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RESEARCH



## Integrating stakeholder preferences into ecosystem services mapping in Yala wetland, Kenya

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### ABSTRACT

Wetlands such as the Yala swamp in Kenya are among the most important and increasingly threatened ecosystems globally due to their ecological significance and complexity, and the importance of the ecosystem services (ES) they provide to wetland communities. Appropriate governance and management of wetlands thus require the use of interdisciplinary tools that take into account both ecological and social considerations. This study used the matrix model combining social preferences with GIS-based maps of land use/land cover (LULC) to analyse the capacity of the Yala swamp to supply ES (flows). We engaged a total of 132 participants who manage and use natural resources in the wetland through a participatory process to identify ES, map LULC, and score the flow of ES on a scale of 0 to 5 using the matrix model. We also analysed the impacts of stakeholder characteristics (gender, environmental expertise, and location) on the scoring of the matrix. Results showed high average scores (score of 4) for trees and shrubs, papyrus, and water bodies across a range of provisioning, regulating and cultural services. The study found that gender and location had little influence on the respondents' scores, while environmental conservation experts provided scores significantly higher than local resource users (farmers/fishermen) across the ES types. Overall, the study contributes to understanding: 1) the importance of linking LULC with ES provision to inform landscape management and 2) the need to incorporate a range of stakeholder perspectives in studies making use of expert knowledge and preferences, for inclusive management.

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## 1. Introduction

Wetland ecosystems are among the most productive on earth (de Groot et al. 2012), providing multiple ES that contribute to the wellbeing of the communities living in and around them (Millennium Ecosystem Assessment 2005). However, wetlands have undergone the greatest human-driven change of all ecosystems, facing threats from several drivers, including land-use change, water abstraction, pollution, and invasive species (Millennium Ecosystem Assessment 2005; Carpenter et al. 2011). Tropical wetlands, in particular, face serious threats from population growth and resultant land-use conversion to more 'productive uses', as well as from climate change (Junk et al. 2013). In Africa, wetland conversion is mainly driven by small-scale subsistence agriculture and large-scale (commercial) agriculture, which produce food for local, national, regional, or international markets (Rebelo et al. 2010). The large-scale agricultural conversion is more often than not accompanied by changes in wetland hydrology and ecology through habitat loss, water abstraction, diversion and channelling, and widespread use of external

inputs (Junk et al. 2013). The consequences of these changes include shifts in wetland ecosystem function from carbon sinks to sources (Kolka et al. 2016), increased vulnerability to disasters, and impacts on livelihoods and food security (Adekola et al. 2012; Zorilla-Miras et al. 2014). The combination of ecological complexity and socio-economic pressures in African wetlands (Rebelo et al. 2010) necessitates the application of interdisciplinary methods for their assessment and management. Such methods must integrate social and natural sciences, assessing both the biophysical and socio-economic factors impacting on wetland management (Turner et al. 2000).

Since the popularisation of the concept of ES, a wide range of assessment and mapping approaches have been developed to fit a variety of contexts (Martínez-Harms and Balvanera 2012). ES mapping approaches are particularly useful to link biophysical processes underlying ecosystem structure with human-induced modifications, such as land-use change (Müller and Burkhard 2012). The mapping approaches can be classified into three types: valuation studies that confer monetary value to a land

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cover type based on previous studies of similar land-cover types (Costanza et al. 1997); socio-ecological assessments that integrate biophysical data with socio-economic data (Khan et al. 2019); and socio-cultural methods that assess social values of ES and link them to land cover maps (Iniesta-Arandia et al. 2014). The matrix model (Burkhard et al. 2009, 2012, 2014), which falls into the latter category, is a simple and highly flexible approach to ES mapping that allows the use of diverse data sources and application across study scales. The model uses a geospatial unit (originally land cover) as a proxy for ES supply, which is then scored in a simple look-up table using data from diverse sources combined with expert judgement (Burkhard et al. 2012). The resultant table shows the capacity of a particular geospatial unit in the landscape to provide ES, or, stated in another way, its ES potential (Depellegrin et al. 2016), flow/use (Burkhard et al. 2014) or supply (Burkhard et al. 2012). Since its development, the matrix model has undergone progressive improvements such as the inclusion of habitat type, scoring for ES demand or use, different statistical methods of scoring, and use of direct and indirect measurements of data (Jacobs et al. 2015). The simplicity of the matrix model, primarily its low requirements for data and technology, has made it popular in recent years (Jacobs et al. 2015), leading to its application in a range of contexts (Burdon et al. 2017; Campagne et al. 2018, 2020; Geange et al. 2019; Vrebos et al. 2015). The model is particularly useful in data-scarce contexts where ES assessments are needed to provide information for landscape management (e.g. Wangai et al. 2018).

The use of expert scores to populate the matrix allows integration of stakeholder values and preferences, providing important information about the social factors affecting the perception and management of a given landscape. In this case, the definition of 'expert' includes community members with an intimate and detailed knowledge of the ES being studied in a particular context (Jacobs et al. 2015), who offer diverse views that may sometimes differ from those of researchers and other professionals. Indeed, studies using ES mapping approaches have found that participant characteristics such as gender, wealth, level of education, ethnicity, type of livelihood, age, cultural traditions, and spatial patterns affect their outcome (Daw et al. 2011; Muhamad et al. 2014; Nahuelhual et al. 2016; Lau et al. 2018; Cuni-Sanchez et al. 2019). Such assessment of the diversity of stakeholder values is increasingly being recognised as an inclusive approach to valuing nature that takes into account the multiplicity of human-nature interactions (Díaz et al. 2018).

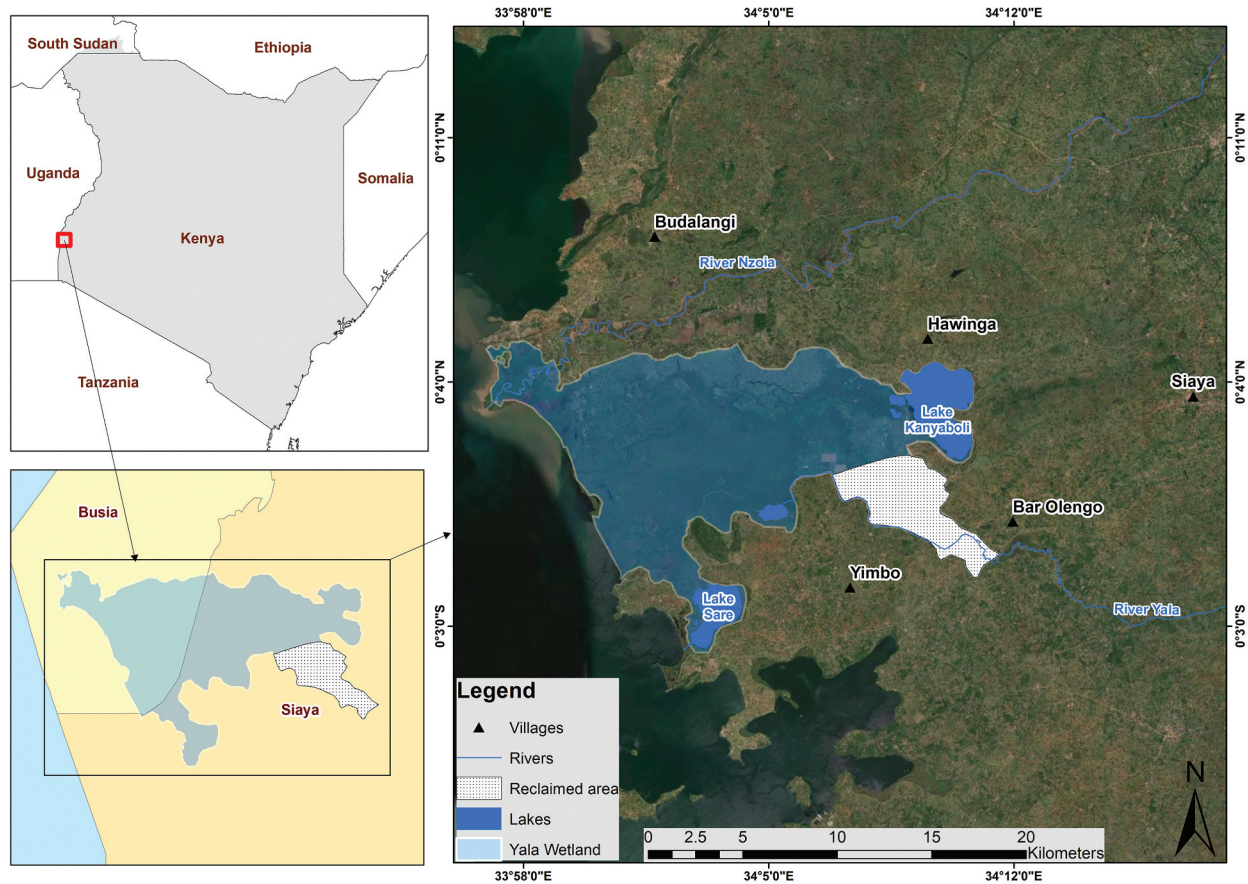
ES provision and human-induced changes in papyrus wetlands in Kenya are increasingly being documented (Abila 2002, 2005; Schuyt 2005; Ikiara

et al. 2010; Rongoei et al. 2013; van Dam et al. 2013), though many of these researchers have focused on ecosystem services valuation. This study builds on work by previous researchers who assessed land-use change in the Yala wetland (e.g. Thenya et al. 2006) and its resultant impacts on ecosystem services (Muoria et al. 2015). The study uses the matrix approach to link land use/land cover (LULC) to ES provision, identify important ES, and establish opinions of local experts on ES flow from different land cover types in the wetland. Such studies are now recognised as essential in providing information on ES trade-offs to enhance policy, community-based conservation, and ecosystem-based approaches to the management of such resources. The objectives of this study were to map ES flow over seven land cover types in Yala wetland using stakeholder preference scoring and to determine how stakeholder characteristics (gender, environmental expertise, and distance of home from wetland) influence how they perceive and score ES flow over the land cover types in the wetland. ES flow as used in this study is defined by Burkhard et al. (2014, p. 5) as the 'de facto used set (bundles) of ecosystem services and other outputs from natural systems in a particular area within a given time period'. This paper contributes to our understanding of the use of interdisciplinary approaches to assess the capacity for the Yala wetland landscape to provide ES from a stakeholder perspective.

## 2. Study area and methods

### 2.1. Site description

Yala wetland is Kenya's largest freshwater wetland, covering an area of 17,500 ha on the northern shores of Lake Victoria, where Rivers Nzoia and Yala drain into the lake at 0° 06' N – 0° 04' S/33° 58' – 34° 13' E (Figure 1). Within the wetlands are three small lakes: Kanyaboli, Nyamboyo, and Sare (Abila 2005). The wetland vegetation, though mainly composed of *Cyperus* species (Thenya and Ngecu 2017), is high in biodiversity and acts as a hydrological buffer, absorbing river flows during wet seasons, and releasing the retained water during dry seasons (Harper and Mavuti 1996). The wetland provides a habitat for several ecologically important species of birds and has been classified as one of Kenya's 60 important bird areas (IBAs) (Bennun and Njoroge 2000). The wetland also provides a refuge to three indigenous species of Lake Victoria tilapia (*Oreochromis eschulentus*, *Oreochromis variabilis*, and *Oreochromis leucostictus*) that have been nearly exterminated from Lake Victoria due to the introduction of the invasive Nile Perch (*Lates niloticus*) and other environmental



**Figure 1.** Map of Yala wetland showing its location on the shores of Lake Victoria and locations of the stakeholder workshops.

changes (Ochumba et al. 1992; Outa et al. 2020). It also has about seven species of Lake Victoria haplochromine cichlids, which have been shown to harbour genetic variations that have either arisen *in situ* or have been lost from cichlid species that live in the lake (Abila et al. 2004, 2008). Yala wetland supports an estimated population of 12,087 people spread across 21 villages (Muoria et al. 2015). The main livelihood activities in the area are fishing, agriculture, brickmaking, and ornaments and papyrus mats making (Ministry of Environment and Mineral Resources 2012).

Yala wetland has been targeted for reclamation since Kenya's independence. Initial government-backed plans led to sub-division of the swamp into three areas (Area I, Area II and Area III), and construction of cut-off and retention dykes at Yala river and Lake Kanyaboli as part of its reclamation efforts. Between the 1960s and 2000s, various agricultural programmes were initiated in the wetland, among them commercial crop farming by the Lake Basin Development Authority (LBDA) in Area I. In 2002, an American agricultural firm leased 6900 ha of the Yala wetland, initially using the 2300 ha extent of Area I for commercial rice, fish, and banana farming (Figure 1) (Siaya County Assembly 2015). The conversion led to conflict over displacement of the

community from communal land, water diversion, pollution and lack of information about the leasing process, among other issues (van Heukelom 2013), eventually leading to the firm's exit in 2018 (Odhiambo 2018). Despite these documented challenges, large-scale agricultural conversion is expected to continue to be an important driver of change in the wetland based on proposed local government plans. The wetland covers two local administrative units (Siaya and Busia counties), which present unique challenges in terms of governance and management due to their dissimilar socio-economic conditions and development priorities. For example, the Siaya County Integrated Development Plan (CIDP) for the period 2018–2022 proposes revitalisation of stalled irrigation schemes and expansion of areas under irrigation along Rivers Yala and Nzoia, which could further exacerbate existing conflicts (Siaya County Government 2018a). The Siaya County spatial plan (2018–2028) proposes the establishment of several industrial developments, including a meat and dairy processing plant, fish processing plant and an industrial estate in the Yala wetland area (Siaya County Government 2018b). Most of Yala wetland is currently unprotected communal land, except for Lake Kanyaboli, which was gazetted as a national reserve in 2010 (Muoria et al. 2015). The challenges

in landscape and natural resource management and ecosystem governance in the area point to the need for a participatory and inclusive management strategy that incorporates views of the local community, investors, and the local government.

## 2.2. Methods

The study adopted the matrix model developed by Burkhard et al. (2009). The approach involves two steps: 1) land cover mapping and identification of ES in the study area and 2) scoring of ES flow from the land cover types using a look-up table (matrix).

### 2.2.1. Land cover mapping and ES selection

Land cover mapping in the wetland was performed using ArcGIS (ArcGIS V 10.8 ESRI, Redlands, California, USA) and IDRISI Terrset (Clark Labs, Worcester, Massachusetts, U.S.A). A Sentinel 2B image for July 2018 was downloaded from the United States Geological Survey (USGS) Earth Explorer, which offers freely downloadable Sentinel images to researchers worldwide (<https://earthexplorer.usgs.gov/>). The data was classified into relevant LULC classes using supervised classification based on training samples identified in the field, and literature on land cover mapping in the wetland (Muoria et al. 2015). Several of the land cover classes found in the literature (e.g. cultivated farms versus large-scale farming and degraded papyrus versus intact papyrus) were combined for simplicity. The data were classified into seven LULC classes: papyrus, water bodies, trees and shrubs, grasslands, farmland, open land, and settlements.

The ES were classified into provisioning, regulating, and cultural services after several common classification systems (de Groot et al. 2010; Haines-Young and Potschin 2010). Supporting services, often considered as a pre-requisite for the production of other categories (Kandziora et al. 2013), were left out of the analysis to avoid double counting. Selection of ES types under the three categories was made using literature (Abila 2002; Mwaura et al. 2003; Ikiara et al. 2010; Muoria et al. 2015) to determine the types of ES that the community obtain from the wetland. Information from key informants was used to validate the ecosystem services selected and to decide which ES to keep in the final analysis. The final ES list was provided to stakeholders for scoring. The key informants included experts on Yala wetland who were directly involved in its conservation and management. They were drawn from government units and other organizations involved in management of the wetland (such as Kenya Wildlife Service, County Meteorological Office, County Fisheries Department, Nature Kenya, and local Water Resource User Associations – WRUAs) and leaders of local

community organisations involved in conservation (such as Yala Site Support Group, Friends of Yala Swamp, Yala Ecosystem Biodiversity and Conservation Network, and Green Initiative for Community Development). These key informants had a deep understanding of the wetland ecosystem, garnered from working or living adjacent to the wetland, as well as a wider perspective of environmental issues. Description of each ES was derived from Kandziora et al. (2013) and Owuor et al. (2017) with some modifications for the local context (Table 1).

### 2.2.2. Matrix mapping of ES flow

The study was carried out through a series of workshops with the local stakeholders around the Yala wetland. A total of 132 participants, including local community groups, resource managers and local government officials, were involved. The participants were purposively selected for their knowledge and use of the wetland. Leaders of local conservation and self-help groups assisted the researchers to mobilise community members representing a range of livelihoods in the wetland including farmers, teachers, conservationists, businesspeople, fishermen and others (see Table 1 in supplementary material). The workshops were carried out between November 2018 and May 2019 in locations surrounding the Yala wetland (Figure 1). The first workshop was held with 15 participants comprising resource managers, county/local government officials and leaders of community groups in Siaya town, the administrative headquarters of the county located about 15 km from the wetland. The second workshop was held in Hawinga at Lake Kanyaboli resort with 27 members of local community groups and organisations while the third, fourth and fifth workshops were held in Bar Olengo, Yimbo and Budalang'i villages, with 27, 30 and 33 participants from the local community in each village, respectively (including members of local community groups). The study was permitted by the National Commission on Science, Technology and Innovation (NACOSTI), which oversees ethical issues related to research work in Kenya. Research participants were briefed about the project and their consent obtained before beginning the workshops.

The researchers held extensive discussions with the participants at each workshop. Several topics were discussed, including the concept of ES, threats to ES delivery, and management status of Yala wetland. Researchers took the participants through an introductory session explaining the concept of ES and the Millennium Ecosystem Assessment classification framework. This was followed by guiding participants through scoring the matrix table (i.e. scoring each LULC against the list of ES presented). Each participant was asked to individually score each land cover type for the ecosystem services received from it. The matrix

**Table 1.** ES categories for Yala wetland with definitions modified from (Kandziara et al. 2013) and corresponding supporting literature for each ES denoted by a number.

Ecosystem services	Definition of ES
<b>Provisioning services</b>	
<b>Firewood</b> <sup>a,b</sup>	Fuel derived from trees within the wetland
<b>Charcoal</b> <sup>b</sup>	Fuel derived from trees cut and slow-burned to produce charcoal
<b>Construction materials</b> <sup>a-c</sup>	Poles, reeds and timber harvested from the wetland and used for building and making furniture and ornaments
<b>Fishing gears</b>	Equipment used for fishing made from local materials e.g. cages, canoes
<b>Honey</b> <sup>d</sup>	Honey harvested from hives set up in the vegetation in the wetland
<b>Medicine</b> <sup>b</sup>	Traditional and locally used medicines derived from natural wetland products
<b>Fisheries</b> <sup>a-c</sup>	Fish harvested from the water bodies in the wetland
<b>Wild Foods</b> <sup>a-c</sup>	Wild foods collected from the wetland e.g. wild vegetables, berries, and meat from small wild game
<b>Regulating services</b>	
<b>Erosion protection</b>	Soil retention and capacity to prevent soil erosion
<b>Carbon sequestration</b> <sup>c</sup>	Long term storage of carbon in the wetland soil and vegetation
<b>Flood protection</b> <sup>c</sup>	Mitigation of impacts of floods in the wetland
<b>Nutrient regulation</b>	Ability of the wetland to store nutrients e.g. nitrogen
<b>Cultural services</b>	
<b>Education and research</b> <sup>c</sup>	Traditional and local knowledge gained from living in the wetland; research by scientists and other researchers in the wetland
<b>Cultural shrines</b> <sup>d</sup>	Places of religious significance to the community where e.g. rituals are carried out
<b>Recreation and tourism</b> <sup>c,d</sup>	Outdoor activities and tourism relating to the natural landscape e.g. hiking and bird watching
<b>Intrinsic values</b> <sup>b</sup>	The desire for the natural environment to exist outside of its usefulness to people

<sup>a</sup>Abila (2005), <sup>b</sup>Ikiara et al. (2010), <sup>c</sup>Muoria et al. (2015), <sup>d</sup>Mwaura et al. (2003)

**Table 2.** Matrix showing flow of ES in Yala wetland. Mean scores: 0 = no flow, 1 = very low flow, 2 = low flow, 3 = medium flow, 4 = high flow, 5 = very high flow.

Ecosystem Services Classes	Provisioning Services								Regulating Services			Cultural Services				
	Firewood	Charcoal	Construction poles	Fishing gears	Honey	Medicine	Fisheries	Wild foods	Erosion protection	Carbon sequestration	Flood protection	Nutrient regulation	Education and Cultural Shrines	Recreation and Intrinsic values		
Land-use land cover classes (LULC)																
Papyrus	2	0	2	2	1	1	3	2	2	4	3	3	3	2	3	4
Water body	1	0	2	3	1	2	4	2	4	2	2	3	3	2	3	3
Shrubs and trees	4	3	4	2	3	4	2	3	4	4	4	3	3	2	3	3
Grassland	1	1	2	1	1	2	1	2	3	3	3	2	2	2	2	3
Farmland	2	2	2	1	2	2	1	2	2	2	2	2	3	1	2	3
Open land	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	2
Settlements	0	1	2	1	1	2	1	1	2	2	2	2	2	2	2	3

scores were defined as: 0 = no flow, 1 = very low flow, 2 = low flow, 3 = medium flow, 4 = high flow and 5 = very high flow (See Table 2 in the supplementary material for a summary of the workshop programme). Discussions at the village level were held in the local Dholuo or Luhya dialects and Kiswahili to ensure understanding and full inclusion of all the participants.

### 2.2.3. Data analysis

Data from the community members and experts was analysed using descriptive and inferential statistics via Microsoft Excel and SPSS version 20. To populate the matrix, measures of means of each class of ES across a particular land cover type were used to determine the score (0 to 5) of that ES over each land cover type. For example, the mean score given by all the participants for each ecosystem service (e.g. firewood) across the papyrus LULC were calculated to give

a score of how much firewood the participants obtained from papyrus. The mean scores across all ES types under the three classes of ES were combined with remotely sensed data to produce the ES flow maps. Measures of proportions were also used to determine the percentage of participants who favoured high flows of the ES (score of 4 or 5) for each ES.

For the ES where more than 50% of participants favoured a high score, a one-way multivariate analysis of variance (MANOVA) was used to determine how expertise, gender and distance influenced the ES score. It is recognised that gender, expertise, and distance from the area providing the ES are among many other factors that affect stakeholder perceptions of the ES in several ecosystems. Here, gender was selected as it affects the use of ES through gender-differentiated roles (Yang et al. 2018), while expertise

closely links to knowledge, practices and decision-making with regard to ES management, and distance affects access to, and therefore the perception of ES (Muhamad et al. 2014; Ouko et al. 2018; Moutouama et al. 2019). For expertise, we divided stakeholders into three categories (conservation/environmental professionals, farmers/fishermen, and ‘other’ expertise). Farming and fishing have been identified as two dominant livelihood activities in the wetland (Abila 2002; Ikiara et al. 2010) and are both highly dependent on the wetland. Distance of the respondent’s home from the wetland was also divided into three categories (0–5 km, 5.1–10 km, >10.1 km). We excluded all scores for which there was data missing in any of the categories. Post-hoc tests were used to determine how the factors influenced the scores.

### 3. Results

#### 3.1. Land cover mapping and ES identification

Papyrus is the most dominant land cover type, covering 9,610 ha (47.6%) of the wetland, followed by farmland (2,727 ha, 13.5%), and grasslands (2,311 ha, 11.4%) (Figure 2). The remaining land cover types each encompass less than 10% of the wetland: water bodies (9.9%), trees and shrubs (9.3%), settlements (6.5%) and open land (1.74%).

The ES provided by the wetland, which were identified through literature review and interviews with experts, are shown in Table 1, along with definitions of the ES based on Kandziora et al. (2013). The final closed list presented to participants for scoring had eight provisioning services: firewood, charcoal,

construction materials, fishing gear, honey, medicine, fisheries, and wild foods. Regulating services identified as important in Yala wetland were erosion protection, carbon sequestration, flood protection and nutrient regulation. The wetland also provides cultural services in the form of education and research, cultural shrines, recreation and tourism, and intrinsic values.

#### 3.2. Matrix scoring of LULCs for ES flow

Results of the expert scores are shown in Table 2. The score for each land cover type was calculated as an average of the scores given by the participants (sum of the score for each LULC/number of participants). Figure 3 shows the percentage of stakeholders who favoured high flow of ES (score of 4 or 5 on the matrix). Expert scores were combined with the LULC types to produce ES flow maps, showing how the different LULC types provide provisioning, regulating or cultural services (Figures 4–6).

##### 3.2.1. Provisioning services

The average scores of the land cover types for provisioning services ranged from medium (3) to very low flow (1) (Figure 4). Table 2 shows the flows of each ES over a specific land cover type, for example, flow of firewood from papyrus. Trees and shrubs showed high flows across three provisioning ES, indicating that trees and shrubs provide a range of provisioning services to the community. The measures of proportions (Figure 3) showed that the majority of respondents gave trees and shrubs a high score (4 or 5) for

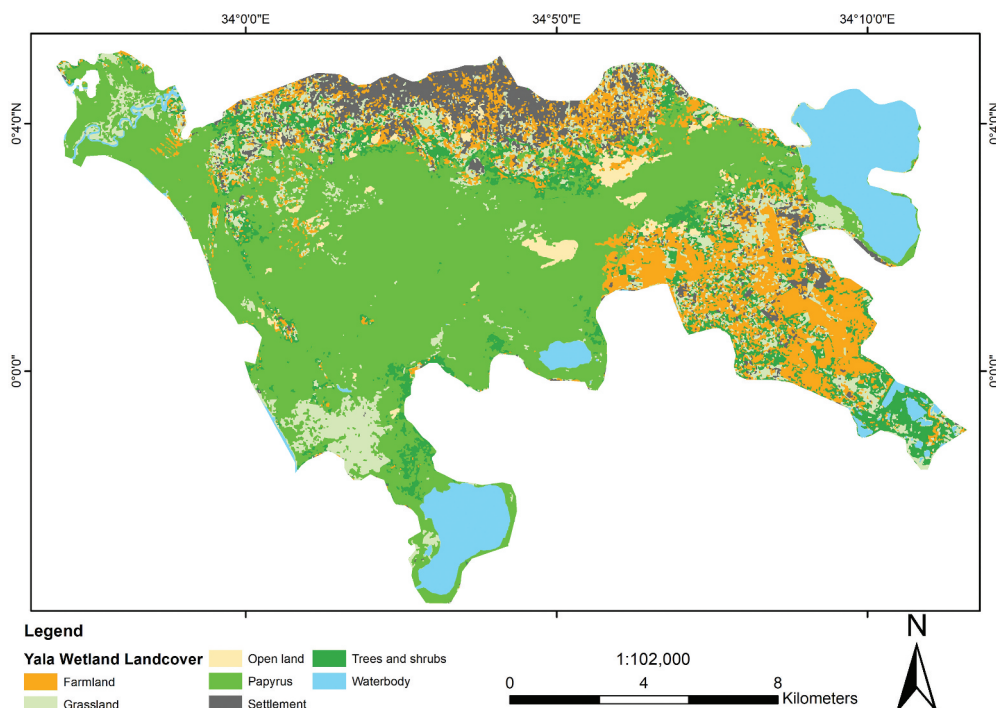


Figure 2. Map showing LULC classes in Yala wetland.

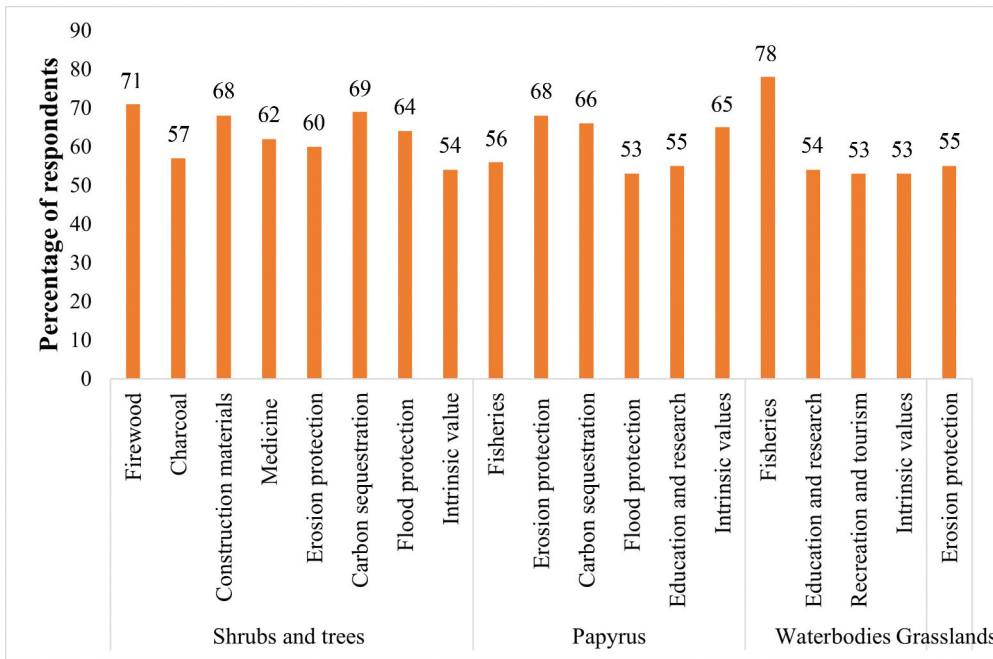


Figure 3. Proportions of respondents who favoured high flows of ES over selected LULC classes (NB: High flows here are defined as a score of 4 or 5 on the matrix).

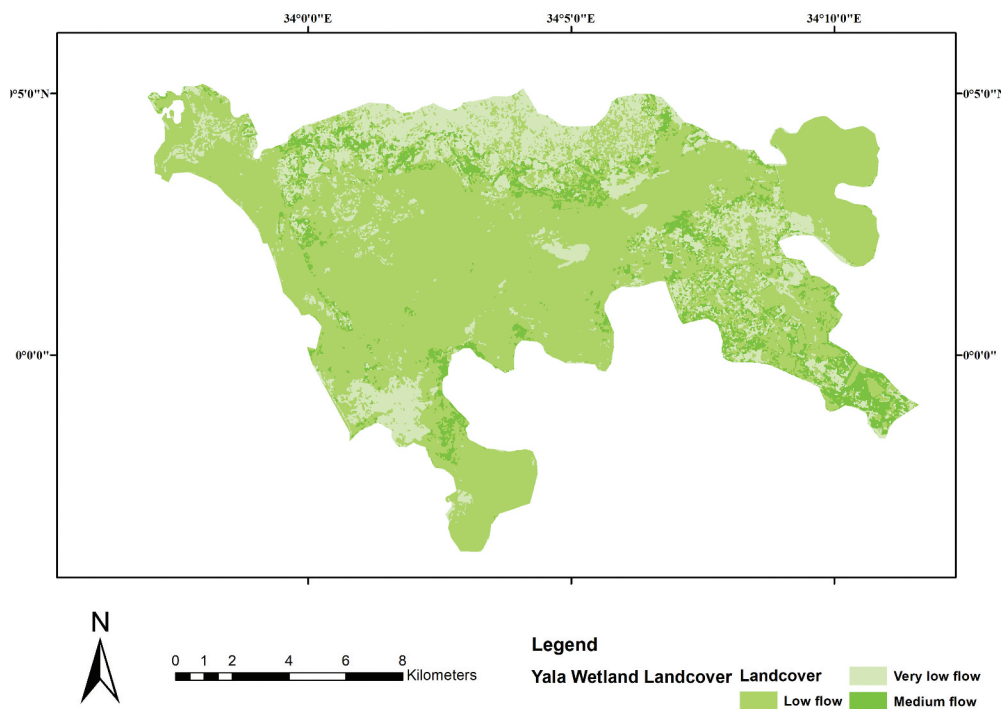


Figure 4. Map showing flow of provisioning services in Yala wetland.

the provision of firewood (71%), charcoal (57%), construction poles (68%) and medicine (62%). Water bodies had high flow for one ES (fisheries) (score of 4) and moderate to low flow for the other provisioning ES. 78% of respondents gave water bodies a high score for the flow of fisheries. Papyrus had moderate flow for fisheries, and low to no flow for all other ES types. The measures of proportions showed that 56% of respondents gave papyrus a high score for fisheries. All other land cover types

(grassland, farmland, open and settlements) showed low flow, very low flow, or no flow across the provisioning ES categories.

### 3.2.2. Regulating services

Matrix scores for regulating services ranged from high to very low flow. Results showed that respondents value trees and shrubs and papyrus for erosion protection, carbon sequestration and flood protection. Trees and shrubs had high flow for



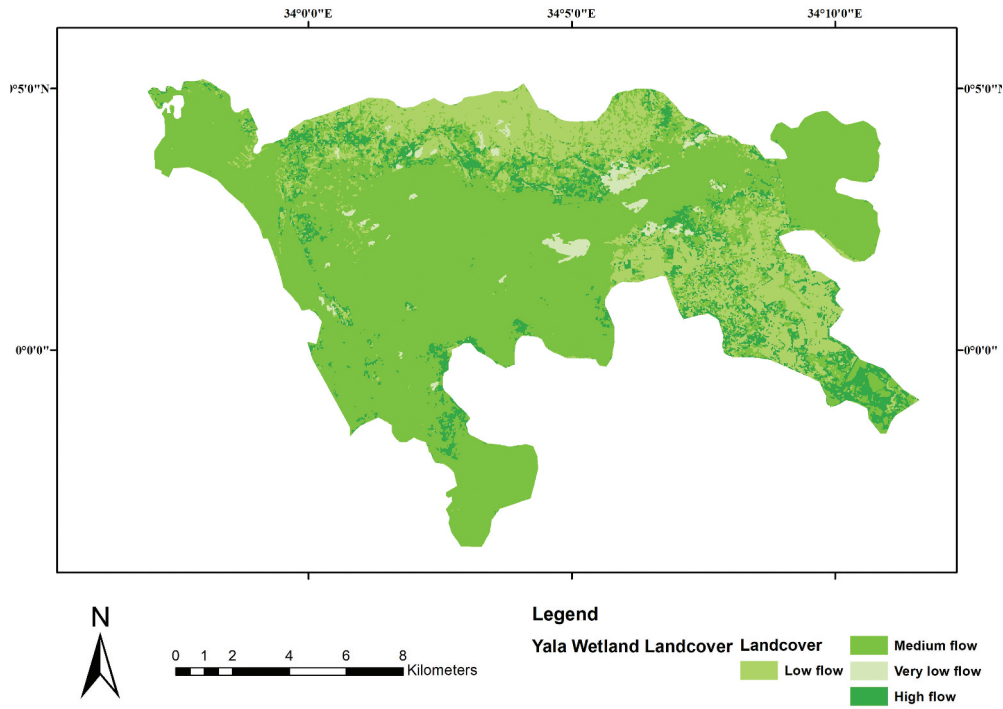


Figure 5. Map showing flow of regulating services in Yala wetland.

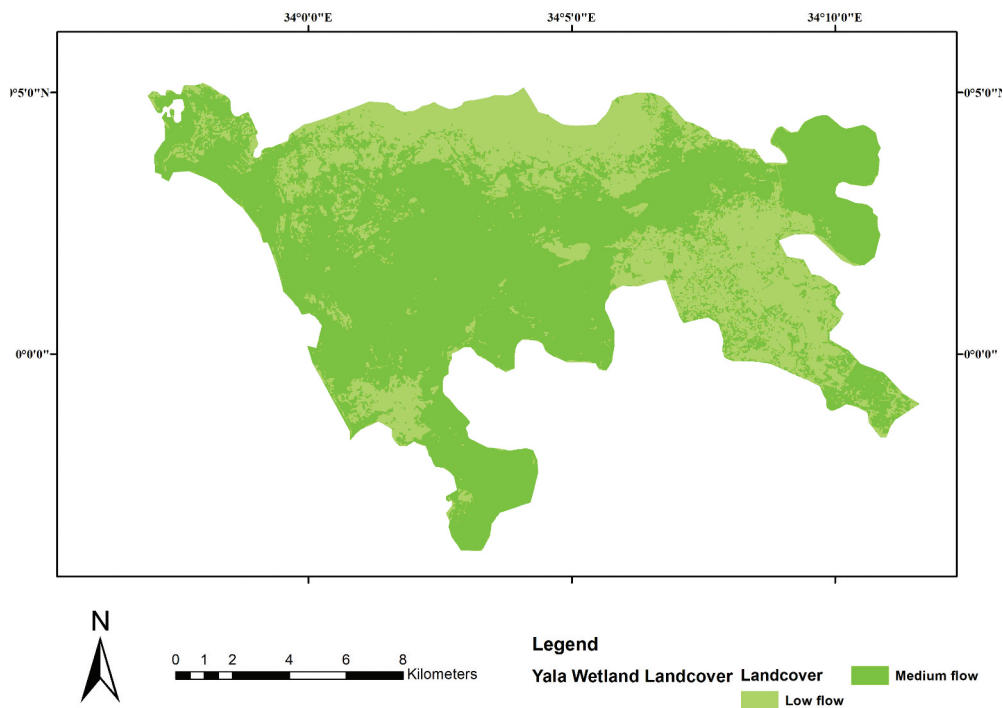


Figure 6. Map showing flow of cultural services in Yala wetland.

one ES (erosion protection) and moderate flow for the other regulating ES. Measures of proportions show that most respondents gave trees and shrubs a high score for erosion protection (60%), carbon sequestration (69%) and flood protection (64%). Matrix scores showed that water bodies and papyrus showed high average flow (4) for one regulating ES each (erosion protection and carbon

sequestration, respectively) and moderate to low flow for the other ES in this category. However, the measures of proportions show that majority of participants gave water bodies low scores for regulating service provision. Papyrus received high scores for erosion protection (68%), carbon sequestration (66%), and flood protection (53%). Grasslands showed moderate flows (3) for erosion

protection, carbon sequestration and flood control and low flow for nutrient regulation. Grasslands also had high proportionate scores for erosion protection (53%). All other land cover types (farmland, open and settlements) showed low flow, very low flow, or no flow across the regulating ES categories.

### 3.2.3. Cultural services

Average scores for cultural services ranged from moderate to low. The overall results showed that respondents value papyrus, trees and shrubs and water bodies for intrinsic value. Papyrus had a high average score for intrinsic value (4), moderate scores for education and research and recreation and tourism, and low flow for cultural shrines. 65% of respondents gave papyrus a high score for intrinsic value. Water bodies and trees and shrubs had a moderate flow across ES in the category except for cultural shrines, which had a score of 2. Measures of proportions showed that 53% of respondents gave water bodies a high score for intrinsic value and 51% gave trees and shrubs a high score for the same service.

## 3.3. Analysis of the influence of stakeholder characteristics on ES scoring

### 3.3.1. Effects of expertise on scoring

Results of the MANOVA test for the effect of expertise on the scoring of ES shows statistically significant differences between scoring by the three groups of experts (environmental/conservation, farmers/fishermen and others) across the three categories of ES (Table 3). For provisioning services, there was a significant difference between the three groups in the scoring of trees and shrubs for provision of firewood ( $p = 0.004$ ), construction materials

( $p = 0.019$ ), and medicine ( $p = 0.009$ ). For regulating services, there were statistically significant differences in scoring of the flow of papyrus for erosion protection ( $p = 0.043$ ) and carbon sequestration ( $p = 0.048$ ) and scoring of trees and shrubs for carbon sequestration ( $p = 0.020$ ). For cultural services, there were differences in the scoring of water bodies for recreation and tourism ( $p = 0.001$ ) and intrinsic value ( $p = 0.015$ ).

Pairwise comparisons revealed significant differences between scoring by the environmental/conservation experts and farmers/fishermen but no significant differences between either of these two groups and experts in the 'other' category (see Table A1 in appendix). In all the cases, experts in the 'environment/conservation' categories scored these ES higher than experts in the 'farming/fishing' group: i) trees and shrubs for flow of firewood ( $p = 0.003$ ), construction materials ( $p = 0.014$ ), medicine ( $p = 0.008$ ) and carbon sequestration ( $p = 0.047$ ); ii) papyrus for erosion protection ( $p = 0.040$ ) and carbon sequestration ( $p = 0.040$ ); iii) water bodies for recreation and tourism ( $p = 0.001$ ) and intrinsic value ( $p = 0.015$ ).

### 3.3.2. Effects of gender and distance on ES scoring

Results of the one-way MANOVA for the effects of gender on the scoring of ES flow showed statistically significant gender differences on only one provisioning (firewood) (Table 4). Women scored trees and shrubs significantly higher than men for the flow of firewood ( $p = 0.005$ ).

The effect of distance of respondent's home from wetland is presented in Table 5. The results show a statistically significant influence of distance on the scoring of education and research value of water bodies ( $p = 0.001$ ) and intrinsic value of trees and shrubs ( $p = 0.037$ ).

**Table 3.** Results of one-way MANOVA test for the effects of expertise on scoring of ES flows (\*denotes significance)  $\eta^2 =$  partial eta,  $n = 99$ .

Ecosystem Service	Land Cover Type	Mean score by Environment/Conservation	Mean score by Farmers/ fishermen (n = 50)	Mean score by other (n = 23)	Mean score of flows by all groups	F-values	p-values	$\eta^2$
<b>Firewood</b>	Trees and shrubs	4.67	3.49	3.90	3.91	5.962	.004*	.113
<b>Charcoal</b>	Trees and shrubs	4.04	2.96	3.67	3.41	3.540	.055	.070
<b>Construction materials</b>	Trees and shrubs	4.56	3.53	4.00	3.92	4.078	.019*	.080
<b>Medicine</b>	Trees and shrubs	4.41	3.31	3.62	3.68	4.988	.009*	.096
<b>Fisheries</b>	Papyrus	3.81	3.39	2.76	3.37	2.222	.114	.045
	Water body	4.67	4.14	4.19	4.30	1.694	.189	.035
<b>Erosion protection</b>	Papyrus	4.56	3.82	3.86	4.03	3.501	.043*	.069
	Shrub and trees	4.07	3.47	4.05	3.76	2.374	.099	.048
	Grasslands	3.89	3.18	3.76	3.51	2.335	.102	.047
<b>Carbon sequestration</b>	Papyrus	4.41	3.55	3.67	3.81	3.387	.048*	.067
	Trees and shrubs	4.37	3.65	4.38	4.01	4.357	.020*	.085
<b>Flood protection</b>	Papyrus	4.15	3.31	3.33	3.55	2.410	.095	.049
	Trees and shrubs	3.89	3.73	3.95	3.82	.251	.778	.005
<b>Education and Research</b>	Papyrus	3.96	3.43	3.90	3.68	1.719	.185	.035
	Trees and shrubs	3.74	3.02	3.67	3.36	2.095	.129	.043
<b>Recreation and Tourism</b>	Water body	4.26	2.98	3.81	3.52	7.649	.001*	.140
<b>Intrinsic value</b>	Papyrus	4.22	3.37	3.76	3.69	2.774	.068	.056
	Water body	4.11	3.04	3.71	3.48	4.386	.015*	.085
	Trees and shrubs	3.85	3.04	3.52	3.37	2.978	.056	.060

## 4. Discussion

### 4.1. Linking land cover with ES provision

The basis of the matrix model is that ES delivery is intricately linked to land cover (Burkhard et al. 2009). Indeed, this study found differences in ES flow within and between land cover types, providing important information on the role of natural and modified land cover types to ES provision at the local scale. The study found that natural land cover types (trees and shrubs, papyrus, and water bodies) were more important for ES delivery than human-modified land cover types (farmland, settlements, and open land) (Table 2). Studies have shown that land use change influences ecosystem service delivery (Palomo et al. 2014; Zorilla-Miras et al. 2014), particularly conversion to human-modified land cover types, such as large-scale agriculture, which potentially leads to loss of ES for the local community (Adekola et al. 2012) or transfer of the ES benefits to users outside the wetland (Wang et al. 2017).

While previous studies have placed emphasis on the role of papyrus in ES provision in Yala wetland (Abila 2002; Mwaura et al. 2003; Mwakubo and Ikiara 2009), this study found that trees and shrubs also play a prominent role particularly for provisioning services (see Table 2). Previous studies of land degradation in the wetland have found a loss of papyrus vegetation driven by both small and large-scale agriculture (Thenya et al. 2006). Other studies show that small-scale agriculture in East African papyrus wetlands allows for rhizomes (which are generally not harvested) to regrow during the wet season (van Dam et al. 2013). This regrowth may be affected by burning during the dry season, a common practice in Yala wetland (Okeyo-Owour et al. 2012), as well as the availability of water flows during the wet season since papyrus is more productive in more permanently inundated soils (van Dam et al. 2013). Recent large-scale agricultural conversion in the

wetland has led to increases in water diversions, river abstraction, and wetland drainage (Osumba et al. 2010; Thenya and Ngecu 2017) which may have impacts on rhizome regrowth. Climatic and hydrological conditions also strongly influence papyrus vegetation, for example, leading to intensive exploitation during exceptionally dry years as shown by research in Nyando wetland, Western Kenya (Rongoei et al. 2013). Further, the recent conversions to large-scale agriculture led to restrictions on community access to the wetland (Siaya County Assembly 2015). The combination of loss of papyrus through land conversion and changes in water flows caused by climate and large-scale farming may lead to reduced availability and use of the papyrus by the community, which may be further compounded by lack of accessibility in some areas of the wetland. Landscape management strategies must consider the important role of trees and shrubs for ES provision in the wetland. Studies are also needed to analyse changes in the role of papyrus in supporting livelihoods in a heavily modified wetland ecosystem. However, the results of this study do support those of previous research on the role of papyrus and water bodies in fisheries. Fish is the most important wetland product, with over 90% of the population relying on it either for commercial or subsistence uses (Abila 2002). L. Kanyaboli plays an important role in regional fish production and consequently has four fish landing sites (Siaya County Government 2018a). Papyrus reeds also serve as nursery grounds for fish, thus contributing to fish production in the wetland.

The study found that papyrus and trees and shrubs had high flow for three out of the four regulating services (erosion protection, carbon sequestration and flood protection). Wetlands provide several regulating services including water quality and quantity regulation, nutrient retention, and carbon sequestration (Mitsch et al. 2015). However, these services are rarely quantified, particularly in papyrus wetlands

**Table 4.** Results of one-way MANOVA test for the effects of gender on scoring of ES flows (\*denotes significance)  $\eta^2$  = partial eta,  $n = 127$ .

Ecosystem Service	Land Cover Type	Mean score by Men	Mean score by Women	Mean score of both groups	F-values	p-values	$\eta^2$
<b>Firewood</b>	Trees and shrubs	3.64	4.39	3.93	8.272	.005*	.062
<b>Charcoal</b>	Trees and shrubs	3.36	3.43	3.38	.040	.841	.000
<b>Construction materials</b>	Trees and shrubs	3.87	3.66	3.79	.547	.461	.004
<b>Medicine</b>	Trees and shrubs	3.64	3.53	3.60	.155	.695	.001
<b>Fisheries</b>	Papyrus	3.24	3.30	3.26	.028	.867	.000
	Water body	4.19	4.09	4.15	.174	.677	.001
<b>Erosion protection</b>	Papyrus	3.87	3.68	3.80	.537	.465	.004
	Shrub and trees	3.55	3.77	3.63	.724	.397	.006
	Grasslands	3.49	3.19	3.38	1.115	.293	.009
<b>Carbon sequestration</b>	Papyrus	3.69	3.64	3.67	.038	.845	.000
	Trees and shrubs	3.73	3.94	3.81	.679	.412	.005
<b>Flood protection</b>	Papyrus	3.38	3.11	3.28	.741	.391	.006
<b>Education and Research</b>	Papyrus	3.58	3.09	3.39	2.941	.089	.023
	Water body	3.15	3.34	3.22	.356	.552	.003
<b>Recreation and Tourism</b>	Water body	3.26	3.57	3.38	1.257	.264	.010
<b>Intrinsic value</b>	Papyrus	3.42	3.85	3.58	2.225	.138	.018
	Water body	3.44	3.23	3.36	.435	.511	.004
	Trees and shrubs	3.37	3.40	3.38	.016	.900	.000

**Table 5.** Results of one-way MANOVA test for the effects of location on scoring of ES flows (\*denotes significance)  $\eta^2$  = partial eta,  $n = 126$ .

Ecosystem Service	Land Cover Type	Mean score (0 to 5 km) n = 104	Mean score (>5 to 10 km) n = 10	Mean score (> 10 km) n = 10	Mean score of flows by all groups	F-values	p-values	$\eta^2$
Firewood	Trees and shrubs	3.91	4.00	3.70	3.90	.118	.889	.002
Charcoal	Trees and shrubs	3.26	4.60	3.30	3.37	2.643	.075	.042
Construction materials	Trees and shrubs	3.76	4.40	3.40	3.78	1.105	.334	.018
Medicine	Trees and shrubs	3.63	3.60	3.60	3.63	.005	.995	.000
Fisheries	Papyrus	3.29	2.60	3.60	3.26	.905	.407	.015
	Water body	4.14	3.80	4.50	4.15	.631	.534	.010
Erosion protection	Papyrus	3.71	3.90	4.50	3.79	1.470	.234	.024
	Trees and shrubs	3.50	4.00	4.50	3.62	2.959	.056	.047
Carbon sequestration	Grasslands	3.27	3.80	4.20	3.39	2.157	.120	.034
	Papyrus	3.59	3.50	4.60	3.66	2.211	.114	.035
Flood protection	Trees and shrubs	3.77	3.80	4.40	3.82	1.007	.368	.016
	Papyrus	3.23	3.00	4.20	3.29	1.559	.214	.025
Education and Research	Trees and shrubs	3.66	3.60	3.40	3.64	.163	.849	.003
	Papyrus	3.46	2.40	3.60	3.39	2.227	.112	.036
Recreation and Tourism	Water body	3.35	1.40	3.60	3.21	6.969	.001*	.103
	Water body	3.33	2.80	4.30	3.36	2.624	.077	.042
Intrinsic value	Papyrus	3.48	4.00	4.10	3.57	1.125	.328	.018
	Water body	3.28	3.20	4.30	3.35	1.799	.170	.029
	Trees and shrubs	3.91	4.00	3.70	3.90	3.378	.037*	.053

(van Dam et al. 2014), and are often more difficult for stakeholders to identify than provisioning services (Zhang et al. 2015). Our findings show a high level of awareness of regulating services in Yala wetland, which can provide a basis for setting up community-owned conservation programmes. Wetlands also provide several cultural services including education, recreation, tourism and spiritual values (Ondiek et al. 2016). This study found that respondents value papyrus, trees and shrubs and water bodies for the provision of cultural services. All three land covers are perceived as having intrinsic value indicating their perception as an important part of the wetland's character. Papyrus and water bodies were found to have high value for education and research. Numerous studies on the wetland's ecology and biodiversity have been undertaken in the area, in part due to the significance of the Yala wetland lakes in the conservation of Lake Victoria's ichthyofaunal biodiversity (Aloo 2003; Abila et al. 2004; Angienda et al. 2011). The wetland has been declared an IBA and is considered a birdwatcher's paradise due to the presence of bird species of conservation importance like the papyrus gonolek (*Laniarius mufumbiri*, NT) and the papyrus yellow warbler (*Calamonastides gracilirostris*, VU) (Bennun and Njoroge 2000). Water bodies also provide recreation and tourism values to the community, for example, Lake Kanyaboli, which hosts recreational activities that are popular with locals and tourists.

#### 4.2. Influence of stakeholder characteristics on scoring

The results of the matrix scoring in this study show some key differences in how stakeholders perceive the flow of ES over land cover types in the wetland. The study found differences in scoring between the genders in only one provisioning service – firewood. Other studies in the East African context have found that gender differences in access, knowledge, institutions and behavioural expectations influence how ES contribute to human well-being for men and women (Fortnam et al. 2019). In the more locally relevant context of Luo Nyanza, Rocheleau et al. (1996) found that women were primarily responsible for food supply in their families. Although this study found few differences in scoring of ES between the genders, the gendered division of roles may explain the difference in scoring of firewood, which is related to food preparation, and which is harvested locally for household use. This finding is also supported by a review on gender and ES by Yang et al. (2018), which found that women had more knowledge of, and value for fuelwood and other ES that were for domestic supply, while men valued ES that could be sold for profit. However, the findings do not show a strong influence of gender on ES perception, possibly due to the interactions with other social factors, such as wealth, age, level of education or livelihood (Brown and Fortnam 2018).

The study found that expertise had an impact on scoring, with stakeholders with environmental or conservation expertise tending to score ES flow higher than the other user groups (Table 3). This finding is supported by Owuor et al. (2017) who found that ES flow scores differed significantly between the local community and researchers/managers in a matrix model study of coastal land-cover types in Kenya. In our study, managers were found to score LULCs significantly higher than farmers/fishermen across the three categories of ES, even though these two livelihoods are highly dependent on the wetland. Differences in knowledge or power dynamics have been found to influence perceptions of ES in other studies. For example, differences in technical knowledge were found to influence perceptions of regulating ES from grasslands in European mountain regions (Lamarque et al. 2011), and the degree of access to forest rights influenced ES perception in Ethiopia (Dorresteijn et al. 2017), while involvement in the setting up of marine protected areas was found to influence stakeholder perception of ES in Kenya (Mahajan and Daw 2016). Research on impacts of large-scale agricultural conversion on local livelihoods in Yala wetland shows increasing disenfranchisement of the local community including loss of access to livelihood resources (Kinari 2008). These factors have been shown to have an impact on perceptions of benefits obtained from forest ecosystems (Sinclair et al. 2011; Turyahabwe et al. 2013). In terms of distance, although the study found few differences in scoring based on distance (Table 5), the results provide some insight into how distance from wetland can impact on ES perception similar to what has been found for forest ecosystems (Ouko et al. 2018; Moutouama et al. 2019). In particular, the importance of water bodies and shrubs and trees was under-estimated by respondents living far from the wetland. Thus, social factors do play a role in how stakeholders perceive ES and, therefore, conservation and management programmes must integrate the views of different stakeholders in order to be inclusive and effective (Quintas-Soriano et al. 2018).

### 4.3. Policy, conservation, and management relevance of the study

The matrix model is applicable to complex social-ecological systems where data is scarce and there is an urgent need for information on sustainable management of the system (Jacobs et al. 2015). The study provides empirical information on local ES provision in the Yala wetland ecosystem to help mitigate the impacts of commercial agriculture and other future developments on ES delivery. Our results link land cover, ES provision and social preferences to provide data that can be fed into ES-based land-use

management policies that integrate the needs of the local community. In particular, the study can inform the implementation of the recently approved Yala wetland land-use management plan and the Siaya County spatial plan that set out areas of the wetland for conservation and development activities, such as fish processing, agriculture, and settlements. These plans should consider how these developments will impact the local community's access to and use of ES from the wetland. Similar to other studies that have employed the matrix model (e.g. Burkhard et al. 2015), this research contributes to knowledge on the use of ES mapping approaches in addressing challenges of land-use conversion in freshwater wetlands since the impacts of human-induced change in wetland ecosystem services in sub-Saharan Africa have not been well studied (Rebello et al. 2010), despite the unprecedented threats they face.

The study also assessed stakeholder perceptions by looking at the differences in ES scoring between diverse stakeholder groups. Understanding and achieving consensus among diverging stakeholder knowledge and interests is key in promoting biodiversity conservation (Müller and Maes 2015). The study demonstrates the need to include the local community's views in decision-making in wetland conservation. Our research has the potential to inform targeted conservation education programmes, to build the capacity of local communities to undertake conservation, and to initiative citizen science approaches to data-gathering within Yala and other similar wetlands. Further, wetland ecosystems contribute either directly or indirectly to the attainment of several of the UN Sustainable Development Goals (SDGs) – zero hunger, good health and well-being, climate action, life on land, and life in water. Our research provides evidence to place wetlands on the global agenda, including supporting recent efforts to have the Yala wetland designated as a wetland of international importance under the Ramsar convention (Chebet 2021).

### 4.4. Limitations of the study

The study experienced uncertainties due to language, sample size, LULC generalisations, the subjectivity of experts and use of a pre-selected list of ES which are inherent in expert-based valuation studies and have been identified in other studies (Hou et al. 2013; Jacobs et al. 2015; Stoll et al. 2015; Campagne et al. 2017). In the case of language, the workshops were conducted in three different languages (English, Kiswahili and Dholuo) depending on the group of experts consulted to ensure that they could fully participate in the exercise, though there were challenges in terms of translation and interpretation, and potential for

misunderstanding. A second challenge related to having a relatively small sample size and low degree of reproducibility (Hou et al. 2013). However, sample size has been found to be less important in research that investigates highly complex systems and attempts to bridge social and natural science concepts (Jacobs et al. 2015). Furthermore, Campagne et al. (2017) found that in an expert panel size of more than 15, the scoring variability caused by differences in knowledge among experts or confidence of each individual expert in their scores were not adversely affected. And, as shown by the results, the integration of various stakeholder views can enrich the outcome of expert-based approaches. The simplification of the LULC into seven classes may also have led to the loss of information. For example, large-scale agricultural land may provide a different set of ES to the local community than small-scale agriculture. In our pre-selected ES list, ES such as grazing that have been identified in the literature were not included for scoring in the matrix. However, the study does provide policy and management-relevant information linking land cover change and ES provision and showing the importance of diversity of stakeholders in the ES assessment process.

## 5. Conclusions and recommendations

The key findings of this study are that: a) land cover influences ES provision in Yala wetland, b) natural vegetation, and particularly trees and shrubs, play an important role in ES provision to the local community across provisioning and regulating services, c) gender may not play a significant role in scoring differences in the ES matrix, except for services linked to gender-differentiated roles, and d) expertise of stakeholders has a strong influence on the perception of ES. These findings suggest that there is a need for landscape management programmes and plans to consider the differentiated role of various land cover types in ES provision in the wetland and demonstrate the important role of the local community (resource users) as experts in studies that integrate social preferences.

The study also uncovers some gaps as potential study areas. At the local scale, a potential area of study is to look at how the historical flow of ES to the local community has changed with the conversion of large tracts of the wetland to agricultural land. This should include the overall loss or gain perceived by the local stakeholders and the change in the spatial distribution of the ES themselves and changes in access to resources, such as papyrus. Studies also needed to uncover the drivers and impacts of recent changes in the role of papyrus in livelihoods in the wetland. There is also potential to explore how future land-use changes and their spatial

distribution will impact on ES supply in the wetland using participatory methods including scenario-building. The findings can be applied to the implementation of the landscape management plans and in community-based wetland conservation programmes.

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**Appendix A. Pairwise comparisons of differences in scoring based on expertise****Table A1.** Pairwise comparisons of Tukey's HSD (\* denotes significance at 0.05 level).

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Firewood from Trees and shrubs	Environment/ Conservation	Farming/ Fishing	1.15*	.339	.003*	.34	1.95
		Other	.71	.408	.193	-.26	1.68
	Farming/ Fishing	Environment/ Conservation	-1.15*	.339	.003	-1.95	-.34
		Other	-.43	.363	.458	-1.30	.43
	Other	Environment/ Conservation	-.71	.408	.193	-1.68	.26
Construction materials from Trees and shrubs	Environment/ Conservation	Farming/ Fishing	.43	.363	.458	-.43	1.30
		Other	1.02*	.356	.014*	.17	1.86
	Farming/ Fishing	Environment/ Conservation	.56	.428	.400	-.46	1.57
		Other	-1.02*	.356	.014	-1.86	-.17
	Other	Environment/ Conservation	-.46	.381	.452	-1.37	.45
Medicine from Trees and shrubs	Environment/ Conservation	Farming/ Fishing	-.56	.428	.400	-1.57	.46
		Other	.46	.381	.452	-.45	1.37
	Farming/ Fishing	Environment/ Conservation	1.09*	.356	.008*	.24	1.93
		Other	.95	.428	.072	-.07	1.97
	Other	Environment/ Conservation	-1.09*	.356	.008	-1.93	-.24
Erosion Protection from Papyrus	Environment/ Conservation	Farming/ Fishing	-.13	.381	.934	-1.04	.77
		Other	-.95	.428	.072	-1.97	.07
	Farming/ Fishing	Environment/ Conservation	.13	.381	.934	-.77	1.04
		Other	.72*	.290	.040	.03	1.41
	Other	Environment/ Conservation	.65	.348	.157	-.18	1.48
Carbon Sequestration from Papyrus	Environment/ Conservation	Farming/ Fishing	-.72*	.290	.040	-1.41	-.03
		Other	-.07	.310	.973	-.81	.67
	Farming/ Fishing	Environment/ Conservation	-.65	.348	.157	-1.48	.18
		Other	.07	.310	.973	-.67	.81
	Other	Environment/ Conservation	.83*	.335	.040	.03	1.63
Carbon Sequestration from Trees and shrubs	Environment/ Conservation	Farming/ Fishing	.68	.403	.215	-.28	1.64
		Other	-.83*	.335	.040	-1.63	-.03
	Farming/ Fishing	Environment/ Conservation	-.15	.359	.912	-1.00	.71
		Other	-.68	.403	.215	-1.64	.28
	Other	Environment/ Conservation	.15	.359	.912	-.71	1.00
Recreation and Tourism from Water Body	Environment/ Conservation	Farming/ Fishing	.69*	.287	.047	.01	1.37
		Other	.01	.345	1.000	-.81	.83
	Farming/ Fishing	Environment/ Conservation	-.69*	.287	.047	-1.37	-.01
		Other	-.68	.307	.072	-1.41	.05
	Other	Environment/ Conservation	-.01	.345	1.000	-.83	.81
Recreation and Tourism from Water Body	Environment/ Conservation	Farming/ Fishing	.68	.307	.072	-.05	1.41
		Other	1.26*	.339	.001*	.45	2.07
	Farming/ Fishing	Environment/ Conservation	.53	.408	.396	-.44	1.50
		Other	-1.26*	.339	.001	-2.07	-.45
	Other	Environment/ Conservation	-.73	.363	.117	-1.59	.14
Other	Environment/ Conservation	-.53	.408	.396	-1.50	.44	
Other	Farming/ Fishing	.73	.363	.117	-.14	1.59	

*(Continued)*

Table A1. (Continued).

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Intrinsic Value of Papyrus	Environment/ Conservation	Farming/ Fishing	.82	.362	.065	-.04	1.68
		Other	.45	.435	.558	-.59	1.49
	Farming/ Fishing	Environment/ Conservation	-.82	.362	.065	-1.68	.04
		Other	-.37	.388	.603	-1.30	.55
	Other	Environment/ Conservation	-.45	.435	.558	-1.49	.59
		Farming/ Fishing	.37	.388	.603	-.55	1.30
Intrinsic Value of Water Body	Environment/ Conservation	Farming/ Fishing	1.05*	.370	.015	.17	1.93
		Other	.38	.444	.664	-.67	1.44
	Farming/ Fishing	Environment/ Conservation	-1.05*	.370	.015	-1.93	-.17
		Other	-.67	.396	.216	-1.61	.28
	Other	Environment/ Conservation	-.38	.444	.664	-1.44	.67
		Farming/ Fishing	.67	.396	.216	-.28	1.61