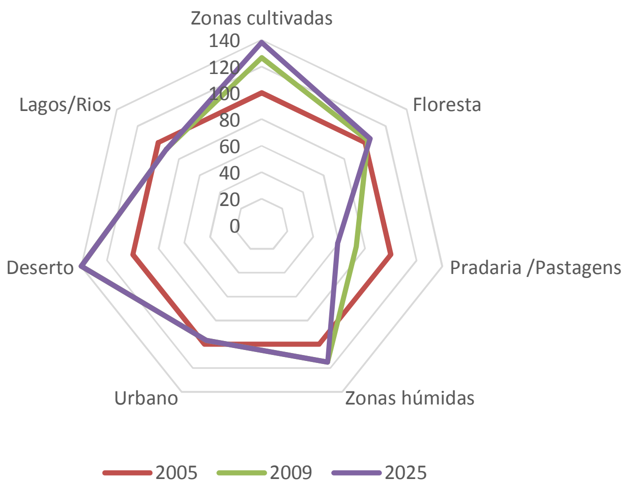


*Figure 4-3: Alterações (%) nas áreas dos biomas entre 2005 e 2025, tomando o ano 2005 como ano de referência (índice 100)*

A partir da consulta da base de dados ESVD foi possível determinar o valor dos SE dos biomas equivalentes aos de Moçambique (Tabela 4.2). O bioma Urbano não foi considerado no cálculo porque não foi encontrado qualquer estudo comparável com as áreas urbanas de Moçambique incluindo o coeficiente urbano revisto em Costanza et al. (2014) e que foi considerado como sendo muito sobrestimado (Yi et al., 2017). Em todo caso, a área urbana total de Moçambique representava apenas 17163ha, i.e. apenas cerca de 0.02% da área total. Assim, o impacto deste bioma no valor dos SE total seria sempre relativamente baixo. Alguns dos valores da Tabela 2 referem-se apenas a um SE para cada bioma (Zonas cultivadas, Pradaria/Pastagens, Deserto e Lagos/Rios) enquanto outros representam múltiplos SE por bioma (Floresta e Zonas húmidas). Neste último caso, foram somados todos os valores para determinar valor dos SE destes biomas. Nos casos em que os valores estavam em moedas diferentes (por exemplo, a Floresta e a Pradaria/ Pastagens) o coeficiente de SE foi convertido em USD de 2009.

*Table 4-2: Biomas e valor de SE correspondente*

| **Bioma** | **Coeficiente de SE (USD/ha/ano)** | **País** | **SE** | **Fonte** |
|---|---|---|---|---|
| Zonas cultivadas | 77.6 | Tanzânia | Alimento | (Turpie, 2000) |
| Floresta | 11.95 (soma de todos os valores de SE e conversão de RAN para USD de 2009) | África do Sul | Matéria-prima, Alimento, Protecção da biodiversidade, Polinização | (Mike H. Allsopp, Willem J. de Lange, 2003) |
| Pradaria/Pastagens | 185 (conversão de PULA para USD de 2009) | Botswana | Alimento | (J. I. Barnes, 2002) |
| Zonas húmidas | 98.3 (soma de todos os valores de SE) | Malawi | Alimento, matéria-prima e água | (Schuijt, 2002) |
| Deserto | 166 (soma de todos os valores de SE) | Quénia | Matéria-prima | (Mogaka, 2007) |
| Lagos/Rios | 1205.4 (soma de todos os valores de SE) | Quénia | Recreação | (Mogaka, 2007) |

O valor total estimado de SE em 2005 foi de 5703.6x10^6 USD. Em 2009, este valor foi de 5054.4x10^6 USD, representando um decréscimo de 649.2x10^6 USD (-11.4%) (Figure 4.4). Para o ano de 2025 espera-se que esta tendência de descida se continue a verificar passando o valor dos SE para 4722.22x10^6 USD (-6.6% entre 2009 e 2025). O bioma com maior valor de SE em 2009 foi a Pradaria/Pastagens (2386.8 x10^6 USD), i.e. 47.2% do valor total dos SE do país. Em 2025 espera-se que este bioma represente apenas 40.8% do valor total de SE, caindo para 1924.6 x10^6 USD. Para 2025 é esperado um aumento importante das Zonas cultivadas, i.e., um aumento de 38.1% entre 2005 e 2025.

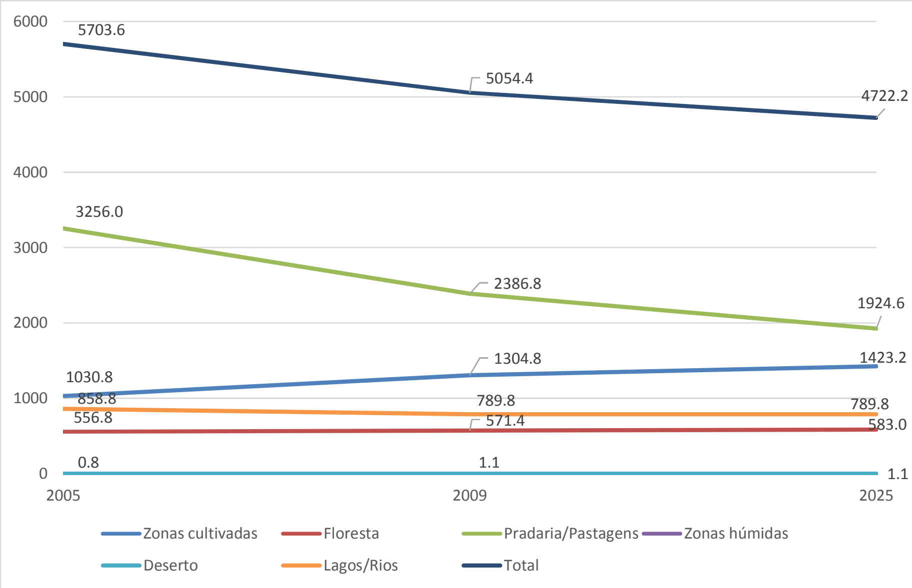


*Figure 4-4: Evolução do valor ($10^{\wedge 6}$ USD) dos SE entre 2005 e 2025*

O valor dos SE de todas as províncias desceram entre 2005 e 2009, sendo Gaza (-16.6%) e Sofala (-15.9%) as que registaram o maior decréscimo. A província de Cabo-Delgado foi a que registou a menor redução (-4.3%) neste período. A província do Niassa foi a que registou o maior valor de SE em 2009 (837.5x10^6 USD). No entanto, esta província perdeu -10.6% do valor de SE desde 2005 até 2009, i.e. -99.35x10^6 USD. A província de Gaza foi a que mais contribuiu na perda do valor de SE com -101.0x10^6 USD. No período entre 2009 e 2025, e embora se preveja uma redução global dos SE (-6.6%) entre 2009 e 2025 para Moçambique, existem províncias que vão ver o seu valor de SE aumentar (Cabo-Delgado, Gaza, Inhambane, Maputo, Nampula e Niassa. De destacar o valor de crescimento elevado de Nampula (501.6%). Este aumento é suportado pelo aumento no bioma Pradaria/Pastagens em 344.2%. Na Figure 4.5 é possível ver as mudanças do valor dos SE (%) por bioma ao nível da província entre 2005 e 2025. Notamos um aumento significativo nas Zonas cultivadas das províncias Manica (207.7%), Niassa (276.8%), e Sofala (286.5%). Exceptuando Cabo-Delgado (43.3%), o bioma Pradaria/Pastagens (43.3%) decresceu em todas províncias. Importa salientar que o aumento de Pradaria/Pastagens nas províncias de Cabo Delgado coincidiu com uma diminuição assinalável no bioma Floresta (-24.5%).

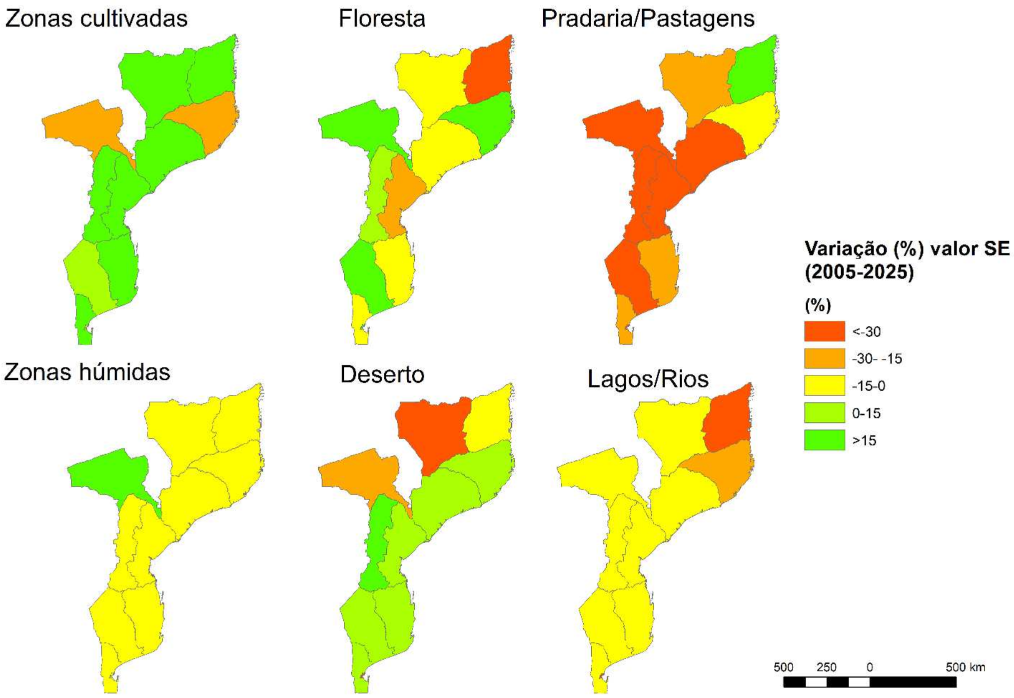


*Figure 4-5: Mudanças dos valores de SE (%) por bioma ao nível de provincial entre 2005 e 2025*

### 4.5. Discussão

Neste estudo os serviços fornecidos pelos biomas Zonas cultivadas e Pradaria/Pastagens estão relacionados apenas com alimentos agrícolas. Contudo, o valor de SE das Zonas cultivadas é de 77.6 USD/ha/ano enquanto que o bioma Pradaria/Pastagens é avaliado em 185 USD/ha/ano, o que afecta negativamente o valor de SE de Moçambique. O bioma Pradaria/Pastagens perdeu área e valor para a Floresta e Zonas cultivadas (Tabela 2). É provável que a longo prazo, tal como confirmado pelo nosso modelo para 2025, que o valor de SE das Zonas cultivadas continue a crescer devido à necessidade crescente de produção de alimentos para atender às necessidades alimentares do país devido ao crescimento populacional (World Bank, 2016). Esta conversão tem um impacto importante nos SE fornecidos pelos biomas Floresta e Pradaria/Pastagens, visto que estes são os biomas que suportarão o crescimento das Zonas cultivadas. A conversão de Pradaria/Pastagens para Floresta é um factor positivo devido à provisão de vários SE, tais como a regulação de inundações que é um problema sério em Moçambique. De notar que as inundações foram muito intensas de 2007 a 2009 (República de Moçambique, 2008; UNISDRI, 2015).

Outros serviços fornecidos pela Floresta e avaliados neste estudo, incluem matérias-primas, alimentos, protecção da biodiversidade e a polinização. Observou-se uma conversão importante entre 2005 e 2009 da Floresta para Zonas cultivadas e é esperado que tal continue a acontecer para 2025. De acordo com a FAO (2013), o principal sistema de cultivo em Moçambique é a agricultura de subsistência com baixos níveis de produtividade devido à falta de condições adequadas, tais como a tecnologia, a acessibilidade ao mercado, a infraestrutura de armazenamento e a organização agrícola (Woodhouse, 2014). Assim, para aumentar a produção, os pequenos agricultores aumentam as áreas agrícolas através da conversão de outros biomas para Zonas cultivadas, principalmente Pradaria/Pastagens (porque é mais fácil para eles prepararem a terra). As mudanças do valor de SE dos outros biomas foram pouco importantes, se tivermos em conta a precisão dos dados e as suas áreas proporcionais, isto é, menos de 1% do total da área de Moçambique (Zonas húmidas, Deserto, Lagos/Rios). Neste grupo de biomas, notámos que o Deserto aumentou o seu valor de SE significativamente entre 2005 e 2009 (39.9%). Este valor foi muito alto nas províncias de Manica, Niassa e Tete. Apesar de este valor ser proporcionalmente baixo, este deverá ser considerado cuidadosamente porque a desertificação severa é um problema grave em Moçambique (República de Moçambique, 2015b).

Ao nível provincial, o valor total dos SE mudaram negativamente em todos os casos. No entanto, as mudanças nos biomas foram diferentes na sua magnitude e localização. Observámos que Cidade de Maputo, Sofala, e Niassa foram as províncias que tiveram maior aumento do valor dos SE nas Zonas cultivadas entre 2005 e 2009. Como foi mencionado antes, o bioma Zonas cultivadas aumentou tendo em vista o aumento da produção de alimento para a redução da pobreza no país (Cunguara et al., 2013). Entre 2005 e 2009, o maior aumento de Zonas cultivadas foi registado na Cidade de Maputo (871.4%). No entanto, é importante notar que este aumento de Zonas cultivadas levou ao declínio do valor de SE e de outros biomas tais como a Pradaria/Pastagens e Floresta que fornecem SE importantes.

Existem vários instrumentos políticos disponíveis em Moçambique que podem beneficiar dos resultados deste estudo dependendo do enfoque individual ou colectivo de SE. De referir que nem todos serviços oferecidos pelos biomas foram avaliados como, por exemplo, o bioma Floresta que tem um papel importante na regulação do clima e que poderia estar ligado a um instrumento político específico, tal como a Estratégia Nacional de Adaptação e Mitigação de Mudanças Climáticas (República de Moçambique, 2015b). Portanto, os resultados apresentados neste estudo apenas podem ser considerados como uma avaliação preliminar dos SE.

O método da transferência de benefício tem sido amplamente utilizada em estudos de valorização de SE (Costanza et al., 2014; Kubiszewski et al., 2013; Maes et al., 2012). No entanto, esse método possui várias falhas como, por exemplo, a propensão a erros resultantes da falta de correspondência entre a estimativa de valor de SE por hectare para todas as áreas com a mesma cobertura ou tipo de habitat (Plummer, 2009). Os SE analisados neste estudo estão limitados apenas aos disponíveis na ESVD. No entanto, estamos cientes de que cada bioma pode fornecer múltiplos SE fazendo, necessariamente, com que as nossas estimativas de valore de SE estejam subestimadas. Além disso, assumindo os valores de SE constantes, a falta nas medições, e tamanhos pouco representativos das áreas de estudo constituem também problemas potencialmente importantes ao transferirem-se valores de SE (Eigenbrod et al., 2010; Frélichová et al., 2014).

Neste estudo, os biomas e valores de SE correspondentes são provenientes de estudos aplicados em diferentes regiões, escalas e datas, constituindo também uma fonte de incerteza. Esses estudos também podem conter dados enviesados devido a condições biofísicas e socioeconómicas diferentes da nossa área de estudo tornando-os inadequados para a aplicação do método da transferência de benefícios (Wilson & Hoehn, 2006). Finalmente, o padrão, a qualidade e os processos ecológicos têm fortes influências na valorização de SE (W. Wang et al., 2014). No entanto, neste estudo as mudanças no valor de SE ignoram esses factores pois apenas as mudanças das áreas do ecossistema é que são consideradas.

A disponibilidade de dados de uso e cobertura do solo foram também uma limitação importante neste estudo. Os dados mais recentes disponíveis eram de 2005 e 2009, o que é bastante desactualizado considerando a crescente actividade económica de Moçambique (World Bank, 2016). A resolução espacial dos dados de uso e cobertura do solo é grosseira e pode levar a problemas de generalização. Por exemplo, as áreas das zonas húmidas podem ser generalizados para outros tipos de uso e cobertura do solo. Além disso, o valor da precisão (73%) dos dados GlobCover encontra-se abaixo do nível mínimo de precisão de interpretação na identificação das categorias de uso e cobertura do solo de dados de detecção remota que devem ser pelo menos de 85% (Anderson et al., 1976). Finalmente, a conversão das classes de uso e cobertura do solo dos dados GlobCover para biomas é também uma fonte de incerteza devido às características de transição de algumas das classes.

Apesar de todas essas limitações, e sabendo que a avaliação de SE usando dados primários é onerosa forçando os investigadores a trabalhar com aproximações (Eigenbrod et al., 2010), tentámos minimizar os erros na nossa abordagem. Os próximos estudos deverão necessariamente ambicionar uma maior precisão na avaliação dos SE incluindo, por exemplo, a utilização de ferramentas tais como InVEST (H Tallis et al., 2015) para reduzir o impacto desses erros.

### 4.6. Conclusões

Este estudo fornece uma avaliação monetária de SE e das mudanças como resultado da mudança do uso e cobertura do solo em Moçambique entre 2005 e 2025 A medição do valor dos SE com o método da transferência de benefício ao nível provincial proporcionou uma perspectiva inovadora e uma melhor compreensão das dinâmicas espaciais do valor dos SE nas diferentes regiões, que estão intimamente ligados ao desenvolvimento económico do país. Estes resultados podem ajudar na definição de políticas que optimizam a estrutura de uso cobertura do solo em Moçambique para maximizar o valor total dos SE. Ao nível da província, os resultados permitem tirar conclusões sobre quais SE devem ser priorizados para a intervenção dos planificadores.

Embora existam alguns estudos adequados no ESVD para se usar o método da transferência de benefício, concluímos que faltam estudos actualizados para África e para Moçambique em particular. No entanto, esta avaliação inicial, dados e metodologia podem ser muito úteis como base para futuros estudos valorização de SE. Estimámos o valor de SE total de Moçambique em 5,054.4x10$^{\wedge 6}$ US$ para o ano 2009, representando a variação de -11.4% desde 2005. Espera-se que este valor caia para 4722.2x10$^{\wedge 6}$ USD em 2025, representando uma perda de -17.2% em relação ao valor de 2005. Apesar desta redução, o valor dos SE para o ano de 2009, ainda representava aproximadamente metade do Produto Interno Bruto (PIB) para esse ano (10910x10$^{\wedge 6}$ USD). Portanto, concluímos também que o valor de SE de Moçambique é muito relevante. Acreditamos que os resultados poderão ser usados para aumentar a consciencialização sobre a importância de preservar SE para melhorar o bem-estar humano em Moçambique, e para ir além do PIB como uma medida de bem-estar e objectivo político. Investigação futura deverá focar-se nos múltiplos SE que existem no país e que ainda não foram estudados e/ou avaliados, com o objectivo de se actualizarem as estimativas do valor do SE.

## 5) Conclusões

Tendo sido constatada a falta de estudos detalhados sobre SE em Moçambique e o desconhecimento da existência ou não de impacto da alteração do uso e cobertura do solo sobre os SE até ao nível provincial, fez com que se elaborasse esta Tese com principal objectivo de realizar a primeira avaliação monetária e biofísica dos SE e analisar os impactos da alteração do uso e cobertura do solo nos SE em Moçambique, entre os anos 2005 e 2025. Para o alcance deste objectivo foram realizados três estudos específicos, onde o primeiro teve como foco a avaliação monetária dos SE e das suas mudanças (Niquisse & Cabral, 2017) e o segundo fez uma avaliação dos SE ao nível biofísico (Niquisse et al., 2017). O terceiro estudo teve o seu enfoque na projecção das tendências dos SE e da biodiversidade, em termos biofísicos e monetários, como consequência da alteração do uso e cobertura do solo entre os ano 2005 e 2025 (Niquisse & Cabral, n.d.).

### 5.1. Resumo dos resultados

O valor de SE total de Moçambique foi estimado em 5,054.4x10^6 US$ para o ano 2009, representando a variação de -11.4% desde 2005. Espera-se que este valor caia para 4722.2x10^6 USD em 2025, representando uma perda de -17.2% em relação ao valor de 2005. Apesar desta redução, o valor dos SE para o ano de 2009, ainda representava aproximadamente metade do Produto Interno Bruto (PIB) para esse ano (10910x10^6 USD). Portanto, concluímos que o valor de SE de Moçambique é muito relevante apesar da diminuição verificada.

O estudo avaliou também o impacto do da alteração do uso e cobertura de terra em SE múltiplos e na biodiversidade usando uma abordagem espaciotemporal que possibilitou uma nova perspectiva sobre as funções e uso do CN de Moçambique.

Os resultados mostram que o serviço de regulação do clima deverá aumentar 10,3% em Moçambique até 2025, confirmando a tendência observada entre 2005 e 2009. No entanto, o serviço de regulação da qualidade da água (retenção de nitrogênio) deverá cair acentuadamente (-30,9%). Todos os outros serviços cairão menos de 6%. A redução da retenção de nitrogênio pela paisagem pode ser explicada pelo aumento da terra cultivada. Houve uma ligeira redução na produção da água de 2005 a 2009 (-1,56%) ao nível do país, e este serviço deverá ser estável até 2025. No entanto, uma análise detalhada ao nível da província (Figure 4.7) mostra que as províncias no sul do país serão afetadas por uma diminuição neste serviço de 2009 a 2025.

As estimativas aqui apresentadas destacam a responsabilidade das 11 províncias pertencentes a este território nas suas capacidades em manter os SE e a biodiversidade

### 5.2. Principais contributos

Este estudo fornece uma valiosa contribuição para a ciência de SE através da apresentação do primeiro estudo de avaliação monetária e biofísica dos SE em Moçambique entre 2005 e 2009, além de projectar estas tendências da variação até 2025.
A medição do valor dos SE com o método da transferência de benefício ao nível provincial proporcionou uma perspectiva inovadora e uma melhor compreensão das dinâmicas espaciais do valor dos SE nas diferentes regiões, que estão intimamente ligados ao desenvolvimento económico do país. Estes resultados podem ajudar na definição de políticas que optimizam a estrutura de uso cobertura do solo em Moçambique para maximizar o valor total dos SE. Ao nível da província, os nossos resultados permitem tirar conclusões sobre quais SE devem ser priorizados para a intervenção dos planificadores.

Acreditamos que os resultados deste estudo poderão ser usados para aumentar a consciencialização sobre a importância de preservar SE para melhorar o bem-estar humano em Moçambique, e para ir além do PIB como uma medida de bem-estar e objectivo político.

### 5.3. Limitações e futuras pesquisas

Os resultados deste estudo podem ser considerados apenas como uma avaliação preliminar dos SE com o objetivo de aumentar a consciencialização dos decisores políticos sobre a importância dos SE.

Embora existam alguns estudos adequados na ESVD para aplicar o método de transferência de benefícios, há uma manifesta falta de estudos de avaliação atualizados, tanto biofísicos como monetários para a África e, em particular, para Moçambique. Assim, há uma forte necessidade de melhorar o número de estudos de avaliação de SE para este importante continente e, mais especificamente, para os países da África Oriental que estão passando por importantes mudanças na ocupação da terra. No entanto, para uma avaliação inicial, os dados e a metodologia utilizados neste estudo podem ser muito úteis como base para futuros estudos de avaliação de SE em Moçambique com o objetivo de preservar o provisionamento de SE.

Investigação futura deverá focar-se nos SE múltiplos que existem no país e que ainda não foram estudados e/ou avaliados, com o objectivo de se actualizarem as estimativas do valor do SE.

**Referências**

Abram, N. K., Meijaard, E., Ancrenaz, M., Runting, R. K., Wells, J. A., Gaveau, D., … Mengersen, K. (2014). Spatially explicit perceptions of ecosystem services and land cover change in forested regions of Borneo. *Ecosystem Services*, *7*, 116–127. http://doi.org/10.1016/j.ecoser.2013.11.004

Anderson, J. R., Hardy, E. E., Roach, J. T., & Witmer, R. E. (1976). *A Land Use And Land Cover Classification System For Use With Remote Sensor Data, Geological Survey Professional Paper 964*.

Bai, Y., Feng, M., Jiang, H., Wang, J., Zhu, Y., & Liu, Y. (2014). Assessing Consistency of Five Global Land Cover Data Sets in China. *Remote Sensing*, *6*(9), 8739–8759. http://doi.org/10.3390/rs6098739

Bai, Y., Zheng, H., Ouyang, Z., Zhuang, C., & Jiang, B. (2012). Modeling hydrological ecosystem services and tradeoffs: a case study in Baiyangdian watershed, China. *Environmental Earth Sciences*. http://doi.org/10.1007/s12665-012-2154-5

Barbier, E. B. (2016). The protective service of mangrove ecosystems: A review of valuation methods. *Marine Pollution Bulletin*, *109*(2), 676–681. http://doi.org/10.1016/j.marpolbul.2016.01.033

Barbosa, F. M. A., Cuambe, C. C., & Bandeira, S. O. (2001). Status and distribution of mangroves in Mozambique. *South African Journal of Botany*, *67*(3), 393–398. http://doi.org/10.1016/S0254-6299(15)31155-8

Barnes, J. (2002). The economic returns to wildlife management in southern Africa. In D. Pearce, C. Pearce, & C. Palmer (Eds.), *Valuing the Environment in Developing Countries*. Edward Elgar Publishing.

Barnes, J. I. The economic returns to wildlife management in Southern Africa. “The valuing the environment in developing countries: case studies,” earce, D., C. Pe arce and C. Palmer (ed) (2002).

Bateman, I. J., Mace, G. M., Fezzi, C., Atkinson, G., & Turner, K. (2011). Economic analysis for ecosystem service assessments. *Environmental and Resource Economics*, *48*(2), 177–218. http://doi.org/10.1007/s10640-010-9418-x

Bhagabati, N., Barano, T., Conte, M., Ennaanay, D., Hadian, O., McKenzie, E., … Tallis, H. (2012). A Green Vision for Sumatra: Using ecosystem services information to make recommendations for sustainable land use planning at the province and district level. A Report by The Natural Capital Project, WWF-US, and WWF-Indonesia. www. ncp-dev.

Boyd, J., & Wainger, L. (2003). Measuring Ecosystem Service Benefits : The Use of Landscape Analysis to Evaluate Environmental Trades and Compensation Measuring Ecosystem Service Benefits : The Use of Landscape Analysis to Evaluate Environmental Trades and Compensation James Boyd and Li.

Brink, E., Aalders, T., Ádám, D., Feller, R., Henselek, Y., Hoffmann, A., … Wamsler, C. (2016). Cascades of green: A review of ecosystem-based adaptation in urban areas. *Global Environmental Change*, *36*, 111–123. http://doi.org/10.1016/j.gloenvcha.2015.11.003

Brouwer, R., & Falcão, M. P. (2004). Wood fuel consumption in Maputo, Mozambique. *Biomass and Bioenergy*, *27*(3), 233–245. http://doi.org/10.1016/j.biombioe.2004.01.005

Burkhard, B., Crossman, N., Nedkov, S., Petz, K., & Alkemade, R. (2013). Mapping and modelling ecosystem services for science, policy and practice. *Ecosystem Services*, *4*, 1–3. http://doi.org/10.1016/j.ecoser.2013.04.005

Cabral, P., Augusto, G., Akande, A., Costa, A., Amade, N., Niquisse, S. S. S., … Santha, R. (2017). Assessing Mozambique's exposure to coastal climate hazards and erosion. *International Journal of Disaster Risk Reduction*, *23*, 45–52. http://doi.org/10.1016/j.ijdrr.2017.04.002

Cabral, P., Feger, C., Levrel, H., Chambolle, M., & Basque, D. (2016). Assessing the impact of land-cover changes on ecosystem services: a first step toward integrative planning in Bordeaux, France. *Ecosystem Services*, *Accepted*.

Campbell, N. . A. (1996). *Biology*. (C. The Benjamin/Cummings Publishing Company, Inc., Menlo Park, Ed.) (4th Editio).

Cardona, O.-D., van Aalst, M. K., Birkmann, J., Fordham, M., McGregor, G., Perez, R., … Thomalla, F. (2012). Determinants of Risk: Exposure and Vulnerability. In C. B. Field, V. Barros, T. F. Stocker, & Q. Dahe (Eds.), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (pp. 65–108). Cambridge: Cambridge University Press. http://doi.org/10.1017/CBO9781139177245.005

Chemane, D., Motta, H., & Achimo, M. (1997). Vulnerability of coastal resources to climate changes in Mozambique: a call for integrated coastal zone management. *Ocean &*

*Coastal Management*, *37*(1), 63–83. http://doi.org/10.1016/S0964-5691(97)00073-2

Chen, J., Sun, B.-M., Chen, D., Wu, X., Guo, L.-Z., & Wang, G. (2014). Land use changes and their effects on the value of ecosystem services in the small Sanjiang plain in China. *TheScientificWorldJournal*, *2014*, 752846. http://doi.org/10.1155/2014/752846

CICES. (2017). CICES. Retrieved November 17, 2017, from https://cices.eu/

Costa, M. B. S. F., Araújo, M., Araújo, T. C. M., & Siegle, E. (2016). Influence of reef geometry on wave attenuation on a Brazilian coral reef. *Geomorphology*, *253*, 318–327. http://doi.org/10.1016/j.geomorph.2015.11.001

Costanza, R., Arge, R., Groot, R. D. De, Farberk, S., Grasso, M., Hannon, B., … van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, *387*(6630), 253–260. http://doi.org/10.1038/387253a0

Costanza, R., Arge, R., Groot, R. De, Farberk, S., Grasso, M., Hannon, B., … Suttonkk, P. (1997). The value of the world ' s ecosystem services and natural capital. *Nature*, *387*(May), 253–260. http://doi.org/10.1038/387253a0

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., … van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, *387*(6630), 253–260. http://doi.org/10.1038/387253a0

Costanza, R., & Daly, H. E. (1992). Capital Natural Development Sustainable. *Society of Conservation Biology*, *6*(1), 37–46. http://doi.org/10.1111/j.1365-2036.2008.03913.x

Costanza, R., Groot, R. De, Sutton, P., Ploeg, S. Van Der, Anderson, S. J., Kubiszewski, I., … Turner, R. K. (2014). Changes in the global value of ecosystem services. *Global Environmental Change*, *26*, 152–158. http://doi.org/10.1016/j.gloenvcha.2014.04.002

Costanza, R., & Ruth, M. (1998). Using Dynamic Modeling to Scope Environmental Problems and Build Consensus. *Environmental Management*, *22*(2), 183–195. http://doi.org/10.1007/s002679900095

Crespin, S. J., & Simonetti, J. A. (2016). Loss of ecosystem services and the decapitalization of nature in El Salvador. *Ecosystem Services*, *17*, 5–13. http://doi.org/10.1016/j.ecoser.2015.10.020

Cunguara, B., Garrett, J., Donovan, C., & Cássimo, C. (2013). *O Sector Agrário em Moçambique: Análise situacional, constrangimentos e oportunidades para o* *crescimento agrário. Direcção de Economia, Ministério da Agricultura.* Maputo, Mozambique.

D'Amato, D., Rekola, M., Li, N., & Toppinen, A. (2016). Monetary valuation of forest ecosystem services in China: A literature review and identification of future research needs. *Ecological Economics*, *121*, 75–84. http://doi.org/10.1016/j.ecolecon.2015.11.009

D'Angelo, C., & Wiedenmann, J. (2014). Impacts of nutrient enrichment on coral reefs: new perspectives and implications for coastal management and reef survival. *Current Opinion in Environmental Sustainability*, *7*, 82–93. http://doi.org/10.1016/j.cosust.2013.11.029

Daily, G. C. (1997). What are Ecosystem Services. Retrieved from courses.washington.edu/cfr550/pdfs/Daily_Chapter1.1997.pdf

Dallimer, M., Irvine, K. N., Skinner, A. M. J., Davies, Z. G., Rouquette, J. R., Maltby, L. L., … Gaston, K. J. (2012). Biodiversity and the Feel-Good Factor: Understanding Associations between Self-Reported Human Well-being and Species Richness. *BioScience*, *62*(1), 47–55. http://doi.org/10.1525/bio.2012.62.1.9

Daly, H. E. (1997). Georgescu-Roegen versus Solow/Stiglitz. *Ecological Economics*, *22*(3), 261–266. http://doi.org/10.1016/S0921-8009(97)00080-3

Das, S., & Crépin, A.-S. (2013). Mangroves can provide protection against wind damage during storms. *Estuarine, Coastal and Shelf Science*, *134*, 98–107. http://doi.org/10.1016/j.ecss.2013.09.021

Dawson, N., & Martin, A. (2015). Assessing the contribution of ecosystem services to human wellbeing: A disaggregated study in western Rwanda. *Ecological Economics*, *117*, 62–72. http://doi.org/10.1016/j.ecolecon.2015.06.018

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., … van Beukering, P. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services*, *1*(1), 50–61. http://doi.org/10.1016/j.ecoser.2012.07.005

de Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, *7*(3), 260–272.

http://doi.org/10.1016/j.ecocom.2009.10.006

Defourny, P., Schouten, L., Bartalev, S., Bontemps, S., Caccetta, P., Bella, C. Di, … Arino, O. (2009). Accuracy Assessment of a 300 m Global Land Cover Map: The GlobCover Experience. *33rd International Symposium on Remote Sensing of Environment, Sustaining the Millennium Development Goals*, (October 2015), 1–5.

Delphin, S., Escobedo, F. J., Abd-Elrahman, A., & Cropper, W. (2013). Mapping potential carbon and timber losses from hurricanes using a decision tree and ecosystem services driver model. *Journal of Environmental Management*, *129*, 599–607. http://doi.org/10.1016/j.jenvman.2013.08.029

Deutschland, N. de T. (2014). Naturkapital Deutschland de TEEB. Retrieved November 20, 2017, from http://www.naturkapital-teeb.de/en/publications/own-publications/report-1.html

Diehl, K., Burkhard, B., & Jacob, K. (2015). Should the ecosystem services concept be used in European Commission impact assessment? *Ecological Indicators*, *61*, 6–17. http://doi.org/10.1016/j.ecolind.2015.07.013

Eastman, R. (2012). *Idrisi Selva*. Clark Labs.

EEA. (2006). *The changing faces of Europe's coastal areas*. Copenhagen, Denmark.

Egoh, B., Rouget, M., Reyers, B., Knight, A. T., Cowling, R. M., van Jaarsveld, A. S., & Welz, A. (2007). Integrating ecosystem services into conservation assessments: A review. *Ecological Economics*, *63*(4), 714–721. http://doi.org/10.1016/j.ecolecon.2007.04.007

Ehrlich PR, E. A. (1981). Extinction: The Causes and Consequences of the Disappearance of Species. In R. House (Ed.), . New York, NY.

Eigenbrod, F., Armsworth, P. R., Anderson, B. J., Heinemeyer, A., Gillings, S., Roy, D. B., … Gaston, K. J. (2010). Error propagation associated with benefits transfer-based mapping of ecosystem services. *Biological Conservation*, *143*(11), 2487–2493. http://doi.org/10.1016/j.biocon.2010.06.015

EPA. (2009). *Valuing the Protection of Ecological Systems and Services A Report of the EPA Science Advisory Board*. Washington, DC: US Environmental Protection Agency.

ESA. (2015). GlobCover.

ESRI. (2014, November). ArcGIS. Redlands, USA: Environmental Systems Research Institute.

Fallis, A. . (2013). Seasonality dynamics for investigating wetland-agriculture nexus and its ecosystems service values in Chibuto, Mozambique. *Journal of Chemical Information and Modeling*, *53*(9), 1689–1699. http://doi.org/10.1017/CBO9781107415324.004

FAO. (2012). *The state of food and agriculture*. Rome.

FAO. (2013). *Mozambique BEFS Country Brief*.

FAO, IIASA, ISRIC, ISSCAS, & JRC. (2012). Harmonized World Soil Database (version 1.2).

Farber, S., Costanza, R., Childers, D. L., Erickson, J., Gross, K., Grove, M., … Wilson, M. (2006). Linking Ecology and Economics for Ecosystem Management. *BioScience*, *56*(2), 121. http://doi.org/10.1641/0006-3568(2006)056[0121:LEAEFE]2.0.CO;2

Feger, C., Cabral, P., Basque, D., Levrel, H., & Chambolle, M. (2015). Grand cycle de l'eau, évaluation des services écosystémiques et aménagement du territoire : un premier retour d'expérience. *Techniques Sciences Méthodes*, (9), 56–67. http://doi.org/10.1051/tsm/201509056

Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics*, *68*(3), 643–653. http://doi.org/10.1016/j.ecolecon.2008.09.014

Frélichová, J., Vačkář, D., Pártl, A., Loučková, B., Harmáčková, Z. V., & Lorencová, E. (2014). Integrated assessment of ecosystem services in the Czech Republic. *Ecosystem Services*, *8*, 110–117. http://doi.org/10.1016/j.ecoser.2014.03.001

Fu, B., Wang, Y. K., Xu, P., Yan, K., & Li, M. (2014). Value of ecosystem hydropower service and its impact on the payment for ecosystem services. *The Science of the Total Environment*, *472*, 338–46. http://doi.org/10.1016/j.scitotenv.2013.11.015

Gaodi, X. I. E., Lin, Z., & Chunxia, L. U. (2010). Applying Value Transfer Method for Eco-Service Valuation in China, *1*(1), 51–59. http://doi.org/10.3969/j.issn.1674-764x.2010.01.007

Geneletti, D. (2011). Reasons and options for integrating ecosystem services in strategic environmental assessment of spatial planning. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *7*(3), 143–149.

http://doi.org/10.1080/21513732.2011.617711

Geneletti, D. (2013). Assessing the impact of alternative land-use zoning policies on future ecosystem services. *Environmental Impact Assessment Review*, *40*, 25–35. http://doi.org/10.1016/j.eiar.2012.12.003

GlobCover, E. (2015). ESA GLOBCOVER.

Goldstein, J. H., Caldarone, G., Duarte, T. K., Ennaanay, D., Hannahs, N., Mendoza, G., … Daily, G. C. (2012). Integrating ecosystem-service tradeoffs into land-use decisions. *Proceedings of the National Academy of Sciences*, *109*(19), 7565–7570. http://doi.org/10.1073/pnas.1201040109

Gómez-Baggethun, E., & Barton, D. N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics*, *86*, 235–245. http://doi.org/10.1016/j.ecolecon.2012.08.019

Gómez-Baggethun, E., de Groot, R., Lomas, P. L., & Montes, C. (2010). The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes. *Ecological Economics*, *69*(6), 1209–1218. http://doi.org/10.1016/j.ecolecon.2009.11.007

Grêt-Regamey, A., Weibel, B., Bagstad, K. J., Ferrari, M., Geneletti, D., Klug, H., … Tappeiner, U. (2014). On the effects of scale for ecosystem services mapping. *PLoS ONE*, *9*(12), 1–26. http://doi.org/10.1371/journal.pone.0112601

Groot, R. S. de. (1987). Environmental functions as a unifying concept for ecology and economics. *Environment Systems and Decisions*, *7*(2). Retrieved from https://link.springer.com/article/10.1007/BF02240292

Guy Garrod and Kenneth G, W. (1999). *Economic Valuation of the Environment: Methods and Case Studies*. (U. Edward Elgar, Cheltenham, Ed.).

Haines-Young, R. (2016). *Report of Results of a Survey to Assess the Use of CICES*. *European Environmental Agency* (Vol. 2016). Retrieved from https://cices.eu/content/uploads/sites/8/2016/07/Report-on-Survey-Results_19072016_Upload.pdf

Halpern, B. S., Walbridge, S., Selkoe, K. A., Kappel, C. V, Micheli, F., D'Agrosa, C., … Watson, R. (2008). A Global Map of Human Impact on Marine Ecosystems. *Science*, *319*(5865), 948–952. JOUR. http://doi.org/10.1126/science.1149345

Hamel, P., & Bryant, B. P. (2017). Uncertainty assessment in ecosystem services analyses: Seven challenges and practical responses. *Ecosystem Services*, *24*, 1–15. http://doi.org/10.1016/j.ecoser.2016.12.008

Hassan, R. M., Scholes, R., & Ash, N. (2005). *Ecosystems and Human Well-Being: Current State and Trends: Findings of the Condition and Trends Working Group*. Island Press.

Hermann, A., Schleifer, S., & Wrbka, T. (2011). The Concept of Ecosystem Services Regarding Landscape Research : A Review Imprint / Terms of Use, 1–37. http://doi.org/10.1177/0170840609104565

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, *25*(15), 1965–1978. http://doi.org/10.1002/joc.1276

Honrado, J. P., Vieira, C., Soares, C., Monteiro, M. B., Marcos, B., Pereira, H. M., & Partidário, M. R. (2013). Can we infer about ecosystem services from EIA and SEA practice? A framework for analysis and examples from Portugal. *Environmental Impact Assessment Review*, *40*, 14–24. http://doi.org/10.1016/j.eiar.2012.12.002

Hou, Y., Burkhard, B., & Müller, F. (2013). Uncertainties in landscape analysis and ecosystem service assessment. *Journal of Environmental Management*, *127 Suppl*, S117-31. http://doi.org/10.1016/j.jenvman.2012.12.002

INE. (2007). População total Censo de 2007, Instituto Nacional de Estatística. Maputo, Mozambique: Portal do Governo.

INE. (2015). População Projectada por distritos, Maputo Cidade 2007_2040. Retrieved August 4, 2016, from http://www.ine.gov.mz/estatisticas/estatisticas-de

INE. (2016a). Recenseamento Geral da População e Habitação.

INE. (2016b). *Relatório final do inquérito ao orçamento familiar - IOF-2014/15*. Maputo, Mozambique.

IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]*. Geneva, Switzerland.

Jiang, C., Li, D., Wang, D., & Zhang, L. (2016). Quantification and assessment of changes in ecosystem service in the Three-River Headwaters Region, China as a result of climate variability and land cover change. *Ecological Indicators*, *66*, 199–211. http://doi.org/10.1016/j.ecolind.2016.01.051

Joshi, G., & Negi, G. C. S. (2011). Quantification and valuation of forest ecosystem services in the western Himalayan region of India. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *7*(1), 2–11. http://doi.org/10.1080/21513732.2011.598134

Kareiva, P., Tallis, H., Ricketts, T. H., Daily, G. C., & Polasky, S. (2011a). *Natural Capital: Theory and Practice of Mapping Ecosystem Services*. New York: OUP Oxford.

Kareiva, P., Tallis, H., Ricketts, T. H., Daily, G. C., & Polasky, S. (2011b). *Natural Capital:Theory and Practice of Mapping Ecosystem Services: Theory and Practice of Mapping Ecosystem Services*. BOOK, New York: OUP Oxford. Retrieved from http://books.google.es/books?id=dAU0YMB_rdEC

Kindu, M., Schneider, T., Teketay, D., & Knoke, T. (2016a). Changes of ecosystem service values in response to land use/land cover dynamics in Munessa-Shashemene landscape of the Ethiopian highlands. *The Science of the Total Environment*, *547*, 137–147. http://doi.org/10.1016/j.scitotenv.2015.12.127

Kindu, M., Schneider, T., Teketay, D., & Knoke, T. (2016b). Changes of ecosystem service values in response to land use/land cover dynamics in Munessa–Shashemene landscape of the Ethiopian highlands. *Science of The Total Environment*, *547*, 137–147. http://doi.org/10.1016/j.scitotenv.2015.12.127

Kremer, P., & Hamstead, Z. A. (2016). The value of urban ecosystem services in New York City: A spatially explicit multicriteria analysis of landscape scale valuation scenarios. *Environmental Science & Policy*, *62*, 57–68. http://doi.org/10.1016/j.envsci.2016.04.012

Kreuter, U. P., Harris, H. G., Matlock, M. D., & Lacey, R. E. (2001). Change in ecosystem service values in the San Antonio area, Texas. *Ecological Economics*, *39*(3), 333–346. http://doi.org/10.1016/S0921-8009(01)00250-6

Kubiszewski, I., Costanza, R., Anderson, S., & Sutton, P. (2017). The future value of ecosystem services: Global scenarios and national implications. *Ecosystem Services*. http://doi.org/10.1016/j.ecoser.2017.05.004

Kubiszewski, I., Costanza, R., Dorji, L., Thoennes, P., & Tshering, K. (2013). An initial estimate of the value of ecosystem services in Bhutan. *Ecosystem Services*, *3*, e11–e21. http://doi.org/10.1016/j.ecoser.2012.11.004

La Notte, A., Maes, J., Grizzetti, B., Bouraoui, F., & Zulian, G. (2012). Spatially explicit monetary valuation of water purification services in the Mediterranean bio-geographical region. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *8*(1–2), 26–34. http://doi.org/10.1080/21513732.2011.645557

Lal, R. (1998). Soil Erosion Impact on Agronomic Productivity and Environment Quality. *Critical Reviews in Plant Sciences*, *17*(4), 319–464. http://doi.org/10.1080/07352689891304249

Lamarque, P., Quétier, F., & Lavorel, S. (2011). The diversity of the ecosystem services concept and its implications for their assessment and management. *Comptes Rendus Biologies*, *334*(5–6), 441–449. http://doi.org/10.1016/j.crvi.2010.11.007

Langbein, W., & Iseri, K. (1995). *Science in Your Watershed - General Introduction and Hydrologic Definitions*. *Methods and practices of the Geological Survey*. Washington: United States Geological Survey.

Lavorel, S., Colloff, M. J., Mcintyre, S., Doherty, M. D., Murphy, H. T., Metcalfe, D. J., … Williams, K. J. (2015). Ecological mechanisms underpinning climate adaptation services. *Global Change Biology*, *21*(1), 12–31. http://doi.org/10.1111/gcb.12689

Lawler, J. J., Lewis, D. J., Nelson, E., Plantinga, A. J., Polasky, S., & Withey, J. C. (2014). Projected land-use change impacts on ecosystem services in the United States, *111*(20). http://doi.org/10.1073/pnas.1405557111

Leh, M. D. K., Matlock, M. D., Cummings, E. C., & Nalley, L. L. (2013). Quantifying and mapping multiple ecosystem services change in West Africa. *Agriculture, Ecosystems & Environment*, *165*, 6–18. http://doi.org/10.1016/j.agee.2012.12.001

Leh, M. D. K., Matlock, M. D., Cummings, E. C., & Nalley, L. L. (2016). Corrigendum to “Quantifying and mapping multiple ecosystem services change in West Africa.” *Agriculture, Ecosystems & Environment*. http://doi.org/10.1016/j.agee.2016.01.035

Lindborg, R., Gordon, L. J., Malinga, R., Bengtsson, J., Peterson, G., Bommarco, R., … Smith, H. G. (2017). How spatial scale shapes the generation and management of multiple ecosystem services. *Ecosphere*, *8*(4), e01741. http://doi.org/10.1002/ecs2.1741

Liquete, C., Zulian, G., Delgado, I., Stips, A., & Maes, J. (2013). Assessment of coastal protection as an ecosystem service in Europe. *Ecological Indicators*, *30*, 205–217. http://doi.org/10.1016/j.ecolind.2013.02.013

Liu, S., Costanza, R., Troy, A., & D 'aagostino, J. (2010). Valuing New Jersey's Ecosystem Services and Natural Capital: A Spatially Explicit Benefit Transfer Approach, 1271–1285. http://doi.org/10.1007/s00267-010-9483-5

Lovelock, C. E., Ball, M. C., Martin, K. C., & C. Feller, I. (2009). Nutrient Enrichment Increases Mortality of Mangroves. *PLoS ONE*, *4*(5), e5600. http://doi.org/10.1371/journal.pone.0005600

Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J. P., … Bidoglio, G. (2012). Mapping ecosystem services for policy support and decision making in the European Union. *Ecosystem Services*, *1*(1), 31–39. http://doi.org/10.1016/j.ecoser.2012.06.004

Mann, L., Tolbert, V., & Cushman, J. (2002). Potential environmental effects of corn (Zea mays L.) stover removal with emphasis on soil organic matter and erosion. *Agriculture, Ecosystems & Environment*, *89*(3), 149–166. http://doi.org/10.1016/S0167-8809(01)00166-9

Martínez-Harms, M. J., & Balvanera, P. (2012). Methods for mapping ecosystem service supply: a review. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *8*(1–2), 17–25. http://doi.org/10.1080/21513732.2012.663792

Martínez, M. L., Pérez-Maqueo, O., Vázquez, G., Castillo-Campos, G., García-Franco, J., Mehltreter, K., … Landgrave, R. (2009). Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico. *Forest Ecology and Management*, *258*(9), 1856–1863. http://doi.org/10.1016/j.foreco.2009.02.023

Martins, V. N., Pires, R., & Cabral, P. (2012). Modelling of coastal vulnerability in the stretch between the beaches of Porto de Mós and Falésia, Algarve (Portugal). *Journal of Coastal Conservation*, *16*(4), 503–510.

Mascarenhas, A., Ramos, T. B., Haase, D., & Santos, R. (2015). Ecosystem services in spatial planning and strategic environmental assessment—A European and Portuguese profile. *Land Use Policy*, *48*, 158–169. http://doi.org/10.1016/j.landusepol.2015.05.012

McLaughlin, A., & Mineau, P. (1995). The impact of agricultural practices on biodiversity.

*Agriculture, Ecosystems & Environment*, *55*(3), 201–212. http://doi.org/10.1016/0167-8809(95)00609-V

MEA. (2005a). *Ecosystems and Human Well-being: Synthesis. Ecosystems* (Vol. 5). Retrieved from http://www.who.int/entity/globalchange/ecosystems/ecosys.pdf%5Cnhttp://www.loc.gov/catdir/toc/ecip0512/2005013229.html

MEA. (2005b). *Rapport de synthèse de l'Évaluation des Écosystèmes pour le Millénaire, Millennium Ecosystem Assessment*. BOOK, Washington, DC: Island Press.

MICOA. (2007). Estratégia Ambiental para o Desenvolvimento Sustentável de Moçambique Aprovada na IXª Sessão do Conselho de Ministro, de 24 de Julho de 2007. Ministério para a Coordenação da Acção Ambiental. Maputo, Mozambique.

MICOA. (2014). CBD Fifth National Report, Convention on Biological Biodiversity in Mozambique, Ministry for the Coordination of Environmental Affairs. Maputo, Mozambique.

Mike H. Allsopp, Willem J. de Lange, R. V. (2003). Economic value of terrestrial and marine biodiversity in the Cape Floristic region: implications for defining effective and socially optimal strategies. *Biol Cons 112: 233–251.*

Millenium Assessment. (2003). Ecosystems and their services. In *Ecosystems and Human Well-being: A Framework for Assessment* (pp. 49–70).

Mogaka, E. B. and H. (2007). *"Kenya's Drylands – Wastelands or an Undervalued National Economic Resource."*

Mononen, L., Auvinen, A.-P., Ahokumpu, A.-L., Rönkä, M., Aarras, N., Tolvanen, H., … Vihervaara, P. (2015). National ecosystem service indicators: Measures of social–ecological sustainability. *Ecological Indicators*, *61*, 27–37. http://doi.org/10.1016/j.ecolind.2015.03.041

Mooney, H. a., Cropper, A., Capistrano, D., Carpenter, S. R., Chopra, K., Dasgupta, P., … Zurek, M. B. (2005). Millennium Ecosystem Assessment Synthesis Report A Report of the Millennium Ecosystem Assessment.

Motta, H., Pereira, M., Gonçalves, M., Ridgway, T., & Schleyer, M. (2002). Coral reef monitoring in Mozambique. II: 2000 report. MICOA/CORDIO/ORI/WWF. Maputo, Mozambique: Coral Reef Management Programme.

Mudaca, J. D., Tsuchiya, T., Yamada, M., & Onwona-Agyeman, S. (2015a). Household participation in Payments for Ecosystem Services: A case study from Mozambique. *Forest Policy and Economics*, *55*, 21–27. http://doi.org/10.1016/j.forpol.2015.03.002

Mudaca, J. D., Tsuchiya, T., Yamada, M., & Onwona-Agyeman, S. (2015b). Household participation in Payments for Ecosystem Services: A case study from Mozambique. *Forest Policy and Economics*, *55*, 21–27. http://doi.org/10.1016/j.forpol.2015.03.002

Nagabhatla, N., Saimone, F., Juizo, D., & Masiyandima, M. (2008). Seasonality dynamics for investigating wetland agriculture nexus and its ecosystems service values in Chibuto, Mozambique. In *Proceedings of the CGIAR Challenge Program on Water and Food. 2nd International Forum on Water and Food* (p. 5). Addis Ababa, Ethiopia: International Water Management Institute.

Nahuelhual, L., Laterra, P., Villarino, S., Mastrángelo, M., Carmona, A., Jaramillo, A., … Burgos, N. (2015). Mapping of ecosystem services: Missing links between purposes and procedures. *Ecosystem Services*, *13*, 162–172. http://doi.org/10.1016/j.ecoser.2015.03.005

NASA. (2012). ASTER Global Digital Elevation Map.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D. R., … Shaw, M. R. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment*, *7*(1), 4–11. http://doi.org/10.1890/080023

Newbold, T., Hudson, L. N., Hill, S. L. L., Contu, S., Lysenko, I., Senior, R. A., … Purvis, A. (2015). Global effects of land use on local terrestrial biodiversity. *Nature*, *520*(7545), 45–50. http://doi.org/10.1038/nature14324

Nicholls, R. J., & Tol, R. S. J. (2006). Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *364*(1841), 1073–1095. http://doi.org/10.1098/rsta.2006.1754

Niquisse, S., & Cabral, P. (n.d.). Avaliação dos serviços de ecossistemas em Moçambique entre 2005 e 2025 (under review). *Revista Brasileira de Gestão E Desenvolvimento Regional*.

Niquisse, S., & Cabral, P. (2017). Assessment of changes in ecosystem service monetary values in Mozambique. *Environmental Development*.

Niquisse, S., Cabral, P., Rodrigues, Â., & Augusto, G. (2017). Ecosystem services and biodiversity trends in Mozambique as a consequence of land cover change. *International Journal of Biodiversity Science, Ecosystem Services & Management*. Retrieved from http://www.tandfonline.com/doi/full/10.1080/21513732.2017.1349836

Nunes, P. A. L. D., & Ghermandi, A. (2015). Understanding and Valuing the Marine Ecosystem Services of the Northern Mozambique Channel.

Nunes, P., & Ghermandi, A. (2015). *Understanding and Valuing the Marine Ecosystem Services of the Northern Mozambique Channel. Consultancy report commissioned for the Northern Mozambique Channel initiative. WWF International*.

Olsson, P., Folke, C., & Berkes, F. (2004). Adaptive Comanagement for Building Resilience in Social?Ecological Systems. *Environmental Management*, *34*(1). http://doi.org/10.1007/s00267-003-0101-7

Openness. (2017). Openness. Retrieved November 17, 2017, from http://www.openness-project.eu/

Pereira, H., Domingos, T., Vicente, L., & Proença, V. (2009). *Ecossistemas e Bem-Estar Humano Avaliação para Portugal do Millennium Ecosystem Assessment (Ecosystems and Human Well-Being: Rating for Portugal's Millenium Ecosystem Assessment*. Escolar Editora.

Perez-Verdin, G., Sanjurjo-Rivera, E., Galicia, L., Hernandez-Diaz, J. C., Hernandez-Trejo, V., & Marquez-Linares, M. A. (2016). Economic valuation of ecosystem services in Mexico: Current status and trends. *Ecosystem Services*, *21*, 6–19. http://doi.org/10.1016/j.ecoser.2016.07.003

Plummer, M. L. (2009). Assessing benefit transfer for the valuation of ecosystem services. *Frontiers in Ecology and the Environment*, *7*(1), 38–45. http://doi.org/10.1890/080091

Polasky, S., Nelson, E., Pennington, D., & Johnson, K. a. (2011). The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the state of Minnesota. *Environmental and Resource Economics*, *48*(2), 219–242. http://doi.org/10.1007/s10640-010-9407-0

Portela, R., & Rademacher, I. (2001). A dynamic model of patterns of deforestation and their effect on the ability of the Brazilian Amazonia to provide ecosystem services. *Ecological Modelling*, *143*(1–2), 115–146. http://doi.org/10.1016/S0304-3800(01)00359-3

Posner, S., Verutes, G., Koh, I., Denu, D., & Ricketts, T. (2016). Global use of ecosystem service models. *Ecosystem Services*, *17*, 131–141. http://doi.org/10.1016/j.ecoser.2015.12.003

Power, A. G., Aizen, M. A., Garibaldi, L. A., Cunningham, S. A., Klein, A. M., Andow, D. A., … Swinton, S. M. (2010). Ecosystem services and agriculture: tradeoffs and synergies. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *365*(1554), 2959–71. http://doi.org/10.1098/rstb.2010.0143

Primmer, E., Jokinen, P., Blicharska, M., Barton, D. N., Bugter, R., & Potschin, M. (2015). Governance of Ecosystem Services: A framework for empirical analysis. *Ecosystem Services*, *16*, 158–166. http://doi.org/10.1016/j.ecoser.2015.05.002

Raudsepp-Hearne, C., & Peterson, G. D. (2016). Scale and ecosystem services: how do observation, management, and analysis shift with scale—lessons from Québec. *Ecology and Society*, *21*(3), art16. http://doi.org/10.5751/ES-08605-210316

Rausser, G. C., Small, A. A., Rausser, G. C., & Small, A. A. (2000). U . C . Berkeley Law and Economics Working Paper Series Working Paper 2000 - 11 Valuing Research Leads : Bioprospecting and the Conservation of Genetic Resources School of Law Center for the Study of Law and Society University of California Berkeley , Cal, *108*(1).

RCM. (2014). Programa de Ação Nacional de Combate à Desertificação (PANCD) Resolução do Conselho de Ministros n.º 78/2014 - Diário da República n.º 248, Série I, de 24-12-2014.

RCM. Estratégia Nacional para as Florestas, RCM n.º 6-B/2015 - Diário da República n.º 24/2015, 1º Suplemento, Série I de 2015-02-04 (2015).

República de Moçambique. (2004). Plano Estratégico para o Desenvolvimento do Turismo em Moçambique. Maputo, Mozambique.

República de Moçambique. (2007). Plano Nacional de Gestão dos Recursos Hídricos em Moçambique. Maputo, Mozambique.

República de Moçambique. (2008). *Cheias em Moçambique : Relatório da Avaliação Inicial Multissectorial sobre Segurança Alimentar e Nutricional*. Maputo. Retrieved from http://documents.wfp.org/stellent/groups/public/documents/ena/wfp197166.pdf?iframe.

República de Moçambique. (2011). Plano de Acção para a Redução da Pobreza (PARP), 2011-2014. Maputo, Mozambique.

República de Moçambique. (2013). Mozambique National Agriculture Investment Plan 2014-2018 (PNISA). Maputo, Mozambique.

República de Moçambique. (2015a). Estratégia e plano de acção nacional para restauração de mangal 2015-2020. Ministério da Terra, Ambiente e Desenvolvimento Rural, Centro de Desenvolvimento Sustentável para as Zonas Costeiras.

República de Moçambique. (2015b). Estratégia Nacional de Adaptação e Mitigação de Mudanças Climáticas 2013-2025, Ministério para a Coordenação da Acção Ambiental.

República de Moçambique. (2016). Comunicado do Secretariado do Conselho de Ministros, 9 de Fevereiro de 2016. Maputo, Mozambique.

Roose, E. (1996). *Land husbandry: components and strategy. FAO soils bulletin*. Rome: Food and Agriculture Organization of the United Nations.

Saarikoski, H., Jax, K., Harrison, P. A., Primmer, E., Barton, D. N., Mononen, L., … Furman, E. (2015). Exploring operational ecosystem service definitions: The case of boreal forests. *Ecosystem Services*, *14*, 144–157. http://doi.org/10.1016/j.ecoser.2015.03.006

Sander, J., Nicolas, D., Berta, M.-L., Nicholas, B. D., Erik, G.-B., Fanny, B., … Carla-Leanne, W. (2016). A new valuation school: Integrating diverse values of nature in resource and land use decisions. *Ecosystem Services*. http://doi.org/10.1016/j.ecoser.2016.11.007

Schröter, M., Albert, C., Marques, A., Tobon, W., Lavorel, S., Maes, J., … Bonn, A. (2016). National Ecosystem Assessments in Europe: A Review. *BioScience*, biw101. http://doi.org/10.1093/biosci/biw101

Schuijt, K. (2002). *Land and Water Use of Wetlands in Africa : Economic Values of African Wetlands*.

SETSAN. (2016). Secretariado Técnico de Segurança Alimentar e Nutricional, Maputo, Mozambique.

Spangenberg, J. H., von Haaren, C., & Settele, J. (2014a). The ecosystem service cascade: Further developing the metaphor. Integrating societal processes to accommodate social processes and planning, and the case of bioenergy. *Ecological Economics*, *104*, 22–32. http://doi.org/10.1016/j.ecolecon.2014.04.025

Spangenberg, J. H., von Haaren, C., & Settele, J. (2014b). The ecosystem service cascade: Further developing the metaphor. Integrating societal processes to accommodate social processes and planning, and the case of bioenergy. *Ecological Economics*, *104*, 22–32. http://doi.org/10.1016/j.ecolecon.2014.04.025

Swetnam, R. D., Fisher, B., Mbilinyi, B. P., Munishi, P. K. T., Willcock, S., Ricketts, T., … Lewis, S. L. (2011). Mapping socio-economic scenarios of land cover change: A GIS method to enable ecosystem service modelling. *Journal of Environmental Management*, *92*(3), 563–574. http://doi.org/10.1016/j.jenvman.2010.09.007

Tallis, H., & Polasky, S. (2009). Mapping and valuing ecosystem services as an approach for conservation and natural-resource management. *Annals of the New York Academy of Sciences*, *1162*, 265–283. http://doi.org/10.1111/j.1749-6632.2009.04152.x

Tallis, H., & Polasky, S. (2011). Assessing multiple ecosystem services: an integrated tool for the real world. In *Natural Capital* (pp. 34–50). Oxford University Press. http://doi.org/10.1093/acprof:oso/9780199588992.003.0003

Tallis, H., Rickets, T., Guerry, A., Wood, S., Sharp, R., Nelson, E., … Griffin, R. (2014). InVEST 3.0.1 User's Guide: Integrated Valuation of Environmental Services and Tradeoffs. The Natural Capital Project.

Tallis, H., Rickets, T., Guerry, A., Wood, S., Sharp, R., Nelson, E., … Vogl, A. L. (2015). InVEST 3.1.1 User's Guide: Integrated Valuation of Environmental Services and Tradeoffs. The Natural Capital Project.

TEEB. (2010). *The economics of ecosystems and biodiversity: ecological and economic foundations*. London ; Washington, DC: Earthscan.

TEEB. (2017). TEEB. Retrieved November 27, 2017, from http://www.teebweb.org/

Tolessa, T., Senbeta, F., & Kidane, M. (2017). The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. *Ecosystem Services*, *23*, 47–54. http://doi.org/10.1016/j.ecoser.2016.11.010

Tolvanen, H., Rönkä, M., Vihervaara, P., Kamppinen, M., Arzel, C., Aarras, N., & Thessler, S. (2014). Spatial information in ecosystem service assessment: data applicability in the cascade model context. *Journal of Land Use Science*, (March 2015), 1–18. http://doi.org/10.1080/1747423X.2014.947642

Trabucco, A., & Zomer, R. J. (2009). Global Aridity Index (Global-Aridity) and Global Potential Evapo-Transpiration (Global-PET) Geospatial Database. CGIAR Consortium for Spatial Information.

Troy, A., & Wilson, M. a. (2006). Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer. *Ecological Economics*, *60*(2), 435–449. http://doi.org/10.1016/j.ecolecon.2006.04.007

Turpie, J. (2000). *The use and value of natural resources of the Rufiji floodplain and delta, Tanzania. Unpublished report to IUCN (EARO)*. Retrieved from http://coastalforests.tfcg.org/pubs/REMP 20 TR17 Value of Natural Resources.pdf

UNDP. (2015). Human Development Indicators. Retrieved from http://hdr.undp.org/en/countries/profiles/MOZ

UNISDR. (2016). DesInventar, Disaster Information System, United Nations Office for Disaster Risk Reduction.

UNISDRI. (2015). Desinventar Information Management System. Retrieved December 5, 2016, from http://www.desinventar.net/DesInventar/main.jsp

Van der Ploeg, S., & de Groot, R. S. (2010). The TEEB Valuation Database – a searchable database of 1310 estimates of monetary values of ecosystem services. Foundation for Sustainable Development, Wageningen, The Netherlands.

van Zanten, B. T., van Beukering, P. J. H., & Wagtendonk, A. J. (2014). Coastal protection by coral reefs: A framework for spatial assessment and economic valuation. *Ocean & Coastal Management*, *96*, 94–103. http://doi.org/10.1016/j.ocecoaman.2014.05.001

von Maltitz, G. P., Gasparatos, A., Fabricius, C., Morris, A., & Willis, K. J. (2016). Jatropha cultivation in Malawi and Mozambique: Impact on ecosystem services, local human wellbeing and poverty alleviation. *Ecology and Society*, *21*(3). http://doi.org/10.5751/ES-08554-210303

Wallace, K. J. (2007). Classification of ecosystem services: Problems and solutions.

*Biological Conservation*, *139*(3–4), 235–246. http://doi.org/10.1016/j.biocon.2007.07.015

Wang, W., Guo, H., Chuai, X., Dai, C., Lai, L., & Zhang, M. (2014). The impact of land use change on the temporospatial variations of ecosystems services value in China and an optimized land use solution. *Environmental Science & Policy*, *44*, 62–72. http://doi.org/10.1016/j.envsci.2014.07.004

Wang, Z., Mao, D., Li, L., Jia, M., Dong, Z., Miao, Z., … Song, C. (2015). Quantifying changes in multiple ecosystem services during 1992?2012 in the Sanjiang Plain of China. *Science of The Total Environment*, *514*, 119–130. http://doi.org/10.1016/j.scitotenv.2015.01.007

Wang, Z., Wang, Z., Zhang, B., Lu, C., & Ren, C. (2015). Impact of land use/land cover changes on ecosystem services in the Nenjiang River Basin, Northeast China. *Ecological Processes*, *4*(1), 11. http://doi.org/10.1186/s13717-015-0036-y

Wangai, P. W., Burkhard, B., & Müller, F. (2016). A review of studies on ecosystem services in Africa. *International Journal of Sustainable Built Environment*, *5*(2), 225–245. http://doi.org/10.1016/j.ijsbe.2016.08.005

Westman, W. E. (1977). How Much Are Nature's Services Worth? *Science*, *197*(4307), 960–964. http://doi.org/10.1126/science.197.4307.960

Wilson, M. A., & Hoehn, J. P. (2006). Valuing environmental goods and services using benefit transfer: The state-of-the art and science. *Ecological Economics*, *60*(2), 335–342. http://doi.org/10.1016/j.ecolecon.2006.08.015

Wischmeier, S. (1978). *Predicting rainfall erosion losses: A guide to conservation planning*. Washington, DC: U.S. Department of Agriculture.

Wong, C., Roy, M., & Duraiappah, A. K. (2005a). *Focus on Mozambique*. *Connecting poverty and ecosystem services: A series of seven country scoping studies*. Retrieved from https://www.iisd.org/pdf/2005/economics_poverty_uganda.pdf

Wong, C., Roy, M., & Duraiappah, A. K. (2005b). *Focus on Mozambique. Connecting poverty and ecosystem services: A series of seven country scoping studies*.

Wong, C., Roy, M., & Duraiappah, A. K. (2005). *Focus on Mozambique. Connecting poverty and ecosystem services: A series of seven country scoping studies*.

Woodhouse, P. Agricultura , Pobreza E a Receita Do Parp (2014).

World Bank. (2016). Mozambique. Retrieved March 19, 2016, from http://data.worldbank.org/country/mozambique

Wu, K., Ye, X., Qi, Z., & Zhang, H. (2013). Impacts of land use/land cover change and socioeconomic development on regional ecosystem services: The case of fast-growing Hangzhou metropolitan area, China. *Cities*, *31*, 276–284. http://doi.org/10.1016/j.cities.2012.08.003

WWF. (2016). Major Biomes of the world. Retrieved January 1, 2016, from http://wwf.panda.org/about_our_earth/teacher_resources/webfieldtrips/major_biomes/

Yi, H., Güneralp, B., Filippi, A. M., Kreuter, U. P., & Güneralp, İ. (2017). Impacts of Land Change on Ecosystem Services in the San Antonio River Basin, Texas, from 1984 to 2010. *Ecological Economics*, *135*, 125–135. http://doi.org/10.1016/j.ecolecon.2016.11.019

Zang, Z., Zou, X., Zuo, P., Song, Q., Wang, C., & Wang, J. (2017). Impact of landscape patterns on ecological vulnerability and ecosystem service values: An empirical analysis of Yancheng Nature Reserve in China. *Ecological Indicators*, *72*, 142–152. http://doi.org/10.1016/j.ecolind.2016.08.019

Zhang, Y., Holzapfel, C., & Yuan, X. (2013). Scale-dependent Ecosystem Service. In *Ecosystem Services in Agricultural and Urban Landscapes* (pp. 105–121). Oxford: A John Wiley & Sons. http://doi.org/10.1002/9781118506271.ch7

Zhongyuan, Y., & Hua, B. (2011). Status Quo of Research on Ecosystem Services Value in China and suggestions to future research. *Energy Procedia*, *5*, 1044–1048. http://doi.org/10.1016/j.egypro.2011.03.184