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Seasonal Papyrus Biomass Harvesting Patterns and its Implications on Productivity in Nyando Floodplain Wetland, Lake Victoria Basin, Kenya

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Abstract

Papyrus production not only maintains the structure and function of the wetland but also meets the needs of the surrounding communities who rely on them directly. Seasonal changes in rainfall patterns has influenced the productivity of Nyando wetland yet there is need to understand the influence of such changing conditions on the provisioning services. Although there have been studies done in these wetlands, there is inadequate understanding on the implication of biomass harvesting on the growth attributes of the papyrus plant in the face of changing seasons. This study focused on Nyando floodplain wetland located in the Eastern part of the shores of Lake Victoria which is a lifeline to many rural communities living around the lake. Papyrus biomass harvesting patterns were assessed in two study sites of Nyando wetland and at different seasons in order to determine its implication on papyrus productivity. Participatory tools, field survey, interviews, observation, field measurements and laboratory measurements were used. The results show the area harvested was different between sites and between seasons in Wasare (107.9 ± 2.7 m^2) dry and wet season (88.8 ± 3.1 m^2). Biomass and height were critical growth attributes that were affected by harvesting frequency and changes in rainfall patterns. Understanding harvesting patterns is important for planning and management of wetland ecosystem so as to continue providing materials while maintaining the structure and function of the wetland.

Keywords: Papyrus Biomass, Harvesting Patterns, Season, Productivity, Nyando Floodplain

INTRODUCTION

Wetlands are important in provisioning and regulating ecosystem services which make an enormous contribution to the livelihoods of millions of people in Sub-Saharan Africa. According to Millennium Ecosystem Assessment (MEA) (2005) and The Economics of Ecosystems and Biodiversity (TEEB) (2010), ecosystem services are the benefits people obtain from ecosystems. These include provisioning, regulating, cultural and supporting services. Provisioning services are the products obtained from ecosystems and include food, water, fuel and other materials while regulating services are benefits obtained from regulation of ecosystem processes. These include water purification, water regulation, climate, and flood control. African wetland areas have supported directly and indirectly livelihoods of millions of the rural poor through provisioning services. Apart from provisioning fertile soil and water for crop cultivation, these wetlands provide plants that are harvested by the communities to be used for making mats, thatching and other artefacts.

The primary productivity of papyrus wetland is crucial in maintaining habitats for various wildlife, provisioning of food as a basis for food chain in the wetland, provide shelter to other organisms such as fish (Kansiime *et al.*, 2007; Kiwango *et al.*, 2008). When this papyrus vegetation is harvested without consideration, most of these functions will be affected. Despite the importance of these ecosystems and the services they provide to humans, wetlands have been threatened mainly by conversion to agriculture (MEA, 2005; Verhoeven & Setter, 2009). Loss of wetlands has been exacerbated by the need to increase economic development, meet food security and to reduce poverty for the growing population. More so, increasing climate uncertainty has led to expansion of dry areas in the wetland that lead to more accessibility for various exploitation activities. A balance between well-functioning ecosystem and maintaining the wellbeing of society has been a concern for environmental managers, decision-makers and planners.

The main aim of this study is to understand the harvesting patterns of papyrus in the wetland and how it influences growth attributes of the main vegetation of the wetland. It is hypothesized that, harvesting of papyrus biomass may play a crucial role in influencing primary productivity of the wetland particularly in the face of unreliable rainfall patterns coupled with increasing human pressures. However, this depends on the harvesting frequency, extent of area harvested, and seasonality. To achieve this, the following specific objectives were formulated: (i) To assess seasonal papyrus biomass harvesting patterns in Ogenya and Wasare in Nyando floodplain wetland; (ii) To determine the effects of papyrus harvesting frequency on its density, girth, height and biomass in a prolonged dry season in Nyando floodplain wetland.

METHODOLOGY

Study Area

The study was conducted in Nyando floodplain wetland at the North Eastern shores of Lake Victoria, Kenya. The wetland is found at an interface between River Nyando and Lake Victoria. It stretches from the mouth of Nyando River at Nyakach bay extending from 0º11'- 0º19'S to 34º47'- 34º57' E (Figure 1).

The annual rainfall received is between 1000 and 1600 mm with a mean of 1184 mm and an estimated mean temperature of 23ºC (van Dam *et al.,* 2011; World Agroforestry, 2006). The long rains are received between March and May while short rains in October and December.

The Luo community living around the wetland practice various socio-economic activities which include fishing, animal husbandry, mat-making, cultivation of crops among others.

Study Approach

From participatory tool, a pair wise ranking matrix was used to list livelihood activities in Nyando floodplain. The most important of these activities was determined with the help of the residents living around Nyando wetland and papyrus harvesting is one such important activity (Rongoei *et al.,* 2013).

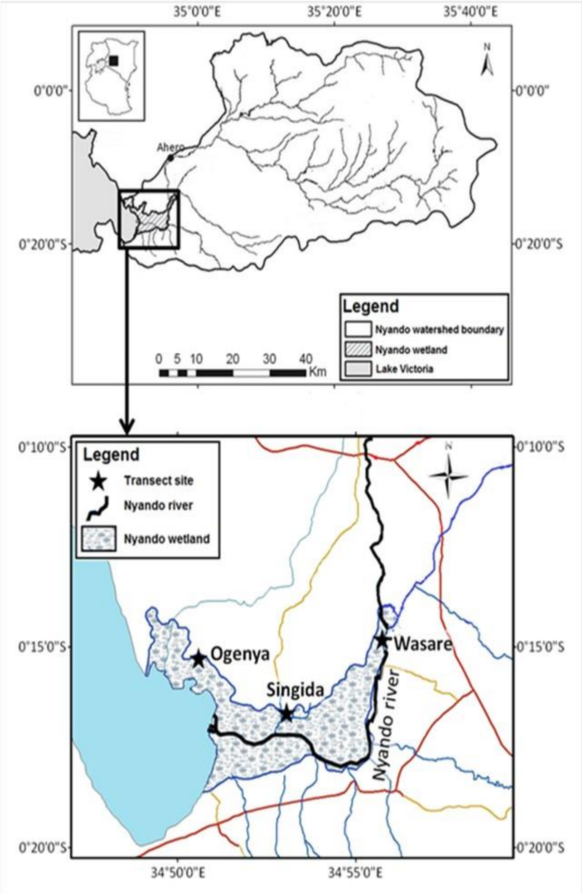

Figure 1: Location of Nyando Wetland in relation to Lake Victoria showing the Study Sites.

Determination of Papyrus Harvesting Patterns in Nyando Floodplain Wetland

The focus of the study in Nyando floodplain was based on Singida, Ogenya and Wasare which had different seasonal flood pulses (Rongoei *et al*., 2014). Harvesting of papyrus biomass occurred in Ogenya and Wasare while fishing was the main activity that took place in Singida and no papyrus harvesting was observed at this site (Rongoei *et al*., 2013, 2014). The study of papyrus harvesting patterns was done for 13 months from June 2011 to June 2012 which covered wet and dry seasons.

Once a month, transect sites were visited between 9.00 am and 2.00 pm where harvesting of papyrus biomass by the community members occurred. The number of people that took part in harvesting activity was determined in the field as well as their gender and age. Individual harvesters were interviewed to determine their frequency of harvesting per week in order to determine the amount and the area harvested.

Observation in the field was done to determine the type of harvesting done by the members which shows a clear-cutting rather than selective cutting. Field measurements using a tape measure were done to determine the size of the area harvested per person per day. The size of the area harvested was used to estimate papyrus biomass that can be harvested per season in each study site. This was to establish the amount of aerial biomass that was harvested and removed from the wetland. The information helped to understand the effects that unsustainable harvesting of papyrus biomass would have in the general functioning of the wetland if harvesting occurred in an expansive area of the wetland and if the number of harvesters increased.

After harvesting, mature papyrus culms were selected and were split into two by the owners. The split culms were left in the field to dry for two to three days before being put into bundles and transported away from the wetland. The weight of transported bundles was determined by weighing the bundles carried home using a spring scale.

Determining the Effects of Harvesting on *C. papyrus* Productivity in Nyando Floodplain Wetland

Two sets of experiments were established to determine papyrus productivity in terms of above ground biomass, girth diameter, culm density and height after harvesting. The first set was done from mid-December 2010 when the experimental plots were cleared and monitoring started at the beginning of January to March 2011 (relatively wet due to the end of short rains and beginning of dry period). The second set was done from April to June 2011 which was to represent the wet season however, there was unforeseen dry period.

To determine changes in biomass over time, plots of 10 m x 10 m was cleared in each site in December 2010 and April 2011. The plants were given time to regrow before samples were collected. The monitoring of papyrus productivity for the period of 12 - 14 weeks was used since it has been successfully used by other researchers in tropical areas (Osumba *et al*., 2010; Terer *et al.*, 2012) as well as in temperate regions (Silvan *et al*., 2004).

At the time of regrowth in the 10 m x 10 m plots, three random quadrats of 1 m x 1 m were demarcated and all above ground plants were harvested after every two weeks so as to follow the accumulation of biomass over time. In the quadrats, the number of life papyrus culms were counted, recorded and expressed as density per m^2. At the same time, culm height was also determined by measuring the length of the culm in each transect using the tape measure from just above the leaf sheath to the tip of culm at the beginning of the umbel and the results given in centimetres. In addition, culm girth was measured in centimetres at a consistent point above leaf sheath at the same period of study in both study sites.

To determine the biomass, the same plants within 1 x 1 m^2 were cut and fresh biomass was measured using the spring balance in the field. Sub-sample fresh biomass was cut into small pieces, re-weighed, recorded and packed in labelled bags to be carried to the laboratory in the Department of Biological Sciences, Egerton University. The samples were sun-dried for 3 days and then oven-dried at 60^{o}C for two days to obtain constant weight. Biomass was determined by weighing the dried matter after obtaining constant weight and above ground dry mass was recorded as grams dry mass per metre square (g DM/m^2).

Data Analysis

Descriptive statistics was used in determining the amount of biomass harvested and the area harvested in both sites. Normal distribution of collected data was done using Shapiro-Wilk test. All tests were conducted at 5% probability level unless otherwise stated. Linear mixed models fit by maximum likelihood was used to determine the effects of papyrus harvesting overtime on its productivity in the wetland study sites. Fixed effects model was used to determine the variations between the area harvested and the months of the study period. All analyses were done using R version 3.1.3 (R core team 2015).

RESULTS

Papyrus Biomass Harvesting Patterns in Nyando Floodplain Wetland

The results show that the average height harvested was above 150 cm which was seen to be mature enough to be used in making mats. Variation on the size of the area harvested, number of bundles, weight of bundles and the frequency of harvesting per person per week in wet and dry seasons is depicted in Table 1. Wasare site had relatively larger size of the area harvested in dry season (107.9 ± 2.7 m^2) than in wet season (88.8 ± 3.1 m^2). This may have been attributed to the fact that during dry period, the wetland is accessible to all and it becomes difficult during wet season as the harvesters have to cross the flooded river. On the other hand, Ogenya site harvested area in dry (104.8 ± 3.5 m^2) and wet (101.7 ± 3.3 m^2) did not differ between seasons as compared to Wasare.

The frequency of harvesting in the wetland per week was different between transects. Ogenya wet season had higher frequency (5.0 ± 0.1times/week) while it was lower in Wasare dry season (4.5 ± 0.1 times/week) ($F = 7.7$, $P < 0.01$). The mode of harvesting was clear cutting which left the young and dry papyrus plants including the umbels in the site. Furthermore, papyrus harvesters spent time in the biomass harvesting that varied between seasons and transects. In Wasare, harvesters spent more time in harvesting than in Ogenya ($F = 10.2$, $P < 0.01$) and between seasons ($F = 6.5$, $P < 0.05$). In both sites, the percentage of frequent harvesters were between the age of 30 and 50 (Table 2). This implies that this age group is energetic and can be able to make a significant impact on the overall ecology of the wetland if the number of harvesters increased.

Table 1: Description of Seasonal Papyrus Biomass Harvesting Patterns in Ogenya and Wasare in the Period June 2011 to June 2012. Mean, Range and Standard Error are based on the Wet and Dry Months in each site.

	Wet							
	Ogenya		Wasare		Ogenya		Wasare	
Parameters measured	Mean ± S.E	Range	Mean ± S.E	Range	Mean ± S.E	Range	Mean ± S.E	Range
Total area harvested (m^2/person/day)	104.8 ± 3.5	20 - 202	107.9 ± 2.7	61.2 - 172	101.7 ± 3.3	64.8 - 261	88.8 ± 3.1	33.8 - 150.1
Weight of bundles (kg/person/day)	60.6 ± 3.7	26 - 160	48.2 ± 2.8	24 - 150	73 ± 3.7	24 - 210	49.8 ± 2.3	27 - 90
Number of bundles (count/person/week)	8.8 ± 0.6	3 - 30	6.3 ± 0.4	3 - 21	9.7 ± 0.6	3 - 25	5.8 ± 0.3	3 - 15
Frequency/ person/week (days)	4.7 ± 0.1	2 - 7	4.5 ± 0.1	2 - 7	5.0 ± 0.1	2 - 7	4.5 ± 0.1	2 - 7

Table 2: Age Frequency of Papyrus Harvesters in Nyando Wetland

Age interval (years)	**Age frequency (no.)**		
	Ogenya	**Wasare**	**Percentage (%)**
< 20	1	0	1
20.1 - 30	8	9	12
30.1 - 40	25	37	45
40.1 - 50	27	20	34
50.1 - 60	6	5	8
Total	67	71	100

Effect of Harvesting on Papyrus Productivity in a Prolonged Dry Season

The effect of harvesting on the growth characteristic (culm density, length, girth diameter and above ground biomass) of *C. papyrus* L. was done in three study sites of Nyando wetland and results presented in Figure 2.

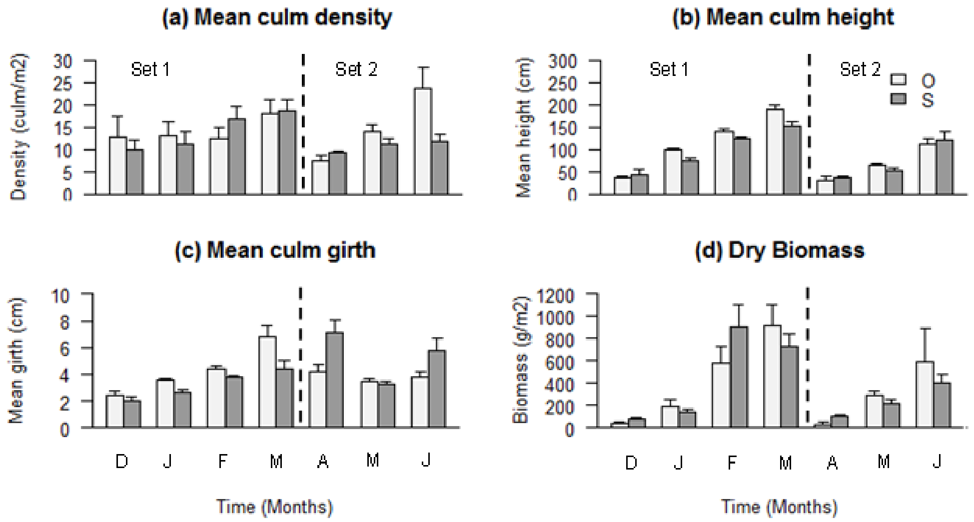

Figure 2: Mean culm density, mean culm height, mean girth diameter, and above ground dry biomass of *C. papyrus* L. after two sets of harvesting separated by the dotted line. First harvest (December 2010) and second harvest (April 2011). The data represents mean ± standard error of mean where n=3. The letters D, J, F, M, A, M, J stand for the months starting from December 2010 to June 2011 while O, S, represent the study sites Ogenya, and Singida, respectively. Wasare site excluded as the plots were interfered with by harvesters during the study period.

C. papyrus L. culm density/m^2 remained constant over four months (December to March) in all the sites after the first harvesting. At the end of March 2011, there was minimal increment in growth and plants started showing signs of senescing due to drying up of the wetland. In Wasare site, papyrus vegetation was burned in February which destroyed the vegetation in the experimental plots hence this site was not included in the statistical analysis. In the second set of harvesting, Ogenya showed a gradual increase in culm density than Singida maintaining it over three months (Figure 2a).

C. papyrus L. culm length was below 50 cm in all the sites after one month of harvesting the first set. They continued to grow gradually to 200 cm high in Ogenya and 150 cm in Singida after three months of harvesting (Figure 2b). In the second set of harvesting, culm length significantly reduced as compared to the first set ($t = -4.1$; $P < 0.001$) in Ogenya and Singida but no variability between transects ($P < 0.05$) (Figure 2b). More so, culm girth diameter did not differ between transects and sets although there was a rapid increase in diameter at Singida (Figure 2c).

Above ground dry biomass increased gradually following the trend of culm length and girth after the first harvesting especially in February and March for Singida and Ogenya sites. However, after the second harvesting, biomass reduced in all the three sites by the end of the third month (June) (Figure 2d). This was due to the prolonged drying conditions living the plants dehydrated. Table 3 depicts linear mixed models fit by maximum likelihood showing culm height and biomass as the main attributes of papyrus productivity that is significantly influenced by harvesting during the continuous dry conditions of the wetland.

Table 3: Results of Linear Mixed Effects Model Fit by Maximum Likelihood Used to Investigate the Effects of Harvesting Papyrus on its Productivity Characteristics

Model* predictors	**AIC**	**BIC**	**LogLik**	**t-value**	**p-value**	**Beta**
Height	823.62	833.05	-407.81	-4.07	< 0.00	-42.24
Girth	309.21	318.64	-150.61	0.63	> 0.05	0.24
Density	536.37	545.80	-264.19	-0.53	> 0.05	-0.87
Biomass	1164.16	1173.58	-578.08	-2.17	< 0.05	-199.70

*Dependent variable: effect on papyrus productivity
AIC is the Akaike Information Criterion while BIC is the Bayesian Information Criterion

The second set of harvesting showed that there was a reduction in the mean biomass of papyrus by -199.7 with a standard error of 92.1 based on 75 residuals ($t = -2.2$; $P < 0.05$). However, harvesting did not affect culm density and girth as they were not statistically significant as depicted by lower LogLik of -150.61 and -264.19, respectively if compared to that of biomass and height. Height and biomass are important in contributing to the livelihoods of the people as they harvest plants that are above 170 cm in height with higher biomass required for their essential uses.

DISCUSSION

Seasonal Papyrus Harvesting Patterns

Papyrus harvesting is one of the main livelihood activities taking place in Nyando floodplain wetland and depended upon by the rural communities to meet their daily needs. This activity is in line with what others have found out to be taking place in most of the wetlands (Obiero *et al*., 2012; Terer *et al*., 2012; Morrison *et al*., 2012; Rongoei *et al*., 2013). Clear-cutting of wetland vegetation was done by the harvesters before they select mature and health plants for their use. Furthermore, harvesters do not transport all the harvested material but only mature culms leaving behind the umbels, young and dry culms including other associated plants. The harvested parts may be used for various purposes depending on the needs of the harvesters which can be to meet subsistence and commercial needs of the households in the study sites (Table 4). This kind of harvesting has an implication on the biomass left to rot in the field and that which is moved to homesteads. This activity is done all year round in all the study sites and it is important since the study site is known to have the highest population density and high poverty levels (Gichuki *et al*., 2001; World Agroforestry Centre, 2012).

Table 4: Summary of Wetland Natural Plant Products Used by People in the Nyando Floodplain Wetland

Plant type	**Part**	**Use**
Cyperus papyrus	Umbel	Broom
Cyperus papyrus	Culm	Mats, chairs, artefacts, roofing
Cyperus papyrus	Roots/rhizomes	Fuel wood
Phragmites sp.	Culms	Fencing, fish traps
Phragmites sp.	Leaves	Forage for livestock
Vossia cuspidata	Whole	Forage for livestock
Cyperus latifolia	Whole	Roofing
Solanum sp.	Whole	Wild vegetable
Ipomoea aquatica	Whole	Forage
Winter berries	Fruit	Wild fruit

This study shows that harvesting of papyrus, number of bundles transported, size of area harvested and weight of bundles depended on the seasonality and the site. Wasare which was mainly disturbed by human activities had light weight of bundles, less number of bundles transported and yet had a bigger area harvested. Accessibility to the wetland during the dry season made it easier for everyone to exploit in order to earn income to improve their wellbeing. The dry season exploitation of the wetland resources has been established by others (Harper and Mavuti 2004; Kiwango and Wolanski, 2007; Osborn 2012). Such over-exploitation may lead to changes in wetland structure, area and reduction of the shoreline vegetation which may negatively influence ecosystem processes and affect the functioning of the wetland (Khisas *et al*., 2013; Barducci *et al*., 2009).

C. papyrus L. Productivity in Prolonged Dry Conditions and Its Implications on Nutrient Storage and Cycling

This study found the average biomass productivity in Nyando floodplain wetland to be 4800 g/m^2 which is within what has been found out by others in other wetlands in the tropical areas of Eastern Africa (Boar, 2006; Mnaya *et al*., 2007; Osumba, 2010; Terer *et al*., 2012; Rongoei & Outa, 2016). This study found out that average standing biomass in Nyando floodplain wetland ranged between 35 and 65 tonnes/ha. Variation in the biomass productivity in the study sites may have depended on the anthropogenic activities and the use of the wetland for several purposes but also according to different growth stages. However, uncertainty in weather conditions have accelerated the problem leading to mortality of papyrus plants due to loss of soil moisture.

Seasonal wetland was affected negatively by various human activities as compared with that of permanent wetland. A study through the Bayesian Network analysis by van Dam *et al*. (2013) showed that human activities have affected negatively on the seasonal than permanent wetland leading to reduction in its functions. Biomass productivity as well as other growth parameters vary according to location, hydrological regimes, nutrient status and the frequency and intensity of disturbance at the study sites. This has also been experienced in other wetlands (Khisa *et al*., 2013; Pal *et al*., 2016). Furthermore, papyrus productivity will help the surrounding communities obtain building materials as well as fuel wood for cooking. This is in line with the fact that most of the poor people in Africa depend on wood fuel as a source of energy (Cerutti *et al*., 2015).

CONCLUSION AND RECOMMENDATIONS

The ecosystem productivity will irreversibly be altered if harvesting pressure which is coupled with other drivers such as conversion to croplands and livestock grazing continue without consideration. With the climate change that is experienced worldwide, papyrus growth attributes will be affected which will have an implication to the livelihoods of the rural poor who directly depend on them. Not only will the economic benefits be reduced but also other ecosystem services will be lost such as water purification, soil nutrient cycling, climate stability and others. Due to such risks and the continuing pressure put on these ecosystems, there is need to establish techniques for managing and sustainably using the resources without compromising on other services. Biomass and height of culm are important attributes that will influence the productivity of the system. These attributes contribute to materials being used by the local community to meet their needs.

It is recommended that selective harvesting of papyrus culms may be practised by the local people so as to have continuous sustainable harvesting throughout the year in both dry and wet seasons. When the hydrology of the system change, there is need for the community to diversify their activities to those outside the wetland other than degrading the system further. They may maximize their harvesting during the wet season when productivity of papyrus is high and will help the system get rid of excess nutrients getting into the lake.

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