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

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## ABSTRACT

The incorporation of ecosystem services (ES) information in planning decisions is an important factor in the sustainable use of natural resources. However, studies assessing the levels and changes of these services at national level are rare. In this paper, we estimate past and future changes in multiple ES and biodiversity, as a consequence of land cover change (LCC) in Mozambique. Water yield, water quality, erosion regulation, climate regulation, and biodiversity were modeled using a spatially explicit approach. Changes in ES and biodiversity were mapped at province level between 2005 and 2009. Through the use of a land change model, land cover was projected for 2025, and the resulting impacts on ES and biodiversity were estimated. We found a moderate increase in climate regulating service between 2005 and 2009. However, water quality (nutrient retention) and biodiversity decreased. LCC for 2025 is expected to have a similar impact on these ES. This study contributes with a methodology that can be useful for monitoring ES and assist decision policies affecting ES provision and trade-offs.

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## 1. Introduction

Ecosystem services (ES) are the benefits that people derive from nature, and these are essential for human well-being (Costanza et al. 1997, 2014; 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. 2011). 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 (Bai et al. 2013; Leh et al. 2013) and economic valuation studies of ES (Kubiszewski et al. 2013; Frélichová et al. 2014; Jacobs et al. 2016; Kindu et al. 2016). ES mapping tools and quantitative biophysical and economic indicators make ES values visible thereby helping to assess the trade-offs associated with these interactions (Tallis and Polasky 2009, 2011; Maes et al. 2012; Burkhard et al. 2013). To this end, several national ecosystem assessments have been carried out under the Millennium Ecosystem Assessment framework (Millennium 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 et al. 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 (Leh et al. 2013; Feger et al. 2015; Tolessa et al. 2017). The effective management of LCC has been considered crucial to design policies able to ensure ES supply (Portela and Rademacher 2001; Nelson et al. 2009; Swetnam et al. 2011; Martínez-Harms and Balvanera 2012; Mascarenhas et al. 2015). 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 and Ruth 1998; Olsson et al. 2004; Kareiva et al. 2011; Maes et al. 2012; Kubiszewski et al. 2017).

Studies about the impact of LCC on ES have been carried out all over the world (Polasky et al. 2011; Feger et al. 2015; Wang et al. 2015). For Africa, these studies are rare, possibly due to the lack of data (Leh et al. 2013; Abram et al. 2014; Dawson and Martin 2015; Kindu et al. 2016; Wangai et al. 2016). This constitutes an important problem because this continent is undergoing significant LCC with important impacts on the supply of ES (Power et al. 2010; Leh et al. 2013; Kindu et al. 2016). Specifically for Mozambique, earlier works have analyzed ES at national, regional, and local levels (C. Wong et al. 2005; Nagabhatla et al. 2008; Mudaca et al. 2015;

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 Supplemental data for this article can be accessed [here](#).

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Nunes and Ghermandi 2015; Von Maltitz et al. 2016). 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 Trade-offs (InVEST) (Tallis et al. 2015) – 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 (Nelson et al. 2009; Goldstein et al. 2012; Delphin et al. 2013; Geneletti 2013; Leh et al. 2013; Cabral et al. 2016; Jiang et al. 2016; Posner et al. 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’, that is, the capacity of a landscape to provide goods and services to society (Lamarque et al. 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.

## 2. Materials and methods

### 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<sup>2</sup> (Figure 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 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).

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 (Chemane et al. 1997; Nicholls and Tol 2006; Cardona et al. 2012). 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) (República de Moçambique 2015a, 2015b; INE 2016a). This exposure is being amplified by the increase of people and associated infrastructures (EEA 2006; Martins et al. 2012), and by the expected increase in coastal flooding and sea level rise (IPCC 2014).

### 2.2. Data and methods

The overall methodology followed in this paper is shown in Figure 2 and explained further below.

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 to 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 and Barton 2013). Therefore, and considering the data availability, the selected ES indicators for modeling included water yield, water quality, sediment retention, carbon storage, and biodiversity. These indicators have been used successfully in other studies (Bhagabati et al.

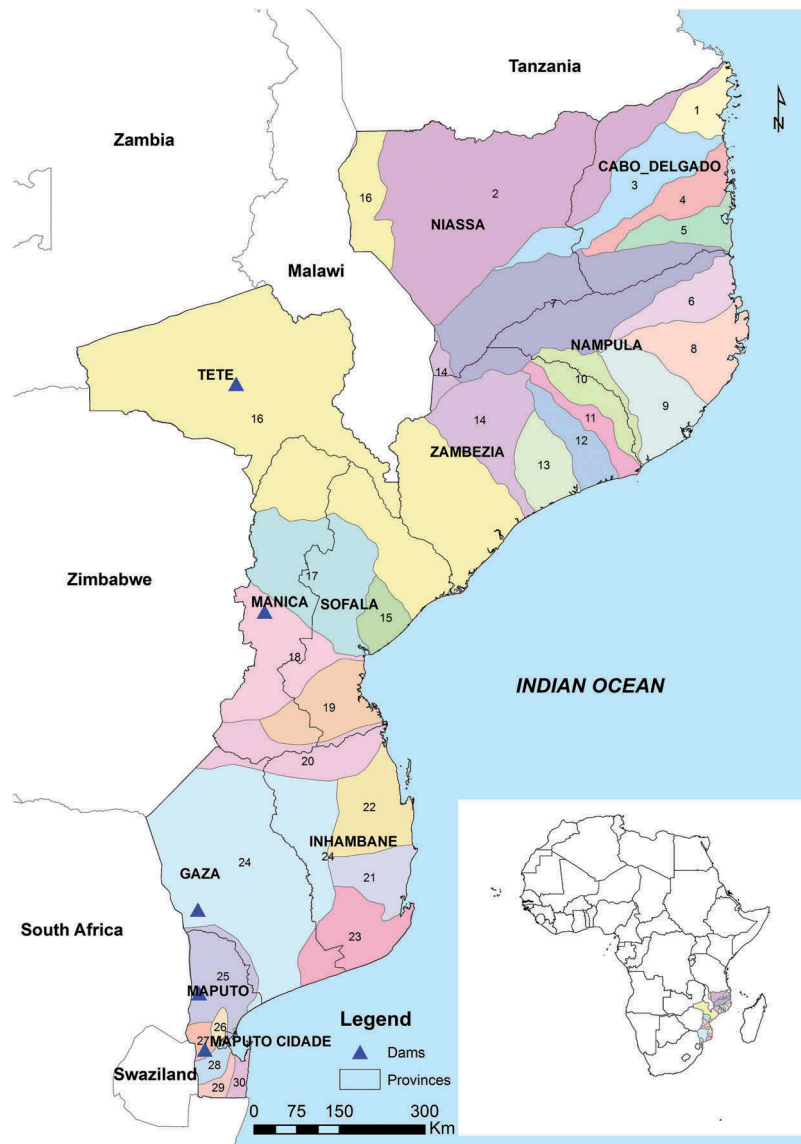


Figure 1. Mozambique provinces, dams, and numbered hydrological basins.

Table 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-Provincia	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

2012; Bai et al. 2013; Leh et al. 2013; Cabral et al. 2016). Table 2 shows the ES and respective ES indicators (units) used in the current study. We used the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) tool (Tallis et al. 2015) 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.

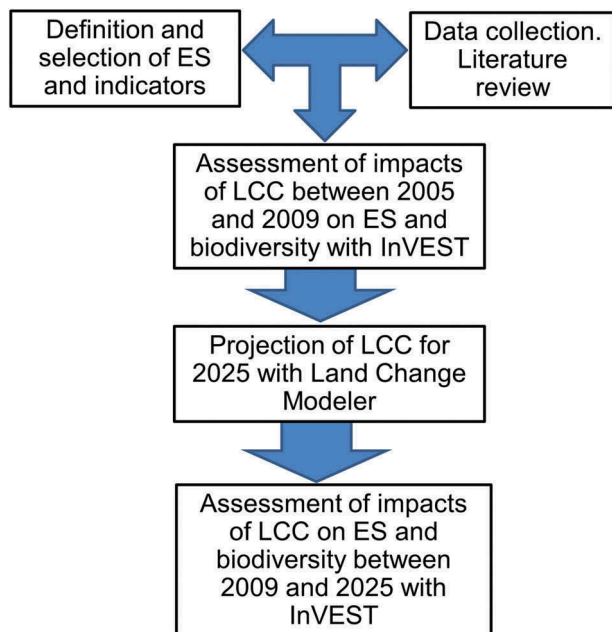
### 2.2.1. Land cover data

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](http://due.esrin.esa.int/page_globcover.php)). These datasets differentiate 19 classes of land cover (Table 3) and are derived from data acquired by the ENVISAT MERIS sensor, with 300m of spatial resolution (ESA 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>).

### 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.

**2.2.2.1. Water yield.** Water yield is the amount of water running off the landscape (Langbein and Iseri



**Figure 2.** Flowchart of the methodology used in the study.

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

Ecosystem services	Ecosystem service indicator, units
Water yield	Water yield, m <sup>3</sup> /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

1995). The Water Yield InVEST model is based on the Budyko curve and annual average precipitation (Tallis et al. 2015). The hydrologic basins, available at the CENACARTA website, are based on the 30 m digital elevation model (DEM) from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). We parameterized this InVEST model using average annual precipitation (Hijmans et al. 2005), annual reference evapotranspiration (Trabucco and Zomer 2009), soil characteristics (FAO et al. 2012), watersheds from CENACARTA, and land cover (ESA 2015) to calculate the average water yield. We report water yield in m<sup>3</sup>/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, 2016).

**2.2.2.2. Water quality.** The InVEST nutrient retention model evaluates land cover effects on water quality (Tallis et al. 2015). 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 (Tallis et al. 2015). The nutrient load is obtained by routing water along flow paths based on slope (Tallis et al. 2015). Finally,

**Table 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

the nutrient load quantity retained by the landscape is calculated using the nutrient retaining capacity of each type of land cover (Tallis et al. 2015). We parameterized this InVEST model using a digital elevation model (DEM) (NASA 2012), annual reference evapotranspiration (Trabucco and Zomer 2009), soil characteristics (FAO, IIASA, ISRIC, ISSCAS, JRC 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).

**2.2.2.3. Erosion regulation.** Soil erosion can be caused by rain and runoff. Harmful effects of erosion include (Lal 1998; Mann et al. 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 (Tallis et al. 2015) 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, IIASA, ISRIC, ISSCAS, JRC 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):

$$\text{USLE} = R * K * LS * C * P \quad (1)$$

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):

$$R = 0.5 * P + 0.05 \quad (2)$$

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 provides the biophysical values used to parameterize the InVEST sediment retention model (Leh et al. 2013, 2016).

**2.2.2.4. Climate regulation.** Carbon storage is an important global climate regulating service (Gómez-Baggethun and 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 (Tallis et al. 2015). 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 provides the biophysical values used to parameterize the InVEST carbon model (Leh et al. 2013, 2016).

**2.2.2.5. 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 et al. 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 (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 (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).

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

LCC was 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, 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.

### 2.2.4 ES changes

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

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

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. Results

### 3.1. Land changes in mozambique between 2005 and 2009

After reclassifying GlobCover classes using a simplified land use and land cover legend (Bai et al. 2014) (Table 3), we observe an important increase in the cropland between 2005 and 2009 (27%) (Table 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

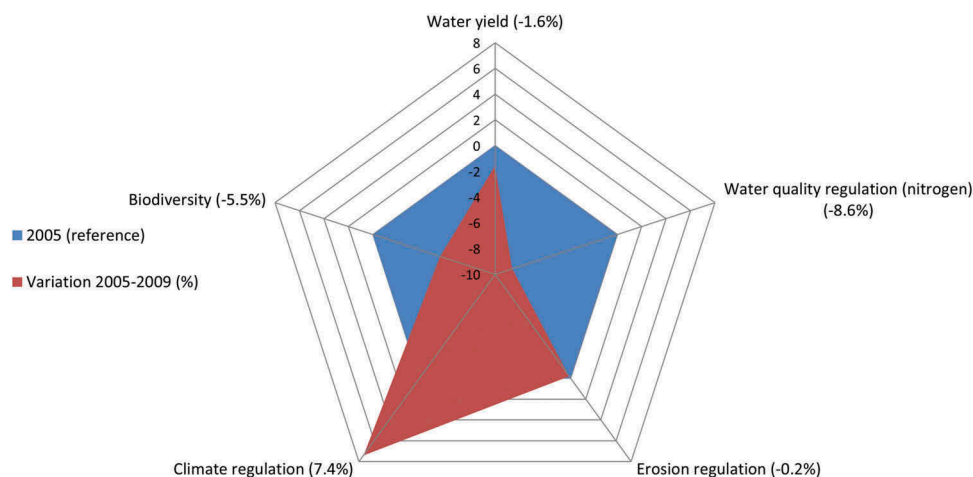
will most likely change into cropland. According to (FAO 2013), the main farming system in Mozambique is rain-fed subsistence farming with low levels of productivity due to the lack of conditions, including technology, market accessibility, storing infrastructure and agricultural organization (Woodhouse 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.

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

Figure 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

**Table 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).

2005	Class	2009								Total ha	%	Var (%) 05–09
		C	F	S	G	W	U	D	WB			
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		
	%	21.70	61.71	14.96	1.69	0.01	0.01	0.01	0.83			



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

(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.

Table 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

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

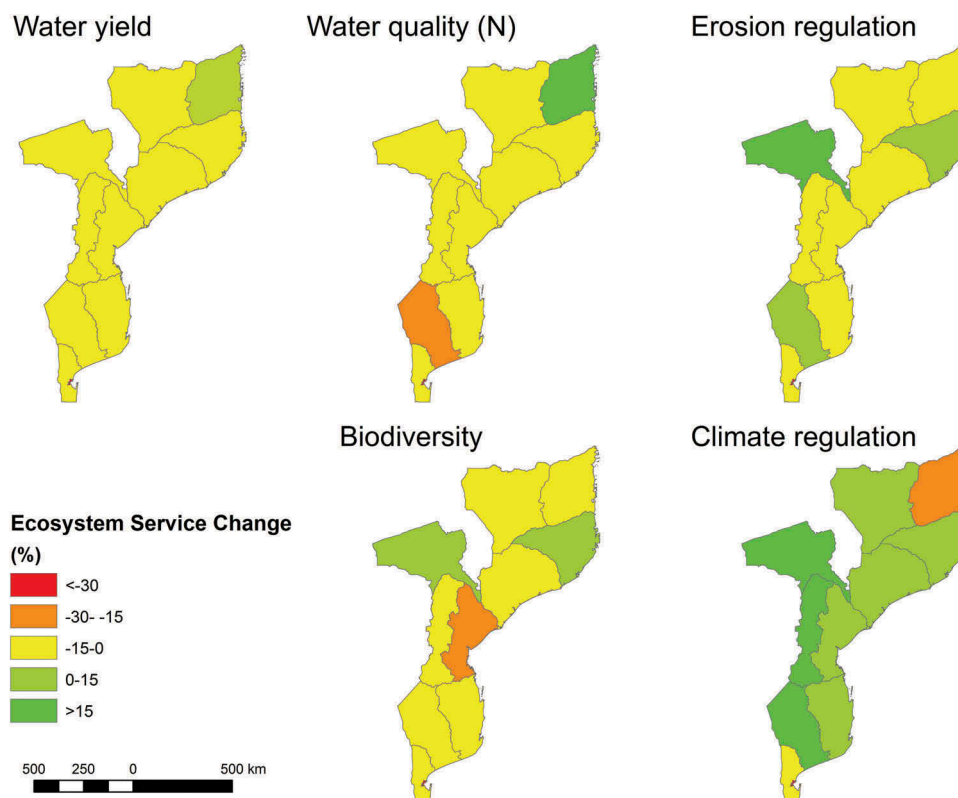
Province	Water yield	Water quality (N retention)	Erosion regulation	Biodiversity	Climate regulation
Cabo Delgado	1.5	4.3	-2.9	-10.4	-23.7
Gaza	-4.8	-22.2	0.6	-5.8	24.2
Inhambane	-0.6	-10.1	-1.5	-8.4	12.4
Manica	-2.9	-10.9	-1.2	-5.2	25.2
Maputo	-0.8	-2.1	-5.4	-13.4	-11.3
Maputo City	-94.6	-96.2	-86.3	-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

(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.

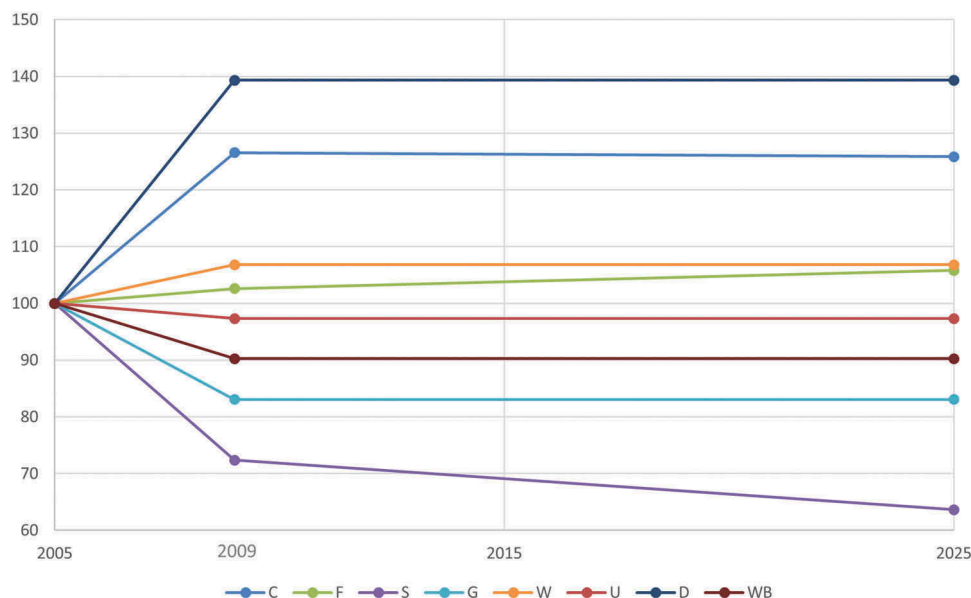
Figure 4 shows the variation of ES for all the provinces using year 2005 as reference. Orange to red colors represent an increasing decline in the ES between 2005 and 2009, while light green to dark green represent an increasing improvement in ES. Maputo city is always red color, indicating a degradation 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 ( $-23.7\%$ ).

### 3.3. Modeled land change trends and impacts on ES for 2025

Figure 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



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



**Figure 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).

decline of this class. Figure 6 shows the variation (%) of the ES indicator levels from 2005 to 2025 (index 100 in 2005).

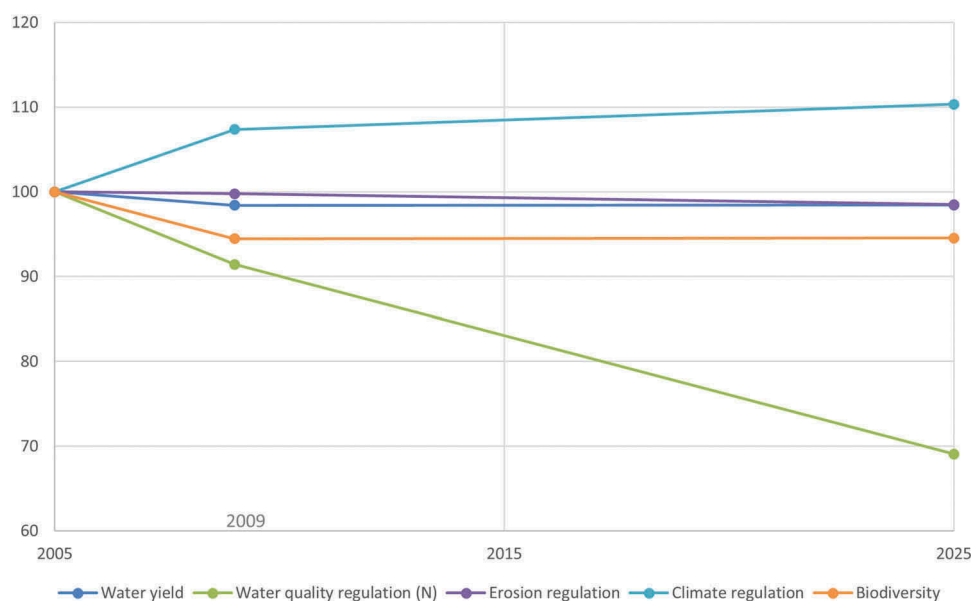
Results show that the climate regulating service is expected to increase 10.3% in Mozambique, confirming the trend seen between 2005 and 2009. However, water quality regulating service (nitrogen retention) is expected to fall sharply (−30.9%). All the other services will fall less than 6%. The reduction 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 7)

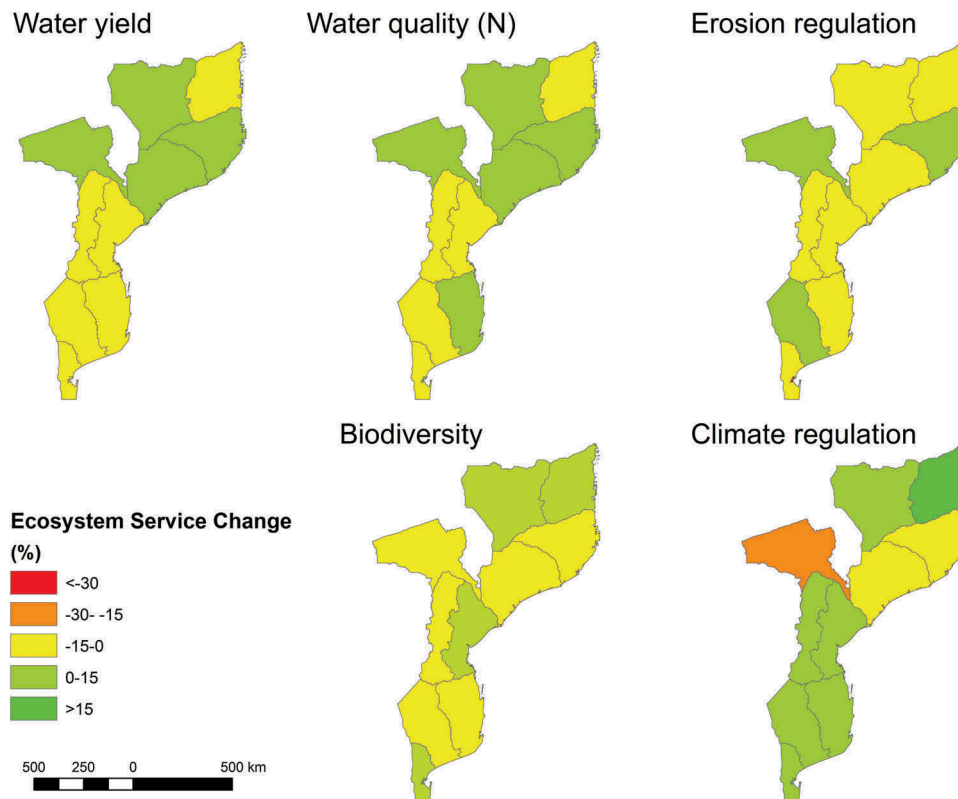
shows that the provinces in the South of the country will be affected by a decrease in this service from 2009 to 2025.

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 and Mineau 1995). This decrease may be explained by the



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



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

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).

## 4. Discussion

### 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.

### 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 et al. 2001), and their ability to protect population and infrastructures from storms and cyclones has been reported in several studies (e.g. Das and Crépin 2013; Barbier 2016). 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<sup>2</sup> (Carissa Wong et al. 2005) and are known to dissipate wave energy and assist in the prevention of sea storm effects on habitats and infrastructures of nearby coasts (Van Zanten et al. 2014; Costa et al. 2016). Coral reefs are also one of the major attractions for Mozambique's developing coastal tourism industry (Motta et al. 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 (UNISDR 2016; Cabral et al. 2017). 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 et al. 2009), and negatively affects coral physiology and ecosystem functioning (D'Angelo and 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 (Hassan et al. 2005; Dallimer et al. 2012; 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.

### 4.3. Limitations

Important aspects to consider when dealing with ecosystem assessments, and which are often overlooked by actors and researchers, are scale (Zhang et al. 2013; Grêt-Regamey et al. 2014) and data and modeling uncertainties (Hou et al. 2013; Hamel and Bryant 2017). The scale of analysis has a variable impact on the results of ES studies (Raudsepp-Hearne and Peterson 2016). It limits the type of ES possible to analyze and also influences estimates of ES values (Zhang et al. 2013; Grêt-Regamey et al. 2014). 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 (Hou et al. 2013; Hamel and Bryant 2017). 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 (Tallis et al. 2015). For instance, the carbon model is very simplified and does not consider full carbon cycle (Tallis et al. 2015). The same is true of the water model, which does not account for the whole hydrologic cycle (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 trade-off analysis to better understand the impact of different planning options on ES.

## 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.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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