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# Valuation of Ecosystem Services: Insight from Lake Malombe, Malawi

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## Abstract

Lake Malombe is endowed with a variety of ecosystem services (ES) that have a considerable economic value. This study used, a combination of market-based and value transfer techniques to evaluate the lake ES. The results showed that the annual economic value of Lake Malombe ES is estimated at US\$ 40.68million, equivalent to US\$635.63/hh/yr. The ecosystem provisioning service (EPS) is ranked the highest (87.45%) in terms of contribution, followed by biodiversity (8.64%), flood regulation (3.70%) then carbon sequestration, culture, and aesthetic services. The ES quality index ranks culture and aesthetic services as the lowest suggesting that investment in the tourism industry in Lake Malombe is not much advanced. Although this study did not take into account all ES components such as non-use values and other regulatory services, the estimated total annual ES value of US\$ 40.68million derived from Lake Malombe provides a strong basis for a need to design an economic incentive model to encourage the local communities to take responsibility for managing the lake. Any decline in the supply of ES can eventually worsen poverty and push the local population to desperately over depend on EPS and degrade even the areas deemed to be conserved for future generations thereby creating a vicious circle of poverty and ecosystem disservices. This study provides a significant insight into the trade-offs between ES and diverse stakeholders. Balancing the interest of local communities given the importance of EPS in sustaining their livelihoods and that of global communities is required to effectively manage the lake.

**Keyword:** Economic value; local communities; ecosystem services; ecosystem disservices; market-based techniques; value transfer technique

## Introduction

The concept of an ecosystem is explicitly defined as a dynamic complex of biodiversity and their interaction with non-biota as a function unit (Brockhoff, et al., 2017). The tangible and intangible benefits that people obtain from ecosystems can be defined as ES (MEA, 2003). The Great African Rift Valley freshwater ecosystems harbor the world's richest lacustrine fish fauna and birds (Wilson & Primack, 2019; Sharma et al. 2015; Makwinja et al. 2019). The lakes are found within a flyway of migratory birds between Africa and Europe (Nindi, 2007) and are ranked as the most productive in the world. They provide a wide range of services to communities locally and at a national level. Evidence has shown that both rural and urban populations depend on freshwater ES such as fishery (Plisnier et al 2018). Provisioning, regulation, and purification play a central role in human sustenance (MEA, 2005). Water and airborne diseases, wastewater, and climate change impact are regulated by freshwater ecosystems. Millennium Ecosystem Assessment (2005) report, documented that the freshwater ecosystem in Africa contributes basic needs, health, and wellbeing in terms of provisioning, food production, pest and disease regulation, biochemicals, regulation of climate, water and nutrient recycling, culture, in terms of identity, sense of place, traditional ecological knowledge, recreational and spiritual values.

The past decades have seen a growing interest in understanding the importance of ecosystem services to people and the ecosystem has been described in terms of services rendered to the society (Hein, et al., 2016). Viewing the ecosystem as an economic asset means defining it as natural capital. The theory underpinning the classification of goods and services rendered by the ecosystem as economic has been linked to the fact that the ecosystem has a value to users (Perry et al. 1997). The term 'value' is depicted as capital. The economic theory identifies four kinds of capital thus human, financial, manufactured, and natural (Chee, 2004). Natural capital associated with the ecosystem is categorized into direct 'capital' derived from consumptive and non-consumptive uses (fisheries, agriculture, recreation), indirect use 'capital' linked to indirect services (flood protection, carbon sinking, nutrient

retention), uses 'capital' related to the premium placed on possible future uses and non-uses (knowledge of the existence of ecosystem also known as existence value or are available for others to use (altruistic value) or in the future (bequest value) (Sharma et al 2015). Several researchers have shown that economic valuation can provide a powerful tool for placing ecosystems on the agendas of conservation and development decision making as economically productive systems (Heal, 2000; Hartel et al. 2014; Rasul, 2009). This is true, particularly in Africa. Unfortunately, few studies exist regarding the subject (IPBES, 2018). A comprehensive literature search revealed that ecosystem valuation studies have only been conducted in approximately 18% of the African countries (Wangai et al, 2016) and none has been conducted in Malawi. This has led to the continued loss, conversion, and degradation of ecosystem services on the continent. Lake Malombe is a common pool asset that has experienced unprecedented ecosystem services loss evidenced by the decline in fish biodiversity, depletion and degradation of water quality, increased pollution, and siltation, invasion of alien species such as water hyacinth (*Eichhornia crassipes*), and overfishing. Wide population explosion, climate change, expansion of human settlements, and agriculture around the lake, has further caused the serious collapse of the lake ecosystem with economic and social consequences. The effort to reverse the situation has failed because the true value of the lake ecosystem services is underappreciated and not documented resulting in ill-informed management decisions which further contributes to the unprecedented loss, conversion, and degradation of the lake. Introduction of gear licenses and permits - an example of command and control approach (Hara & Nielsen, 2003) to alienate people from accessing resources from the lake to conserve, failed to achieve its objective due to lack of economic incentive measures desired for novelty. Currently, most experts and experienced fishers concur that the productivity of the Lake Malombe ecosystem services is now much lower than in the last two or three decades (Hara & Njaya, 2016). This led to the theory that the lake ecosystem has generally been overexploited and the trend is likely to continue unless proper actions are taken. Therefore, the primary objective of this study was to generate information that will enhance decision-making awareness of the values of the lake ES, create a market for Lake Malombe ecosystem investment, improve management approaches and provide a framework for decision making for sustainable management of the lake. The findings of this study can also be applied to other lakes in Malawi, Africa, and the globe.

## **Concepts and theories of ecosystem valuation**

### **Theories underpinning ecosystem valuation**

The notion of ecosystem valuation (EV) rose as far back as around the 1960s (Bateman et al. 2000). Later in the year, the concept gained a strong political momentum (Small et al. 2017) and helped environmental economists to conventionally address natural ES changes (Martínez-Paza et al, 2014; Sarvilinna et al. 2018). In 1995, United Kingdom Environmental Act established Environmental Agency (EA) which was mandated to take into account environmental costs and benefits arising from its policies (Bateman et al.2000). United Kingdom National Ecosystem Assessment report recommended the EV concept (Vačkář et al 2018). The aspect of the EV concept has also been considered in the Spanish National Ecosystem Assessment program (Vačkář et al 2018). According to Quintas-Soriano et al.(2015), a meta-analysis of valuation studies was adopted in Spain from 649 economic value estimates within the 150 primary studies documented. A national study carried out in the Czech Republic by Frélichová et al. (2014), used a novel Consolidated Layer of Ecosystems developed in the Czech Republic and comprising 41 land cover categories differentiating natural and human-influenced ecosystems and 17 ES to estimate the total economic value of ES by unit value transfer at the national scale. In New Zealand, the 1991 Resource Management Act (RMA) transformed the EV approaches from mainly an academic exercise into a government decision support tool for policy decision-making. In New Zealand, the concept was framed to help the policymakers to understand the economic consequences of the mismanagement of natural ecosystems and also to find ways of incorporating the ES into a cost-benefit analysis of public policy. During the Tenth Conference of Parties (COP) to the Convention on Biological Diversity in Nagoya in 2010, the Economics and Biodiversity (TEEB) report highlighted the significance of EV. The report pointed out that the notion could serve as a basic governance resource tool that could change our individual and collective choices (COP, 2010). The report further recognizes EV as a key for more effective mainstreaming of biodiversity. Recently, the concept of EV has received overwhelming support in Finland and has been used as a tool for holistic land-use planning (Jäppinen & Heliölä, 2015). The integration of spatial EV data into planning, decision making, and management has been highly recommended (Jäppinen & Heliölä, 2015). Several research publications supported the COP notion and further explained that estimating EV that reflect the social importance of ES is the most prerequisite for better management choices (Landell-Mills & Porras, 2002).

### **The debate over the ecosystem valuation as policy supporting tool**

Although EV has received enormous support, many heated arguments have been going on over the past years regarding the perception of the EV concept. Economists have claimed that EV alone does not provide enough

reasoning for ecosystem management (Myers & Reichert, 1997). Boyd & Banzhaf (2007) also argued that the big picture of ES related flows is complex and proper cost-benefit analysis would need to consider non-ecological flows. Balmford et al. (2011) also added that valuing natural ES is not necessary for coherent and consistent choice about the environment. de Groot, et al. (2010) further argued that valuation of ES in monetary units can never in themselves provide easy answers to difficult decisions and hence should be treated as additional information, complementing quantitative and qualitative assessments to help decision-makers by giving approximations of the value of ES involved in the trade-off analysis. Schröter et al. (2014) also added that EV cannot capture the complex biophysical and socio-cultural benefits provided by ES. However, other researchers have disputed that there is growing evidence of the potential benefits of the EV concept as a tool for decision making in ES management (Geneletti, 2011). For instance, the EV concept has been used for policy interpretation and decision-making tools (Geneletti et al. 2018; Cortinovis & Geneletti, 2018). Posner et al. (2016) explained that the EV concept promotes ecosystem sustainability through the awareness of stakeholders. Kates (2011) also added that human wellbeing along with biodiversity and ecosystem conservation can be achieved when EV knowledge is deliberately put into actions to produce outcomes that can support new policies. Other researchers have also argued that the increased threat of global ES provides sufficient evidence of the significance of accurate EV (Pandeya, et al. 2016). Ecologists have also argued that by nature, human beings protect what they value (Heal, 2000). This implies that natural ecosystems can only be protected if it has a value to human beings and this value needs to be quantified. Ndebele (2009) also added that comprehensive cost-benefit analysis of policy can bring a true picture of ES that reflects the total cost and benefits of the policy to society. Recently, United Nation acknowledged EV for its positive contribution to economic, environmental, and social well-being-the three pillars of sustainable development. Faust et al. (2013) also argued that ample evidence has indicated that current ES utilization and management are unsustainable and there is a need for stakeholders to develop action plans and evolve towards the integration of participatory approach in the decision-making process and it can only be achieved through a comprehensive assessment of the ES services (Gleick & Palaniappan, 2010).

### **Materials and methods**

The study was framed within the context of well-established and useful ecosystem framework for categorizing diverse values associated with Lake Malombe ES. The framework consists of direct use, indirect use, and non-use values. This approach is commonly used because it avoids the error of double-counting of ecosystem functions, intermediate services, and final services.

### **Description of the Study Site**

Lake Malombe (Figure 1) is described as a permanent floodplain lake fed by the water from Lake Malawi via a 19km stretch of Upper Shire River. It lies in a broken depression running northwest from Lake Chilwa to Lake Malawi, parallel to the Shire River between latitude 14°21' to 14°45' south and longitudes 35°10' to 35°20' east in the southern part of Mangochi District (Fisheries Department, 2019). The lake forms part of the complex African Great Rift Valley system and is ranked as the third-largest in Malawi (30km in length and 15km in width, with a total area of 450km<sup>2</sup>, mean depth of 2.5, and a maximum depth of 7m) (Dulanya et al. 2014). It shares unique characteristics of Lake Malawi's aquatic biological diversity, including a high level of fish fauna, genetic pools, and endemism. It is described as one of the most productive lakes in Africa due to its shallowness, turbid and nutrient-rich waters, with shelving vegetated shores without many rock outcrops. Although fish productivity is lower in Lake Malombe as compared to Lake Malawi, the lake productivity is higher due to inflowing nutrient-rich streams from its highly populated catchment and by recycling of nutrients in the sediments. The west bank of Lake Malombe is bordered by the hills, which lie within 3-7km from the lake while on the eastern side is bordered by Mangochi hills. The southeastern part is the Liwonde National park. The local fishing population is trapped within narrow strips of land along the lake on both sides making the most densely populated area with little land for farming. The communities around the lake are predominately fishers and the lake has approximately 65 fishing beaches scattered over the three major administrative strata known as Lake Malombe East coded as 1.1, Lake Malombe West coded 1.2 and Upper Shire coded 1.3. The surrounding area of Lake Malombe is densely populated by the Yao ethnic tribe consisting of over 85% of the fishing population. Few tribes such as Chewa, Lhomwe, and Nyanja are also found around the Lake.

### **Data collection preparation**

The study adopted sequential procedures for estimating the total economic values of the lake ecosystem (Table1). The main beneficiaries of the lake ecosystem (local population, Government agencies, non-governmental organizations, and local governance structures) were identified. All use and non-use ES values were documented after wide consultation with diverse stakeholders. The different ES values were ranked by each group of

stakeholders based on their degree of importance. The score was used to select the top ES values. The total economic value of Lake Malombe ecosystem services took into account the direct use, and indirect use (Table 2).

### Primary data collection

The data collection began with exploratory surveys and field observation which was conducted from April to September 2019. These were done to contextualize the area in which the research was to be conducted and helped to reduce the cost for data collection and also avoid collecting data that is already available as well as avoiding collecting data that is not related to the research objective. This phase was further used to obtain permission from the Mangochi district council as well as the relevant ministry to conduct the research. At the end of this phase, research tools such as semi-structured and structured questionnaires, and a checklist for key informants as well as focus group discussion were framed and pretested. Multiple approaches were used to select respondents. The household was taken as a unit of measure. The data collection process was done in three phases. The first phases involved stratified sampling of riparian communities around the lake. The second stage involved random sampling of villages within the lake catchment that was accessible and the last phase was a random sampling of households who were the direct beneficiaries of the lake ecosystem. The household survey was done from October to December 2020.

### Sample size and sampling design

The study adopted a comprehensive socio-economic survey approach. Households for interviews were purposively sampled based on their proximity to the lake. To calculate the sample size for the study area, the following formula was used:

$$n_r = p(1 - p) \left( \frac{z}{\epsilon} \right)^2 \quad (1)$$

Where  $n_r$  = sample size and  $z$ = value from standard normal distribution reflecting the level of confidence ( $z=1.96$  for 95% level of confidence) of unknown population proportion ( $p$ ).  $P=0.05$  and assumes maximum heterogeneity. To have a statistically representative sample size with the highest accuracy, 0.043 margins of error ( $\epsilon$ ) was used. The calculated sample size from the formula above is approximately 519 households. However, to ensure a high degree of precision, the sample size was increased to 533 households. The questionnaire for the survey was designed in English, which is an official language in Malawi. However, during interviews, the questionnaire was translated into either Yao or Chichewa. The data collection procedure conformed to high ethical values and the questionnaire was only administered to the respondents after seeking concession. Highly skilled and qualified graduates from Mzuzu University and Lilongwe University of Agriculture were recruited to administer questionnaires after being trained and pre-test the questions in a different community. Data were collected for 25 days. Complementary data were obtained from available published literature (Pant et al. 2012), government official statistics, documentations made by NGOs working in the area, and revenue generated from the Lake Malombe ecosystem.

### Valuation techniques

A combination of both direct market (DM) and value transfer approaches (VTA) was used to estimate the economic value of major direct and indirect uses of ES provided by Lake Malombe. The VTA is a technique of estimating the value of an ES by assigning an existing valuation estimate for a similar ecosystem elsewhere ( Brander, 2004). The technique has been heavily recognized by several researchers and is widely adopted in many EV studies especially when budget and time are major limitations (Wilson & Hoehn, 2006). The hypothesis that underlies VTA is that the economic value of ecosystem goods and services can be determined with a high degree of precision by examining existing valuation studies at other sites elsewhere. In this study, unit VTA where ES is expressed as a value per unit area or per beneficially was adopted. The meta-analytical function approach was also adopted to complement the data (Troy & Wilson, 2006). The main Lake Malombe freshwater ES that were considered in this study include provision services (livestock folders, fish, water supply, flood plain agriculture, fuel-wood, construction materials, medicines, fruits, household furniture, objects of art such as wood carvings, curios, and others), regulating services (flood protection and carbon sequestration) and cultural services such as tourism. Supporting services were considered independently for valuation because they are either biophysical or intermediate benefits that contribute to the provision of a range of final benefits from either provisioning, regulating, or culture services (Sharma et al. 2015). The economic value of non-use values and some components such as indirect use (regulating services) such as water purification, habitat provision, and micro-climate stabilization were not considered due to lack of data (Cortinovis & Geneletti , 2018).

### Provisioning services

The average annual value of directly used ecosystem products per household was estimated based on average quantities harvested, their prices, and associated cost, irrespective of what proportion was sold i.e. value of product consumption at market prices. The total values of the EPS per all dependent households residing in the buffer zone were calculated as the average annual value of resources harvested per household multiplied by the estimated total number of dependent households using Equation 2 as described by Sharma et al. (2015). (2)

$$TVP_i = \sum_{i=1}^n (\%hh_i * HH_i * NV_i)$$

Where 'i' represents the different Lake Malombe EPS, %hh<sub>i</sub> is the percentage of total households dependent on the i<sup>th</sup> EPS (dependency weight), HH<sub>i</sub> is the total number of households in the buffer zone and NV<sub>i</sub> is the average annual benefit per household calculated by subtracting the annual cost of the products from their respective gross value using the net benefit technique (Sharma et al. 2015). The cost involved in realizing the benefits from other lakes ES (floods plain agriculture, livestock, fishery, and others) were included while assuming zero opportunity cost for collecting them. The total number of dependent households residing in the buffer zone were estimated using the household dependency weight (percentage of households extracting or realizing benefits from the lake to the projected total number of households residing in Lake Malombe buffer zone (Viboonpun, 2000).

### Domestic water benefits

A comprehensive literature review displays that scientific biophysical or hydrological information on groundwater recharge from Lake Malombe as a source of domestic water supply to the communities around is scarcely available. Therefore, data extracted from the unit adjusted transfer value approach was used. The study conducted by Emerton (2003) in Muthurajawera Marsh, coastal wetland (3068ha), Colombo, Sri Lanka was used as an example of VTP. In this study, the avertive expenditure avoided method was used assuming that this ecological service is absent and deep wells have to be dug to reach freshwater reserves or additional shallow wells would need to be dug in the dry season. The results from this study estimated that domestic water supply benefit from the wetland could be estimated at US\$ 24,5/household/year. Using this data, inflation-adjusted unit transfer value per household in 2019, economic value for domestic water benefits was calculated. The consumer price index (CPI) method was used to estimate the value of domestic water supply benefits. The CPI is expressed as

$$CPI = \frac{\text{consumer market basket in a given year}}{\text{cost of market basket at the base year}} * 100 \quad (3)$$

The calculated inflation value of domestic water supply benefits in 2019 is approximately US\$ 33.42/household/year assuming that the Lake Malombe ecosystem is the only source of water provision. This value was multiplied by the percentage of total household's dependent water supplied by the lake and the total number of households.

### Flood control benefits and regulation services

The exploratory literature review demonstrates that studies on flood control benefits have never been done in Malawi. This study, therefore, relied on a unit adjusted transfer value data derived from a study conducted in Hail wetland (14,000ha) in Bangladesh (Thompson and Calavito, 2007). Using a cost-avoided approach, the proposed value transfer benefit of flood control was estimated at BDT 1910/ha (US\$22.7/ha) in 2000. This calculation was based on the assumption that the surrounding watershed is allowed to degrade and erosion continues unabated and the ability of the wetland to absorb floodwater has decreased drastically and flood control measures are urgently required (CSUWN, 2011). Adopting the same approach in the Lake Malombe study assuming that the cost of the flood control scheme is annualized by amortizing the capital cost to arrive at the annual value of flood benefits, the inflated unit value calculated using CPI in 2019 was estimated at US\$ 49.34/ha/year. This value is used as an opportunity cost of not having the lake.

### Carbon sequestration

Although some researchers have argued that freshwater lakes could also be the major source of carbon through methane formation (Cao et al. 1996), others have disputed that carbon sequestration is directly linked to vegetation biomass found in the lake (Olschewski & Benítez, 2005). In Malawi, the studies focusing on the value of carbon sequestration in lakes have never been done. This study used unit adjusted transfer value data from studies conducted elsewhere. Default values based on the carbon sequestration index (CSI) was used. Pagiola, et al., (2004) studied carbon sequestration values in 28 different land use in the soil while Pant et al. (2012) did a quantitative estimation of carbon sequestration in Kanchenjungal Landscape in Eastern Nepal. On the other hand, Rasul (2009) did the same study in the Himalayas, Bangladesh. From these studies, CSI was scaled so that one point is equal to 10tC/ha/year (tC=metric tons of carbons). With the CSI price of USD, 75/point/year was equivalent to paying USD

7.5/tC in terms of carbon emissions reductions. Using the data generated from previous studies, the CSI inflated value of carbon sequestration of Lake Malombe was estimated at US\$ 10.04/ha/year. The World bank's conservative estimate of carbon sequestration was put at US\$14-20/tC (World bank, 2004). To find the total annual value of Lake Malombe carbon sequestration, the total area (ha) covered by vegetation in the lake was multiplied by CSI inflated value (US\$ 10.04/ha/year).

#### **Culture and aesthetic**

The net economic value of culture and the aesthetic value was estimated using the net revenue approach. This approach estimates the total gross revenue less the cost to give an estimate of the net benefit local communities derive from the ecosystem services.

#### **Biodiversity conservation**

The revealed price was used as the best indicator of the ES values of biodiversity in Lake Malombe. The funds allocated by national or international conservation organizations for the conservation of biodiversity hot-spot areas were used as the proxy value of Lake Malombe biodiversity. This study used financial support provided by the national government and conservation partners towards the conservation of biodiversity in the lake (Pearce & Moran, 1994) as an indicator for annual ES values for biodiversity. Building Climate Change Resilience in the Fisheries Sector in Malawi currently implemented in Lake Malombe by Fisheries Department and FAO was used as a proxy.

### **Results**

#### **Characteristics of the respondents**

The study targeted a total sample size of 600. However, 533 questionnaires were administered, representing 83% of valid responses. Table 3 shows the summary of the results with descriptive statistics, such as variable name, mean value, minimum, maximum values, and standard error. The mean household size was assessed to depict productivity capacity and equity in the distribution of EPS. The results showed that the mean household size (6) reported in this study is higher than the national household size (5) suggesting increased pressure on Lake Malombe ES. About 58.8% of the sampled households were substance farmers. The study further showed that Lake Malombe riparian communities consist of a youthful population with about 60.9% of the sampled households below the age of 40, about 75.6% work as crew members in fishing activities, 24% have no education at all, and 63.9% only attended primary school level. The study further showed that the mean annual income level among the local communities is US\$554.07, equivalent to US\$1.54 per day less than the US\$1.9 per day average poverty line for the least developed countries (O Campos et al. 2018).

#### **Lake Malombe ecosystem service values**

The results from the household surveys showed that the majority of the riparian communities depend on a wide range of ES (Figure 2a shows that the lake contributes about 16% of flood plain agriculture, 12% fishery, thatched grass, food gathering, and transport 9%, fuel and fodder 4%, water supply 18% and casual labor 14%) derived from Lake Malombe. Ranking the overall ecosystem services in terms of quality, Figure 2b showed that carbon sequestration was ranked the lowest while ecosystem provisioning services (EPS) were ranked the highest suggesting that the majority of the local population depend on EPS. Tables 4 and 5 show that Lake Malombe EPS values are estimated at US\$35.58million (equivalent to US\$555.89hh/yr, US\$192.55ha/yr, and about 87.45% of the aggregated value of the ES assessed). The lake plays an important role in freshwater supply for both irrigation and domestic consumption. The study shows that about 98% of the riparian households depend on water from the lake for drinking, domestic and agricultural purposes. The water supply in Lake Malombe further contributes 5.89% of total annual EPS and 5.15% of the total aggregate ES. Using a unit adjust transfer value of US\$ 24. 5/household/year, the total annual economic value for water supply is estimated at US\$2.1million, equivalent to US\$32.75 hh/yr and US\$11.34/ha/yr. With about 58.80% of total households around the lake depend on flood plain agriculture, the total annual net benefit generated from the agricultural activities by the riparian communities after deducting the average cost of cultivation, which was assumed to be 30% of the gross values of crops is estimated at US\$7.28million, accounting for 20.45% of the total EPS and 17.88% of the total aggregated economic value of the total ES assessed.

Fishing is one of the main sources of livelihood for the majority of Lake Malombe riparian communities. About 96% of the total households around the lake depend on fishing and it accounts for 59.68% of the total EPS and 52.19% of the total aggregate ES. The study shows that the overall total annual benefit derived from the fishery is estimated at US\$21.23million, equivalent to US\$331.76hh/yr and US\$114.92ha/yr. Lake Malombe periphery is also considered as the major source of fuelwood. The study showed that fuelwood contributes about 0.08% of the EPS and 0.07% of the total aggregate ES assessed. About 0.78% of the households around the lake depend on the

mangroves as the source of energy and had an estimated total economic value of US\$0.029million, equivalent to US\$0.45hh/yr and US\$0.16 ha/yr. Lake Malombe fishery employs about 73.5% of the riparian households working as crew members. The total annual indirect economic benefit derived from the lake ecosystem was estimated at US\$3.56million, equivalent to US\$55.56hh/yr and US\$ 19.25ha/yr. This indirect benefit contributed 10% of total EPS and 8.74% of total aggregate ES benefits. Other indirect EPS include rental and transport which overall contribute US\$ 0.19million and US\$ 0.009million, equivalent to (US\$2.98hh/yr and US\$0.14) and (US\$1.03ha/yr and US\$0.16ha/yr) and contribute (0.54% and 0.03%) of total EPS and (0.47 and 0.07%) of total aggregate ES values assessed.

Other ES benefits from Lake Malombe include non-farm business (mat making and other products), fodder for livestock, grass for constructing and thatching houses, and food gathering. About 6.30% of the total households depend on non-farm business such as mat making and other products which account for 0.93% of the total EPS and 0.81% of the total aggregate ES assessed. The total economic value for non-farm business was estimated at US\$0.33 million, equivalent to US\$5.16 hh/yr and US\$1.79/ha/yr. 3% of the household benefited from fodder, 3.65% from grass, and 46% from food gathering. The total ES values for these products were estimated at (US\$ 0.279million, US\$ 0.203million, and US\$0.376 million) equivalent to (US\$4.36/hh/yr, US\$3.80hh/yr, US\$5.87/hh/yr) and (US\$1.51/ha/yr US\$1.10/ha/yr, US\$2.03/ha/yr) with the contribution of 0.78%, 0.57% and 1.06% of total EPS and 0.69%, 0.50% and 0.92% total aggregate ES assessed. Lake Malombe play important role in carbon sequestration. Using the CSI inflated value (US\$ 10.04/ha/year), the total economic value for carbon sequestration was estimated at US\$0.58million, equivalent to US\$0.9hh/yr and US\$ 0.31ha/yr. The total economic value for flood regulation services was estimated at US\$ 0.058million, equivalent to US\$0.9/hh/yr and 0.31/ha/yr with a total aggregate ES contribution of 0.14%. Flood regulation services were estimated at US\$1.5million, equivalent to US\$23.5/hh/yr and US\$8.14/ha/yr, with a total aggregate ES contribution of 3.70%. Culture and aesthetic provided US\$ 0.025 million, equivalent to US\$0.4/hh/yr and US\$0.14/ha/yr translating to 0.06% of the total ES values assessed.

For zoogeographical reasons, the Lake Malombe catchment has a high species richness of flora and fauna. The lake ichthyofauna is dominated by cichlids (comprised phylogenetic lineages: the tilapiines (consist of the general *Oreochromis* (subgenus *Nyalapia* comprised species such as *Oreochromis squamipinnis*, *Oreochromis karungae*, and *Oreochromis lidole* and other tilapia (categorized as riverine species (*Oreochromis shiranus* and *Tilapia rendelli*)) and haplochromine cichlids (described as both small demersal haplochromine, species such as *Nyassachromis argyrosoma*, *Otopharynx argyrosoma*, *Lethrinops lethrinus*, *Copadichromis chrysonotus*, *Diplotaxodon spp*) and large demersal haplochromine cichlid (*Buccochromis spp* and *Rhamphocromis spp*). Other important families include Cyprinidae, Characidae, Mochokidae, Bagradae, Mormyridae, and Claridae. The Lake is also rich in three species of snails (Gastropoda, Bivalvia, and Gastropoda), reptiles, and amphibians (snakes, lizards, chameleons, terrapins, tortoises, *Crocodylus niloticus*), Waterfowls, hippopotamus, 321 bird species. The aquatic and terrestrial ecosystem is rich with large and small mammals like *Loxodonta african*, Rhinos, *Panthera leo*, *Trigelofas angasi*, Leopards, Buffalo, Antelopes, common duikers, klipspringers, hyenas, bushbucks, bush pigs, hippopotamus, and many others. The National Herbarium and Botanic Gardens (NHBG) describes flora species in the Lake Malombe ecosystem, as flowering plants (angiosperms), non-flowering plants (gymnosperms), ferns (pteridophytes), Moses (bryophytes), and Lichens. Tree species such as *Uapaca kirkiana*, *Adamsonia digitate*, miombo woodlands tree species, palm forest dominated by the *hyphaene petersiana*, *khaya anthotheca*, *Pterocarpus angolensis*, *Adina microcephala*, and *Colophospermum mopane* are also found in the lake catchment. Biodiversity conservation had an estimated economic value of US\$3.52million, equivalent to US\$54.94/hh/yr and US\$19.03/ha/yr, and account for 8.64% of the total aggregate ES assessed.

The overall annual economic value generated from Lake Malombe EPS, regulating, culture, and aesthetic services assessed was estimated at US\$40.68million, equivalent to around US\$635/hh/yr or about US\$220.18/ha/yr (Table 5). This translates to a net present value (NPV) of around US\$1.006 billion estimated from the future benefit over 50 years assuming a discount rate of 3% and constant flow of current benefit. The economic value derived from EPS (Table 4) was ranked the highest (87.45%), followed by biodiversity conservation (8.64%), regulation services (3.70%) then carbon sequestration, culture, and aesthetic services. These proportions indicate that the values of various ES contribute to the diverse stakeholders such as local, regional as well as global communities. For example, local communities are primary beneficiaries of the EPS which sustain their livelihood. Carbon sequestration on the other hand offers benefits to both local and global communities by mitigating the impact of climate change.

## Discussion

This study demonstrates how significant Lake Malombe is in terms of providing diverse ES. The total annual ES values derived from the lake is estimated at US\$40.68million. The EPS contributes about 87.45%, followed by biodiversity conservation (8.64%), flood regulation (3.70%) then carbon sequestration, culture, and aesthetic services. The total annual benefit of ES to the local communities is estimated at US\$635.63/hh/yr. The findings show how heavily the local communities depend on diverse Lake Malombe EPS for their sustenance. Similar findings are reported by several authors such as Sharma et al (2015) in Koshi Tappu Wildlife Reserve and Li et al. (2020) in China's coastal zones. Fishing is ranked as the main source of livelihood for the majority of the local population. About 96% of the total households around the lake depend on fishing and it accounts for 41.57% of the total EPS and 38.52% of the total aggregate ES. The highest contribution of the fishery to the total aggregate ES indicates that the majority of these local population have limited land for farming, living under extreme poverty that is difficult to escape, and harvesting of fisheries resources offers the greatest option for their sustenance. The investment in the tourism industry in Lake Malombe is not much advanced. The ES quality index in Figure 2b ranks culture and aesthetic services among the lowest. This could be attributed to increased catchment degradation due to poor agricultural practices, depletion and degradation of water quality, frequent disease outbreaks such as urinary schistosomiasis (*Schistosoma haematobium*) (Madsen et al. 2010) instigated by the depletion of molluscivores fish species such as *Trematocranus placodon* in the lake (Kapute, 2018), lake level fluctuation (Dulanya et al. 2013), loss of biodiversity and lack of clearly well-defined strategy and management plan to protect the resources in the lake to attract investors.

However, the estimated total annual ES value of US\$ US\$40.68 million derived from Lake Malombe provides a strong basis for a need to design an economic incentive model to promote the local communities to take responsibility for managing the lake. The NPV was calculated to project the long-term economic benefit of lake ES assuming that there is no degradation. However, given the pressure facing Lake Malombe ES, it is very likely that these current benefits will decline over time if proper management measures are not put in place. This study provides a significant insight into the trade-offs between ES and diverse stakeholders. For example, increasing fishing activity in Lake Malombe was done at the expense of removal of heavily overgrown weeds in around 1970 and 1980s (Njaya, 2007) which provided habitat heterogeneity for various aquatic biodiversity, played a significant role in carbon sequestration and water quality purification. Currently, few weed beds occur in the lake. An increase in flood plain agriculture was done at the expense of vegetation, mangroves, and forest and hence limiting the capacity of the lake for carbon sequestration (Rojas-Downing et al. 2017) and flood regulation which benefits both local and global communities. Estimates show that a 10% decline in natural vegetative cover in the lake catchment can increase flood frequency by 4% to 28%. This consequently results in economic loss as well as ecosystem provisioning disservices. Yaron et al (2011) estimated the flood economic cost from 1881, 1998, 2000, and 2001 in Malawi and showed an economic loss of approximately US\$ 32million, translating to US\$3.2million annual economic cost for flood prevention. The increased agricultural and fishing activities instigated by rapid population growth are done at the expense of biodiversity. For example, studies have shown that many aquatic fauna and flora in Lake Malombe are either critically endangered or facing an extremely high risk of extinction in their immediate future (Malawi Government, 2013). The local population largely depends on wild plants for medicines, fruits, construction materials, household furniture, objects of art such as woodcarvings, curios, and others. Human encroachment, pollution, illegal resource use, and deforestation displaces the fauna and interferes with normal breeding patterns, causes loss of genetic diversity, and affects the normal functioning of the ES. This implies that balancing between the interest of local communities given the importance of EPS in sustaining their livelihoods and the global communities is required to effectively manage the lake ecosystem. Any reduction in the supply of EPS can eventually worsen poverty and push the local population to desperately over depend on ES and degrade even the areas deemed to be conserved for future generations (Billé et al. 2012) thereby creating a vicious circle of poverty and ecosystem disservices.

## **Conclusion**

This study assessed the economic value of selected Lake Malaombe ES. The results show that the local population depends heavily on the ES provided by the lake for their sustenance. The findings further demonstrate that a significant threat to the Lake Malombe freshwater ecosystem is socio-economic and the conservation of the lake ecosystem must aim at generating tangible economic benefits to the local population as a prerequisite condition for the sustainability of the lake. Failure to consider this will eventually put the economic livelihood of the local population at risk, thereby threatening the conservation of the lake. The study further suggests that appropriate policies are urgently required to engage the local population in the management of the lake while reducing poverty through the provision of sustainable alternative livelihood options such as integrated agriculture-aquaculture and

other sustainable enterprises. Given the trade-off between EPS and regulating services, it is clear that the Malawi government needs to take a strong role to provide incentives to the local communities to reduce over-dependence on the EPS. The study recommends the promotion of local tourism industry through identification and mapping of all the potential fish breeding grounds, creating a fish nursery and sanctuary using local community participatory approach, capacity building of the local governance structures such as village beach committees (BVCs) and village natural resources management committees (VNRMCs) to closely monitor the ecological integrity of the lake and promotion of climate-smart technology as an alternative energy source to ensure the conservation of the mangroves while developing adaptive responses to the effects of climate change.

### **Declaring a conflict of interest**

The authors of this paper declare that there is no conflict of interest.

**Author Contributions:** RM conceptualizes the study, developed the methodology, sourced the data, analyzed the data, and developed the original manuscript. Authors SM, EK, TA FJ supervised the study, reviewed and edited the manuscript, visualized, and validated the study. All authors have read and agreed to the published version of the manuscript.

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### **Data availability**

All data generated or analysed during this study are included in this published article (and its supplementary information files)

### References

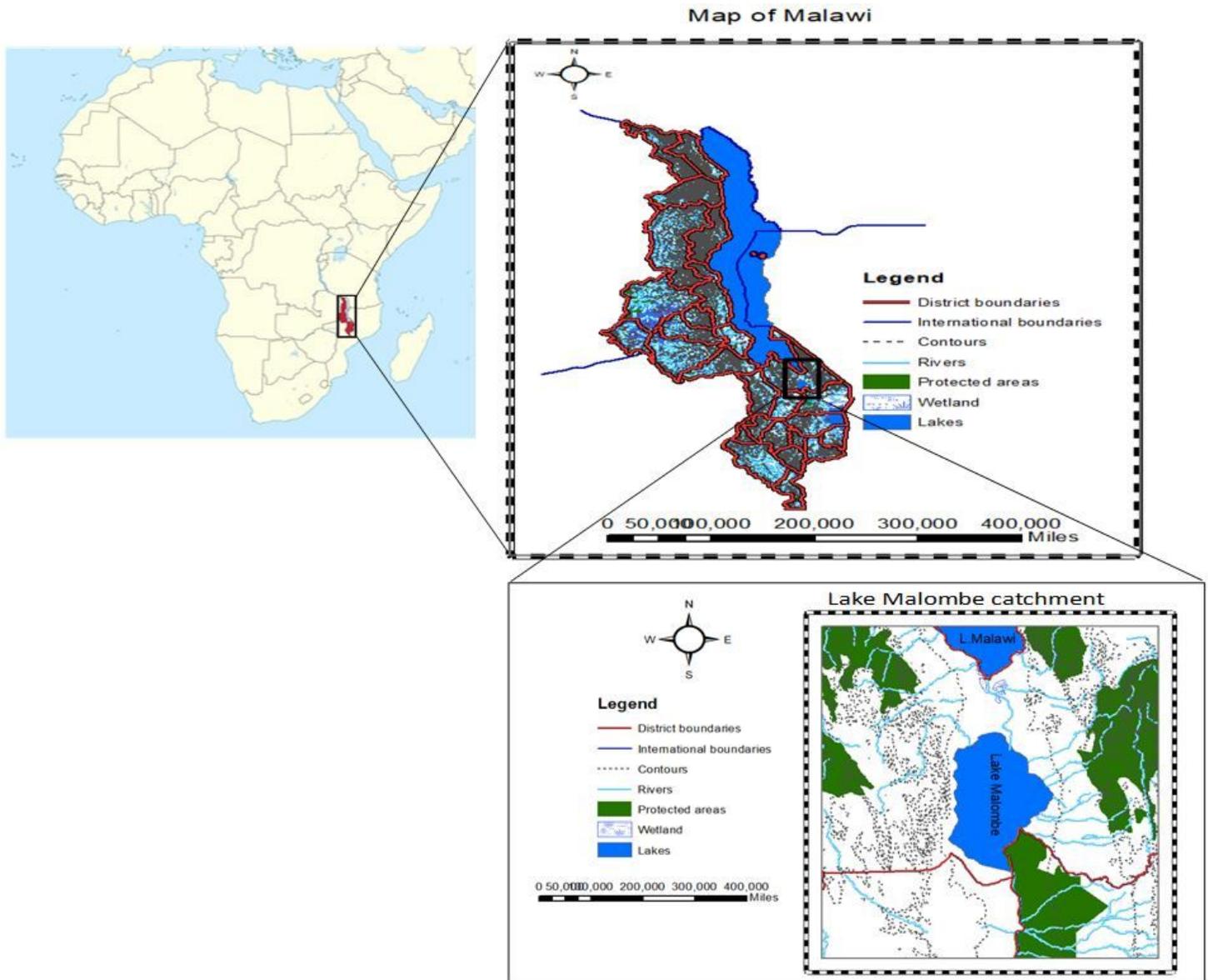
- Balmford, A., Fisher, B., Green, R., Naidoo, R., & Rodrigues, A. (2011). Bringing ecosystem services into the real world: an operational framework for assessing the economic consequences of losing wild nature. *Environmental and Resource Economics*, 48(2011)161-175.
- Baral, S., Basnyat, B., Khanal, R., & Gauli, K. (2016). A Total Economic Valuation of Wetland Ecosystem Services: An Evidence from Jagadishpur Ramsar Site, Nepal. *The Scientific World Journal*, 2016, 9. doi:<https://doi.org/10.1155/2016/2605609>
- Bateman, I., Langford, I., Nishikawa, N., & Lake, I. (2000). The Axford Debate Revisited: A Case Study Illustrating Different Approaches to the Aggregation of benefit Data. *Journal of Environmental Planning and Management*, 31(6) 571-582.
- Billé, R., Lapeyre, R., & Pirard, R. (2012). Biodiversity conservation and poverty alleviation: A way out of a deadlock? *SAPIENS*, 5(2012)1-15.
- Boyd, J., & Banzhaf, S. (2007). What are ecosystem services? The need for standardized environmental accounting units. *Ecol. Econ*, 63(2007) 616-626.
- Brockerhoff, E., Barbaro, L., Castagneyrol, B., Forrester, D., Gardiner, B., Gonza'lez-Olabarria, J., . . . Plas, F. (2017). Forest biodiversity, ecosystem functioning, and the provision of ecosystem services. *Biodivers Conserv*, 26(2017) 3005-3035.
- Cao, M., Marshall, S., & Gregson, K. (1996). Global carbon exchange and methane emissions from natural wetlands: Application of a process-based model. *Journal of geography research*, 101(9)14399-14414.
- Chee, Y. (2004). An ecological perspective on the valuation of ecosystem services. *Biological Conservation*, 120 (2004) 549-565.

- COP. (2010). *A Reporting Service for Environment and Development Negotiations*. Nagoya: International Institute for Sustainable Development (IISD).
- Cortinovis, C., & Geneletti, D. (2018). Mapping and assessing ecosystem services to support urban planning: a case study on brownfield regeneration in Trento, Italy. *One Ecosyst*, 3:2. 54-77.
- CSUWN. (2011). *An Economic Valuation Tool for Wetlands of Nepal*. Kathmandu, Nepal: Ministry of Forest and Soil Conservation,
- de Groot, R., Alkemade, R., Braat, L., & Hein, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management, and decision making. *Ecol. Complex*, 7(2010) 260–272.
- Dulanya, Z., Croudace, I., Reed, J., & Trauth, M. (2014). Palaeolimnological reconstruction of recent environmental change in Lake Malombe (S.Malawi) using multiple proxies. *Water SA*, 40(4)717-726, <http://dx.doi.org/10.4314/wsa.v40i4.17>.
- Dulanya, Z., Reed, J., & Trauth, M. (2013). Mapping changing shorelines in the Malombe and Chiuta lakes of Malawi-environmental effects of recent climatic variations. *Catena*, 104(2013)111-119.
- Emerton, L. (2003). *Valuing Wetlands in Decision-making: Where are We Now? Wetland valuation Issues Paper 1: Integrating Wetland Economic Values into River basin Management*. Gland, Switzerland: IUCN.
- Faust, K., Abraham, D., & DeLaurentis, D. (2013). Assessment of stakeholder perceptions in water infrastructure projects using system-of-system and binary probit analysis: A case study. *Journal of Environmental Management*, 128(2013)866-876.
- Fisheries Department. (2019). *Status of the fisheries of Lake Malombe and Upper Shire River*. Lilongwe: Department of Fisheries.
- Frélichová, J., Vačkář, D., Pártl, A., Loučková, B., Harmáčková, Z., & Lorencová, E. (2014). Integrated assessment of ecosystem services in the Czech Republic. *Ecosystem Services*, 8 (2014) 110–117.
- Geneletti, D. (2011). Reasons and options for integrating ecosystem services in a strategic environmental assessment of spatial planning. *International Journal of Biodiversity Science, Ecosystem Services and Management*, 7(3)143-149.
- Geneletti, D., Scolozzi, R., & Esmail, B. (2018). Assessing ecosystem services and biodiversity trade-offs across agricultural landscapes in a mountain region. *International Journal of Biodiversity Science, Ecosystem Services and Management*, 14(1)188-208.
- Gleick, P., & Palaniappan, M. (2010). Peak water limits to freshwater withdrawal and use. *PNAS*, 107(25)11155-11162.
- Hara, M., & Nielsen, J. (2003). Experiences with Fisheries Co-Management in Africa. In D. Wilson, J. Nielsen, & P. Degnbol, *The Fisheries Co-management Experience; Fish and Fisheries Series* (pp. [https://doi.org/10.1007/978-94-017-3323-6\\_6](https://doi.org/10.1007/978-94-017-3323-6_6)). Dordrecht.: Springer.
- Hara, M., & Njaya, F. (2016). Between a rock and a hard place: The need for and challenges to implementation of rights-based fisheries management in small-scale fisheries of southern Lake Malawi. *Fish. Res*, 174 (2016)10-18.
- Hartel, T., Fischer, J., Campeanu, C., Milcu, A., & Fazey, I. (2014). The importance of ecosystem services for rural inhabitants in a changing cultural landscape in Romania. *Ecology and Society*, 19(2):42.
- Heal, G. (2000). Valuing ecosystem services. *Ecosystems*, 3(2000)24-30.
- Hein, L., Bagstad, K., Edens, B., Obst, C., de Jong, R., & Lesschen, J. (2016). Defining Ecosystem Assets for Natural Capital Accounting. *PLoS One*, 11(11): DOI: 10.1371/journal.pone.0164460.

- IPBES. (2018). *THE IPBES regional assessment report on biodiversity and ecosystem services for Africa*. Bonn, Germany: IPBES Secretaria.
- Jäppinen, J., & Heliölä, J. (2015). Towards a sustainable and genuinely green economy. The value and social significance of ecosystem services in Finland (TEEB for Finland). In J. Jäppinen, & J. Heliölä, *Synthesis and roadmap*. T. Helsinki: The Finnish Environment 1en/2015; The Finnish Ministry of Environment.
- Kapute, F. (2018). The role of the Liwonde National Park in conserving fish species diversity in the upper Shire River, Malawi. *Aquatic Ecosystem Health & Management*, 21(2)132-138.
- Kates, R. (2011). What kind of science is sustainability science? *PNAS*, 108(49)19449-19450.
- Landell-Mills, N., & Porras, I. (2002). *Silver Bullet or Fool's Gold? A Global Review of Markets for Forest Environmental Services and Their Impact on the Poor*. London: IIED.
- Li, X., Yu, X., Hou, X., Liu, Y., H, L., Zhou, Y., . . . Zhang, L. (2020). Valuation of Wetland Ecosystem Services in National Nature Reserves in China's Coastal Zones. *Sustainability*, 12(8), 3131; <https://doi.org/10.3390/su12083131>.
- Madsen, H., Kamanga, K., Stauffer Jr, J., & Likongwe, J. (2010). Biology of the Molluscivorous Fish Trematocranus placodon (Pisces: Cichlidae) from Lake Malawi. *Journal of Freshwater Ecology*, 25(3)449-455.
- Makwinja, R., Kosamu, I., & Kaonga, C. (2019). Determinants and Values of Willingness to Pay for Water Quality Improvement: Insights from Chia Lagoon, Malawi. *Sustainability*, 11, 4690; doi:10.3390/su11174690.
- Malawi Government. (2013). *Shire River basin Management Programme (Phase I) Project: Final Environmental and Social Assessment Report*. Lilongwe: Ministry of Water Development and Irrigation.
- Martínez-Paza, J., Pellicer-Martíne, F., & Colinoa, J. (2014). A probabilistic approach for the socio-economic assessment of urban river rehabilitation projects. *Land Use Policy*, 36 (2014) 468– 477.
- McDonald, R., Green, P., Balk, D., Fekete, B., Revenga, C., Todd, M., & Montgomery, M. (2011). Urban growth, climate change, and freshwater availability. *PNAS*, 108(15) 6312-6317.
- MEA. (2003). *Ecosystems and Human Well-Being: A Framework for Assessment*. Washington, DC: Island Press.
- MEA. (2005). *Ecosystems and Human Well-Being: Synthesis*. Washington, DC: Island Press.
- Myers, J., & Reichert, J. (1997). *Perspectives on nature's services*. In G. Daily, *Nature's Services. Societal Dependence on Natural Ecosystems*. . Washington D.C.: Island Press.
- Ndebele, T. (2009). *Economic Non-Market Valuation: The theory and application to ecosystems and ecosystem services: A case study of the restoration and preservation of Pekapeka Swamp: MSc Thesis*. Palmerston North, New Zealand: Massey University.
- Nindi, S. (2007). Changing Livelihoods and the Environment along Lake Nyasa, Tanzania. *African Study Monographs Supp*, 36(2007) 71-93.
- Njaya, F. (2007). Governance challenges for the implementation of fisheries co-management: experiences from Malawi. *International Journal of the Commons*, 1(1)123-139.
- O Campos, A., Villani, C., Davis, B., & Takagi, M. (2018). *Ending Extreme Poverty in Rural Areas: Sustaining livelihoods to leave no one behind*. Rome: Food and Agriculture Organisation of the United Nations.
- Olschewski, R., & Benítez, P. (2005). Secondary forests as temporary carbon sinks? The economic impact of accounting methods on a reforestation project in the tropics. *Ecol.Econ*, 55(3),380–394.
- Pagiola, S., Agostini, P., Gobbi, J., Hann, C., Ibrahim, M., Murgueitio, E., . . . Ruíz, J. (2005). Paying for Biodiversity Conservation Services. *Mountain Research and Development*, 25(3)206-2011.

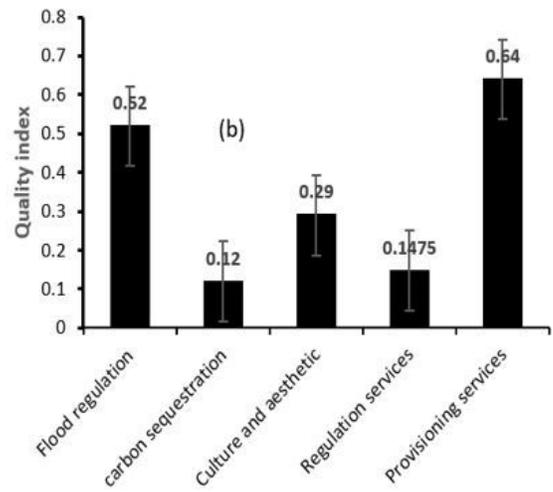
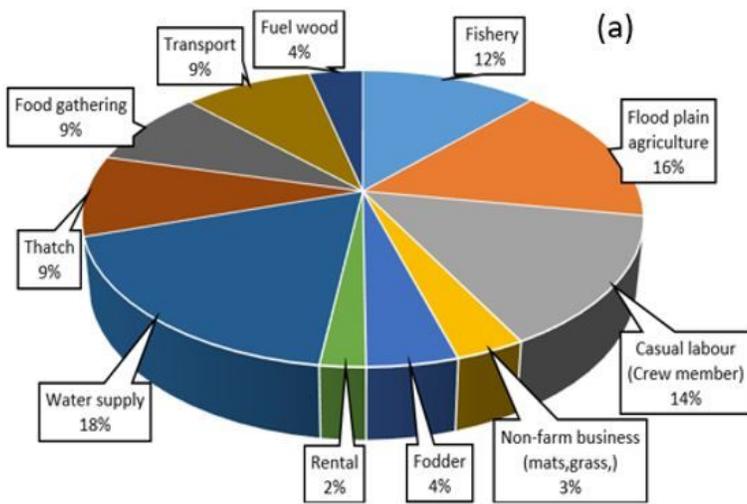
- Pandeya, B., Buytaert, W., Zulkafli, Z., Karpouzoglou, T., Maoe, F., & Hannahe, D. (2016). A comparative analysis of ecosystem services valuation approaches for application at the local scale and in data-scarce regions. *Ecosystem Services*, 22(2016)250-256.
- Pant, K., Rasul, G., Chettri, N., Rai, K., & Sharma, E. (2012). *Value of Forest Ecosystem Services: A Quantitative Estimation from the Kanchenjunga landscape in Eastern Nepal: ICIMOD Working Paper 2012/5*. Kathmandu: ICIMOD.
- Perry, C., Rock, M., & Seckler, D. (1997). *Water as an economic good: A solution, or a problem? Research Report 14*. Colombo: Sri Lanka: International Irrigation Management Institute.
- Plisnier, P., Nshombo, M., Mgana, H., & Ntakimaz, G. (2018). Monitoring climate change and anthropogenic pressure at Lake Tanganyika. *Journal of Great Lakes Research*, 44 (2018) 1194–1208.
- Posner, S., McKenzie, E., & Ricketts, T. (2016). Policy impacts of ecosystem services knowledge. *PNAS*, 113(7)1760-1765.
- Quintas-Soriano, C., Martin-Lopez, B., Santos-Martin, F., Montes, C., Benayas, J., & Garcia-Llorente, M. (2015). Ecosystem services values in Spain. *A meta-analysis Environmental Science & Policy*, 55(2015) 186-195.
- Rasul, G. (2009). Ecosystem services and agricultural land-use practices: a case study of the Chittagong Hill Tracts of Bangladesh. *Sustainability: Sci.Pract.Policy*, 5 (2),15–27.
- Rojas-Downing, M., Nejadhashemi, A., Harrigan, T., & Woznicki, S. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management*, 16(2017)145-163.
- Sarvilinna, A., Lehtoranta, V., & Hjerpe, T. (2018). Willingness to participate in the restoration of waters in an urban-rural setting: Local drivers and motivations behind environmental behavior. *Environmental Science and Policy*, 85 (2018) 11–18.
- Schröter, M., der Zanden, E., van Oudenhoven, A., Serna-Chavez, H., Groot, R., & Opdam, P. (2014). Ecosystem Services as a Contested Concept: a Synthesis of Critique and Counter-Arguments. *Conservation Letters*, 7 (6) 514-523.
- Sharma, B., Rasul, G., & Chettri, N. (2015). The economic value of wetland ecosystem services: Evidence from the Kosh Tappu Wildlife Reserve, Nepal. *Ecosystem Services*, 12(2015)84-93.
- Small, N., Munday, M., & Durance, I. (2017). The challenge of valuing ecosystem services that have no material. *Global Environmental Change*, 44 (2017) 57–67.
- Thompson, E., Berger, M., Blomquist, G., & Allen, S. (2002). Valuing the Arts: a Contingent Valuation Approach. *Journal of Cultural Economics*, 26(2) 87-113.
- Vačkář, D., Grammatikopoulou, L., Daněk, J., & Lorencova, E. (2018). Methodological aspects of ecosystem service valuation at the national level. *One Ecosystem* 3, e25508. <https://doi.org/10.3897/oneeco.3.e25508>.
- Wangai, P., Burkhard, B., & Muller, F. (2016). A review of studies on ecosystem services in Africa. *International Journal of Sustainable Built Environment*, 5(2016) 225–245.
- Wilson, J., & Primack, R. (2019). *Conservation Biology in Sub-Saharan Africa*. Cambridge, UK: Open Book Publishers.
- Yaron, G., Mangani, R., Mlava, J., Kambewa, P., Makungwa, S., Mtethiwa, A., . . . Kazembe, J. (2011). *Economic Valuation of Sustainable Natural Resource Use in Malawi*. Lilongwe: Ministry of Finance and Development Planning.

# Figures



**Figure 1**

Map of Lake Malombe ecosystem Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



**Figure 2**

The direct contribution ecosystem provisioning services from Lake Malombe (a) and ecosystem services quality index (b) Note: in Figure 2b, 0 means the worst while 1 means the best