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Characteristics of macrophytes in the Lubigi Wetland in Uganda

John K. Kayima and Aloyce W. Mayo*

Department of Water Resources Engineering, University of Dar es Salaam, P. O. Box 35131, Dar es Salaam, Tanzania.

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The Lubigi wetland, which is located in the north-western part of Kampala, the capital city of Uganda has been severely strained from anthropogenic encroachment and activities. These activities include harvesting of *Cyperus papyrus* and other plants, land filling for reclamation, human settlements and disposal of wastewater into the wetland among others. As a result of these anthropogenic activities, the macrophytes diversity and biomass in the wetland have been affected, which in turn affects the effectiveness of wetland for removal of pollutants. It is therefore important to investigate the characteristics of wetland macrophytes in the Lubigi wetland. Pertinent field investigations, surveys, data collection and laboratory tests and analyses were carried out. The problem being addressed was the current lack of information and knowledge about the biomass and biodiversity of the Lubigi wetland to protect the downstream Mayanja River and Lake Kyoga. Three transects each of 1.0 m wide was cut across this zone at about 700 m downstream of the main wastewater inlet, the second at about 1,440 m downstream of the main wastewater inlet and the third at about 1,930 m downstream of the main wastewater inlet. In each of the 3 transects, 5 sampling points were established. Samples were analyzed in order to determine plant biomass, diversity, density and vegetation zonation. The determination of nitrogen content in the biomass parts and sediments was also carried out in accordance with standard methods for the examination of samples. The results show that there are 9 dominant native wetland plants species, which account for about 60% of all the plants species recorded. Of these dominant plant species, three exhibited the monotype form of dominance, one is ubiquitous, the other three were the compressed form of dominance, six are aberrant, two are diffuse and one is patchy. The most dominant species are *C. papyrus, Echinochloa pyramidalis*, *Typha capensis, Rottboellia cochinchinensis* and *Oldenlandia lancifolia*, with biomass production mean values of 1.52±0.13, 0.16±0.03, 0.26±0.04, 0.03±0.01 and 0.37±0.05 kgDWm^{-2}, respectively. However, there is no statistically significant difference between the biomass of the plant species in the three transects. Plant densities range from 5.0±3.09 to 19.56±15.29 plants/m^2, with a mean value of 10.19±4.69 plants/m^2. The overall mean plants and sediments nitrogen content are 67.54±37.9 and 157.5 g/m^2, respectively.

Key words: Lubigi wetland, plant biodiversity, plant biomass, plant density, vegetation zonation.

INTRODUCTION

Natural wetlands have distinctive plants and animals living together and are adapted to flooding and climatic conditions of the area (Mitsch and Gosselink, 2007). One of the main functional aspects of wetlands of natural wetlands is ecological functions, which includes maintenance of the water table. This helps in recharging the ground water table, which in turn helps plants in the immediate environment of the wetland to have easy access to water supplies (Commission of the European Communities - CEC, 1995; Dugan, 1990; Maltby, 1990). Wetlands also prevent soil erosion, traps sediments and reduces impacts of floods (CEC, 1995; Hogan et al., 1992). Sediment retention prevents downstream resources such as dams, farmland, rivers and lakes from being silted up. Another ecological benefit of wetlands is a haven for wildlife habitats and centres of biological diversity (Kayima et al., 2018a). Natural wetlands provide natural habitats for a variety of plants and animals, some of which depend entirely on the wetlands for their survival (Hammer and Bastian, 1989; Muraza, 2013; Kayima et al., 2018b). In Uganda for example, natural wetlands are natural habitats for the Sitatunga and the Shoe Bill, among other animal species. The Crowned Crane, Uganda's national symbol bird, breeds in natural wetlands with a preference for seasonal grass swamps (Kayima, 2018).

Wetlands have various socioeconomic benefits to the population sorrounding the wetlands. For instance, natural wetlands harbour a variety of fish species, which have traditionally been harvested by people as an important food item (Balirwa, 1998). The marginal parts of natural wetlands, where the soil is permanently or seasonally moist, have for a long time been used by people for agriculture and livestock grazing especially during the dry seasons. In addition, plants like *Cyperus papyrus* and other wetland plants have been traditionally harvested by people as structural building materials, for house thatching, timber, firewood, medicines and production of mats and baskets (CEC, 1995; Dugan, 1990; Hogan et al., 1992; Terer et al., 2012; Muraza, 2013). Communities living near wetlands also mine sand and clay from natural wetlands for building purposes and for making pottery (Kayima, 2018).

The diversity of natural wetland biological communities have a potential for attracting tourists and thus generating tourism revenue income. Natural wetlands have capacities to remove pollutants, nutrients and toxins from water, thus to some extent filtering and purifying it, which enables them to act as ecological transition zones that protects the quality of water in downstream fresh water bodies such as rivers and lakes (Terer et al., 2005; Henry and Semili, 2005; Marwa, 2013; Mayo et al., 2018). Because of this function, it has been possible for rural communities to obtain fairly clean water supplies from their natural wetlands. At Kampala in Uganda, natural watelands have been used for disposal of municipal wastewater (Kansiime, 2004; Kayima, 2018).

Natural wetlands cover about 10% of Uganda's total land surface area, and provide a wide variety of bio-physical and socio-economic functions. The wide distribution of natural wetlands in Uganda, means that a large proportion of the population have access to the utilization of the natural wetlands, resulting in their degradation. This demands for particular urgency in their efficient management and sustainable utilization (Ministry of Water and Environment, Uganda, 2015). In spite of all these socio-economic values of wetlands, their benefits have been put into serious jeopardy, due to poor management practices (Ministry of Water and Environment, Uganda, 2015).

The importance of natural wetlands to national development, and the threats to their continued existence were recognised in 1986, when the Government of Uganda issued administrative guidelines to curtail the devastation of wetland resources. In addition, the Government instituted the National Wetlands Conservation and Management Programme within the Department of Environment Protection, to analyse existing activities and assess the full range of functions and values provided by natural wetlands in the country. Some of the objectives of the Uganda National Policy for the Conservation and Management of Wetland Resources include maintainance of biological diversity in the natural wetlands either in the natural communities of plants and animals, or in the multiplicity of agricultural activities (Ministry of Water and Environment, Uganda, 2015).

Lubigi is one of the largest Lake Kyoga drainage basin wetlands located in the north-western part of Kampala, the capital city of Uganda (Kansiime et al*.,* 2007). This wetland has continued to come under severe strain from anthropogenic encroachment and activities including deliberate landfilling for reclamation, human settlements, draining away of water for agriculture and livestock farming, clay and sand extraction, brickmaking, harvesting of *C. papyrus* and other plants for handcrafts and house roof thatching, inappropriate and illegitimate solid waste disposal along with municipal and industrial effluent discharges (African Development Fund, 2008; Kayima, 2018).

To exacerbate the Lubigi wetland problems, the Government of Uganda itself has constructed major projects in the wetland contributing further to its degradation. These projects include Kampala Northern Bypass Highway, which continues to attract the construction of other new developments along its 21 km route from Bweyogerere to Busega, the 132 kV High Tension Electric Power line, from the Kawanda sub-station to the Mutundwe sub-station and the 5,400 m^3/day National Water and Sewerage Corporation Lubigi

*Corresponding author. Email: aloyce.mayo@yahoo.com.

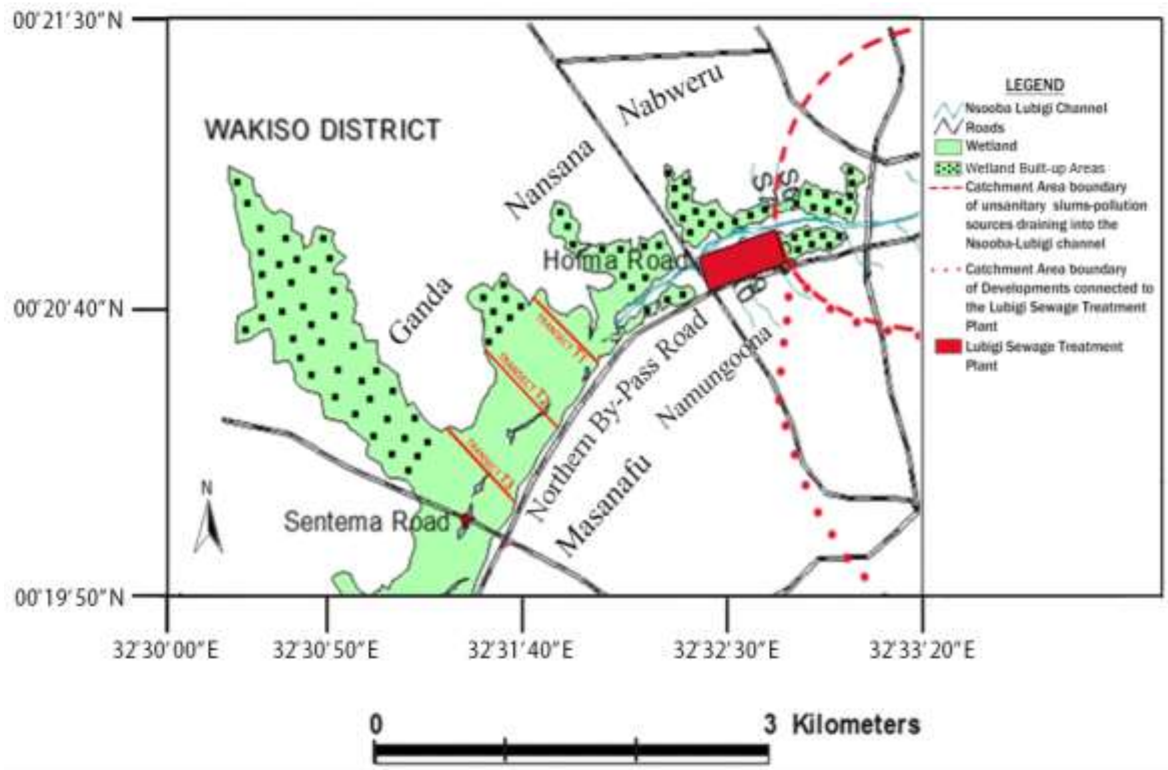

Figure 1. Map of the Lubigi Wetland main study area.
Source: Modified from Kayima et al. (2018).

Sewage Treatment Plant (Watebawa, 2012). GIS mapping is showing the wetland being degraded at over 40%, which is well above the national average of 30% (Habonimana, 2014).

To determine the dominating plant species in the wetland, various indices are used. One of such indices is Species Dominance Index (SDI), which was developed by Frieswyk et al. (2009), whereby three attributes of dominance namely, Tendency Toward High Cover (THC), Mean Species Suppression (MSS) and Mean Cover (MC) were used. The Tendency Toward High Cover (THC) is a ratio of the number of times a species is "influential" in a plot, that is, having > 25% absolute cover and the most cover, to the number of times it is present in a plot. Mean Species Suppression (MSS) is the mean of the reciprocal of the number of plant species, in a quadrat where the plant species of interest is influential. Mean Cover (MC) is the average cover of a plant species.

The knowledge of plant species diversity and density helps in determination of dynamics of nutrient removal by plants, which was the fundamental objective of the research project. It is well documented that biodiversity and biomass content of a wetland significantly influences nitrogen trapping and tranformation in the wetland (Mayo et al., 2018). Unfortunately, information on biodiversity and biomass in Lubigi wetland is very scanty (Kayima, 2018). To achieve this objective it was necessary to investigate the current status of Lubigi wetland macrophytes biomass and biodiversity, which is the main objective of this part of the research study.

MATERIALS AND METHODS

The Lubigi wetland main study area

The main study area investigated in this research study is as shown in Figure 1. The area comprises the Upper Lubigi wetland, which is delineated in the north-east of Kampala city by the Hoima Road, with the main wastewater inlet located at latitude 00˚20'48" N and longitude 32˚32'28" E; and in the south-west by the Sentema Road with the main effluent outlets located at latitude 00˚19'56" N and longitude 32˚31'34" E. This section of the wetland covers an area of approximately 1.1 km^2, at an altitude of approximately 1,158 m above mean sea level, with a total drainage catchment area of about 40 km^2. This is the section of the wetland, which receives the initial and direct impacts of the heavily polluted wastewater from the upstream Nsooba-Lubigi storm water drainage channel and the Lubigi Sewage Treatment Plant. This is the only section of the Lubigi wetland where the Government of Uganda grants permission for human activities, such as controlled plants harvesting and investigative research work. The diverse macrophytes zones in this section made the research study more intriguing. The rest of the wetland is gazzeted as a strictly protected area.

Before choosing the location of the transects, preliminary reconnaissance transect surveys were conducted throughout the whole wetland. This was followed by identification of major vegetation zones that is most representative of the plant diversity in the whole wetland. These major vegetation zones were delineated for more detailed investigations and studies. Within the major vegetation zones, the section closest to the wetland main wastewater inlet was observed to be dominated by *Echinochloa pyramidalis* and *Paspalum scrobiculatum*, with abundance of other assorted types of plant species. Hence, transect T1 of 1.0 m wide was established in this section which is about 700 m downstream of the wetland main wastewater inlet. The middle section was observed to be dominated by *C. papyrus* and *Typha capensis*, with abundance of other assorted types of plant species. Hence, transect T2 of was cut across this zone which is about 1,440 m downstream of the wetland main wastewater inlet. The section closest to the main wetland outlets was observed to be dominated by *C. papyrus* and *Thelypteris acuminata*, with abundance of other assorted types of plant species. Hence, transect T3 was established in this section which is about 1,930 m downstream of the wetland main wastewater inlet (Figure 1).

In each of the three transects, five sampling points were established in order to closely follow the spatial variability across the widths of the wetland, as one moves from the main central drainage channel away towards the edges of the wetland on either side of the channel. The transects and sampling points were geo-referenced using a Garmin Global Positioning System (GPS) device, in order to determine and record the co-ordinates of their locations. Then they were transferred to a digitized map of the area, to ensure that the same transects and points are used every time sampling is done. To facilitate movements and work within the transects, *C. papyrus* culms were cut and tied in bundles which were laid down to make walkable paths. Dinghy boats and motor vehicles were used as alternatives, to access places that were not easily accessible by foot. Life rafts and jackets and other safety precautions and measures were used throughout the research field work.

Vegetation zonations

To determine the existing major vegetation zones in the Lubigi wetland, three transects T1, T2 and T3 each 1.0 m wide were cut across the zone. Transect T1 was cut at a distance of about 700 m downstream of the main wastewater inlet, while transects T2 and T3 were cut about 1,440 m and 1,930 m downstream of the main wastewater inlet, respectively (Figure 1). The vegetation zonations by dominant plant communities were established by ground surveys in the transects. A 1 m x 1 m quadrat grid system marked with permanent numbered eucalyptus poles, was used to identify the locations of the major vegetation communities in the wetland. The 1 m x 1 m quadrats grid system, consisted of five sampling quadrats established at spacings of approximately 50 m in each transect. The coordinates and altitudes of each sampling quadrat were recorded using a Garmin Global Positioning System (GPS) device. A vegetation Community Diversity Index (CDI) was developed to quantify the diversity in the wetland vegetation zonations. This index used the relative areas of the vegetation communities encountered during the transect surveys, followed by the application of the Shannon-Weaver Diversity Index (S-W DI), using the area of each vegetation community instead of the number of individuals of each species. The Community Diversity Index (CDI) is as expressed by Equation 1 in accordance with Shannon and Weaver (1949).

$$CDI = -\sum_{i=1}^{N} Ci \ln(Ci) \quad (1)$$

Where CDI is the Community Diversity Index, C_i is the approximated percentage cover of a given vegetation community "i", expressed as a decimal varying between 0 and 1 and N is the number of transects included in the survey.

The Shannon-Weaver Diversity Index (S-W DI) is given by Equation 2.

$$S - WDI = e^{CDI} \quad (2)$$

Where S-W DI is the Shannon-Weaver Diversity Index and CDI is the Community Diversity Index. From the S-W DI index, major vegetation zones were marked, and it is in these zones that the determination of the vegetation dominance, densities, biomass and nitrogen contents was done.

Determination of plant species

From the transect surveys, two major vegetation zones were delineated in the wetland, based on the types of vegetation observed and the S-W DI calculations. These zones were marked and recorded with the use of a Garmin Global Positioning System (GPS) device. The voucher specimens of plant species were collected from the field, assigned collection identities, notes recorded about each of them and sent to the Makerere University Herbarium in Uganda for scientific identification. The authenticity of the scientific names, was verified using the African Plant Database.

Determination of plant dominance

To determine the vegetation dominance in the identified major vegetation zones, the established 1 m x 1 m quadrats grid system was used. Dominant plant species are the most abundant, and exert the most influence or control on the habitat and other plant species (Carpenter, 1956; Greig-Smith, 1986; Ricklefs and Miller, 1990). Dominance forms can differ with plant species, and plant species can change their form of dominance over time (Frieswyk et al*.,* 2009). Vegetation data was collected from the two major vegetation zones, which represent a random sample of the whole wetland. In each of the two major vegetation zones, the covers of the various plant species rooted in 1 m x 1 m quadrats were visually assessed.

The collected vegetation data was used to compute the corresponding Tendency Toward High Cover (THC), Mean Species Suppression (MSS) and Mean Cover (MC) for the dominant plant species in the wetland. Thereafter, the Species Dominance Index (SDI) was computed as the average of the Tendency Toward High Cover (THC), Mean Species Suppression (MSS) and Mean Cover (MC) as expressed by Equation 3. The Species Dominance Index (SDI), was computed for plant species that were considered to be potentially dominant. Potentially dominant plant species must be "influential" in at least one quadrat, and be present in at least 1/3 of the quadrats in the transects included in the survey. These attributes are inter-connected through the 7 forms of dominance shown in Table 1.

$$SDI = \frac{MC + MSS + THC}{3} \quad (3)$$

After the Species Dominance Index (SDI) was computed for each of the potentially dominant plant species, dominant plant species were selected using the mean Species Dominance Index (SDI) as a cut-off, whereby plant species with Species Dominance Index (SDI) above the mean value were considered to be dominant. Thereafter,

Table 1. Framework for 7 Forms of Plants Species Dominance (Zedler et al., 2005).

Form	MC	MSS	THC
Monotype	High	High	High
Matrix	High	Low	High
Compressed	Low	High	High
Patchy	High	Low	High
Ubiquitous	High	High	Low
Aberrant	Low	High	Low
Diffuse	High	Low	Low
Not dominant	Low	Low	Low

using the mean values as cut-offs to dichotomise each of the three components of the Species Dominance Index (SDI) into "high" and "low" values, seven forms of dominance were differentiated as shown in Table 1. In this way, a dominance form was assigned to each occurrence of dominant plant species. After the dominant plant species were established in each quadrat, the mean value of the dominant plant species was estimated for each vegetation zone, by finding the average dominance per zone, from which the overall dominant plant species in the wetland was computed.

Determination of plant densities

From the major vegetation zones, the densities of the five most dominant plant species were determined within the 1 m x 1 m quadrats established along each transect. In each quadrat, the plants existing were counted and recorded in pre-designed field data sheets. The plants densities for each quadrat, were established by summing up the number of all existing plant types falling under the quadrat under consideration. To get the mean values of plants densities in each transect, densities from the respective quadrats forming that transect were summed up and divided by the number of quadrats as shown in Equation 4. Determination of the average plants density for the entire wetland in general, was done by averaging the densities from the respective transects as shown in Equation 5.

$$AveragePlantDensity(Transect) = \frac{\sum PlantDensityFromEachQuadrat}{NumberOfTransects} \quad (4)$$

$$AveragePlantDensity(Wetland) = \frac{\sum AveragePlantDensity(Transect)}{NumberOfTransects} \quad (5)$$

Determination of plant biomass

The sampling of plants for biomass determination was done in October and November 2016. The five most dominant plants namely *C. papyrus, E. pyramidalis*, *T. capensis, Rottboellia cochinchinensis* and *Oldenlandia lancifolia* were analysed. These most dominant plant species were harvested, from the already established 1 m x 1 m sampling quadrats in the 3 transects T1, T2 and T3. The above-ground biomass was cut and separated into leaves/umbel, stalk/culm and roots/rhizomes depending on the plant type. Then these parts were weighed using a digital balance in the field, in order to obtain the total wet weight of each plant part. The below-ground biomass was removed by digging up all roots/rhizomes in the 1 m x 1 m quadrats, and carefully washing off all the dead materials and soil/peat. The roots/rhizomes were also weighed in the field, in order to obtain the total wet weight. From the whole sample of each plant part in a 1 m x 1 m quadrat, a sub-sample weighing 500 g was taken for sun-drying in the Makerere University Plant Sciences, Microbiology and Biotechnology Laboratory, in Uganda. The sun-dried samples of each plant part were thereafter oven-dried at 105°C. The dry weight to wet weight ratio of the 500 g sub-sample was used to calculate the total dry weight in the 1 m x 1 m quadrats in the transects.

Determination of plant nitrogen content

Total nitrogen (TN) was chosen as the basic element for nitrogen used up by plants. The Total nitrogen (TN) content of the dried plant parts was determined according to the methods used by Novozamsky et al*.* (1983). To undertake these analyses, fine materials out of every plant part were obtained by grinding a portion of the dried plant parts in a manual grinder. Thereafter, the fine materials were sieved through a 0.5 mm sieve in the Kawanda National Agricultural Research Organisation Laboratory in Uganda, and the ensuing powder was preserved following the preparation methodology devised by Muthuri and Jones (1997). Furher, portions of the dried powder were scooped up and transferred quantitatively into the destruction tubes in which digestion was done in a block, using a concentrated Sulphuric-salicylic mixture with Selenium as a catalyst. The analysis of Total nitrogen (TN) in the digested samples was then carried out following the Total nitrogen (TN) determination procedures in accordance with the Standard Methods for the Examination of Water and Wastewater (American Public Health Association-APHA et al., 2012).

Finally, the wetland plants nitrogen content determination was done following the approach described by Muraza et al. (2013). In this approach, the plants biomass content in kilogrammes of plants dry weight per square metre of wetland (kg DWm^{-2}), and the plants nitrogen content as a percentage of plants dry weight (%DW) were first determined. Then the plants nitrogen content in gm^{-2} was determined as the product of the plants biomass content and the plants nitrogen content as a percentage.

Determination of wetland sediment nitrogen content

The collection of wetland sediments, was done simultaneously with plants biomass sampling in October and November 2016. The sediments were collected from 3 of the 5 sampling quadrats, in each of the 3 transects T1, T2 and T3. The sediments samples were packed in cool boxes and transported to the Makerere University Plant Sciences, Microbiology and Biotechnology Laboratory in Uganda, where they were-oven dried at 105ºC. After drying, the samples were ground in a manual grinder and sieved through a 0.5 mm sieve size in the Kawanda National Agricultural Research Organisation Laboratory in Uganda, in order to obtain the dry powder.

Sub-samples of appropriate weights were taken and digested in a block using a concentrated sulphuric-salicylic mixture with selenium as a catalyst. The analysis of Total nitrogen (TN) in the digested samples was then carried out, in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA et al., 2012). The determination of the nitrogen content in the sediments in gm^{-2} was done by using the results of the sediments nitrogen content in grammes of nitrogen per kilogramme of sediments (gkg^{-1}), multiplied by the sediments density of approximately 1,050 kgm^{-3} and then by 0.5 m. This was based on the consideration that the effective sediments depth for nitrogen sedimentation is approximately 0.5 m. At depths in the sediments exceeding 0.5 m, layers of stiff and almost impermeable clay soils are encountered.

RESULTS AND DICUSSION

Plant dominance

In Lubigi wetland, the zone closest to the wetland main wastewater inlet was dominated by *E. pyramidalis*, but the middle zone was dominated by a mix of *C. papyrus* and *T. capensis*. The last zone closest to the wetland main effluent outlet was dominated by *C. papyrus*. The analysis of plants dominance showed seven forms of plant dominance. This is a naturally occurring phenomenon that was observed not only in the Lubigi wetland alone, but also in other natural wetlands such as Mara wetland (Muraza et al., 2013). It is not implausiblethat a plant species can be encountered in different locations of the same wetland, exhibiting different forms of dominance due to various environmental factors within the wetland such as competition for nutrients with other plants in that particular location/community, different soil conditions, different conditions related to access to water and light.

The analysis of plant dominance indicates that nine species are dominant. Of these dominant plant species, 3 exhibit the monotype form of dominance, 1 is ubiquitous, 3 exhibit the compressed form of dominance, 6 are aberrant, 2 are diffuse and one is patchy. Aberrant, monotype and compressed, are the most common forms of dominance in the 3 transects T1, T2 and T3. There was no specie which exhibited the matrix form of dominance. Three dominant species showed only one form of dominance, while the rest showed two forms. *E. pyramidalis* was observed to proliferate mainly in the wetland main water inlet zone, and also along the wetland main central drainage channel.

The plants species encountered in the Lubigi wetland are largely native wetland species, without colonising woody and/or early successional plants species. This would suggest that the wetland has a relatively stable vegetal cover. However, though not encountered in transects T1, T2 and T3, there was observed along the Namungoona-Masanafu edge of the wetland, an emergence of non-native plant species, which could distort the vegetal composition of the wetland as time goes on.

Table 2 shows the plant Species Dominance Index (SDI) in the transects. Transect 1 was largely dominated by *Echinochloa* sp., *Penisetum* and *Paspalum scrobiculatum,* but other plant species such as *Cyphostemma adenocule, Enhydra fluctuans* Lour and *Miscanthus violaceus* (K.Schum.) Pilg.were also found in smaller quantities. On the other hand, *C. papyrus and Ipomoea rubens* Choisy were more dominant in Transect T2 although smaller quantities of *Echinochloa* sp., *Mikania cordata* (Burm. F.) B.L. Rob., *C. adenocule, T. acuminata* (Houtt.) Morton, and *P. scrobiculatum* were also observed. Transect T3 was rich in *C. papyrus, T. capensis* and *O. lancifolia* (Schumach) DC. Others species that were found, albeit in small densities were *P. scrobiculatum, Commelina, I. rubens* Choisy and *M. cordata* (Burm. F.) B.L. Rob. Plant species that are of a lesser significance in the wetland include *Achyranthes aspera, Ipomoea cairica, Commelina, Enhydra fluctuans* Lour, *R. cochinchinensis and Persicaria salicifolia* (Brouss. Ex Willd.) Assenov.

Plant densities

The results showed that the average plant density in the wetland was 10.19±4.69 plants/m^2. The plants densities ranged from 5.0±3.09 plants/m^2 in Transect T1 to 6.0±5.06 and 19.56±15.29 plants/m^2, in Transects T1 and T3, respectively. From these plants densities, it should be evident that the Lubigi wetland is well-endowed with abundant vegetation. In a striking contrast, in a study carried out by Mayo et al. (2014) in the Mara River Basin wetlands upstream of Lake Victoria in Tanzania, which unlike the Lubigi wetland do not directly receive wastewater effluents, plants densities ranged from 3.1±0.3 to 3.3±0.3 plants/m^2, with a mean value of only 3.2±0.3 plants/m^2.

Plant biomass

The most dominant plants species in the Lubigi wetland are *C. papyrus, E. pyramidalis*, *T. capensis, R. cochinchinensis* and *O. lancifolia*. These most dominant plant species, are the ones for which plants biomass productions were analysed. Results from these analyses, are shown in Tables 3 and 4 and Figure 2. From these results, *C. papyrus* exhibited the highest biomass

Table 2. Species dominance index (SDI) in the transects.

Transect	Plant species	Species Dominance Index (SDI)
T1	*Echinochloa* sp.	0.764
	Paspalum scrobiculatum	0.330
	Enhydra fluctuans Lour	0.113
	Miscanthus violaceus (K.Schum.) Pilg.	0.111
	Penisetum	0.687
	Ipomoea rubens Choisy.	0.091
	Cyphostemma adenocule	0.113
	Ipomoea cairica	0.111
T2	*Cyperus papyrus*	0.592
	Thelypteris acuminata (Houtt.) Morton	0.100
	Paspalum scrobiculatum	0.100
	Cyphostemma adenocule	0.293
	Ipomoea cairica	0.073
	Ipomoea rubens Choisy.	0.420
	Rotboellia cochinchinensis	0.095
	Persicaria salicifolia (Brouss. Ex Willd.) Assenov.	0.094
	Echinochloa sp.	0.123
	Mikania cordata (Burm. F.) B.L. Rob.	0.112
	Commelina	0.069
	Enhydra fluctuans Lour	0.070
	Typha capensis	0.470
T3	*Thelypteris acuminata* (Houtt.) Morton	0.100
	Cyperus papyrus	0.580
	Paspalum scrobiculatum	0.260
	Ipomoea rubens Choisy.	0.078
	Mikania cordata (Burm. F.) B.L. Rob.	0.077
	Achyranthes aspera	0.059
	Ipomoea cairica	0.059
	Typha capensis	0.520
	Commelina	0.170
	Oldenlandia lancifolia (Schumach) DC	0.496

production, while *R. cochinchinensis* had the least biomass production. In addition, biomass generally tends to decrease from the wetland water inlet zone, towards the effluent outlet zone for all the most dominant plant species of the Lubigi wetland (Table 3). This phenomenon is attributed to the fact that ammonia- nitrogen (NH_3-N), which is preferentially utilised by plants for cellular matter production, also tends to get depleted from the wetland water inlet zone towards the effluent outlet zone. For *C. papyrus*, the maximum above-ground (culms and umbels) biomass recorded in this research study is 1.73±0.43 $kgDWm^{-2}$, and the maximum below-ground (rhizomes and roots) biomass recorded is 0.73±0.30 $kgDWm^{-2}$. Hence, the above-ground biomass production is much higher than the below-ground biomass production, accounting for 70.01 and 20.99% of the total biomass, respectively.

For *E. pyramidalis*, the maximum above-ground biomass recorded is 0.34±0.09 $kgDWm^{-2}$ and the maximum below-ground biomass recorded is 0.07±0.01 $kgDWm^{-2}$. Hence, the above-ground biomass production is much higher than the below-ground biomass production, accounting for 83.49 and 16.51% of the total biomass, respectively. For *T. capensis*, the maximum above-ground biomass recorded is 0.52±0.12 $kgDWm^{-2}$ and the maximum below-ground biomass recorded is 0.08±0.08 $kgDWm^{-2}$. Hence, the above-ground biomass production is relatively higher than the below-ground biomass production, accounting for 77.11 and 22.89% of the total biomass, respectively.

For *R. cochinchinensis*, the maximum above-ground biomass recorded is 0.05±0.05 $kgDWm^{-2}$ and the

Table 3. Plant biomass production in kg dry weight per m^2.

Plants species	Plant part	T1	T2	T3	Means
Cyperus papyrus	Rhizomes+Roots	0.00	0.73±0.30	0.65±0.40	0.46±0.23
	Culms	0.00	1.29±0.53	0.96±0.59	0.75±0.39
	Umbels	0.00	0.44±0.19	0.52±0.33	0.32±0.16
	Totals	0.00	2.46±0.25	2.13±0.13	1.52±0.13
Echinochloa pyramidalis	Roots	0.07±0.01	0.01±0.01	0.00	0.03±0.02
	Stems	0.26±0.06	0.07±0.05	0.00	0.11±0.08
	Leaves	0.08±0.01	0.02±0.02	0.00	0.03±0.02
	Totals	0.41±0.06	0.1±0.02	0.00	0.16±0.03
Typha Capensis	Roots	0.00	0.08±0.08	0.06±0.06	0.05±0.02
	Stems	0.00	0.14±0.14	0.01±0.01	0.05±0.05
	Leaves	0.00	0.38±0.38	0.09±0.09	0.16±0.11
	Totals	0.00	0.60±0.09	0.16±0.02	0.26±0.04
Rottboellia cochinchinensis	Roots	0.01±0.01	0.00	0.004±0.004	0.01±0.003
	Shoots	0.05±0.05	0.00	0.02±0.02	0.02±0.01
	Totals	0.06±0.02	0.00	0.024±0.01	0.03±0.01
Oldenlandia lancifolia	Roots	0.00	0.00	0.27±0.27	0.09±0.09
	Stems	0.00	0.00	0.18±0.18	0.06±0.06
	Leaves	0.00	0.00	0.66±0.66	0.22±0.22
	Totals	0.00	0.00	1.11±0.15	0.37±0.05

Table 4. Biomass production in kgDWm^{-2} as a function of Below-Ground (BG) and Above-Ground (AG) plant organs.

Plant	T1		T2		T3	
	BG	AG	BG	AG	BG	AG
Cyperus papyrus	0.00	0.00	0.73±0.30	1.73±0.43	0.65±0.4	1.48±0.22
Above-Ground / Below-Ground	0.00		2.37		2.28	
Echinochloa pyramidalis	0.07±0.01	0.34±0.09	0.01±0.01	0.09±0.03	0.00	0.00
Above-Ground / Below-Ground	4.86		9.00		0.00	
Typha capensis	0.00	0.00	0.08±0.08	0.52±0.12	0.06±0.06	0.10±0.04
Above-Ground / Below-Ground	0.00		6.50		1.67	
Rottboellia cochinchinensis	0.01±0.01	0.05±0.05	0.00	0.00	0.004±0.004	0.02±0.02
Above-Ground / Below-Ground	5.00		0.00		5.00	
Oldenlandia lancifolia	0.00	0.00	0.00	0.00	0.27±0.27	0.84±0.20
Above-Ground / Below-Ground	0.00		0.00		3.11	

maximum below-ground biomass recorded is 0.01±0.01 kgDWm^{-2}. Hence, the above-ground biomass production is relatively higher than the below-ground biomass production, accounting for 76.02 and 23.98% of the total biomass, respectively. For *O. lancifolia*, the maximum above-ground biomass recorded is 0.84±0.20 kgDWm^{-2} and the maximum below-ground biomass recorded is 0.27±0.27 kgDWm^{-2}. Hence, the above-ground biomass production is relatively higher than the below-ground biomass production, accounting for 75.84 and 24.16% of the total biomass, respectively.

The overall wetland above-ground biomass production

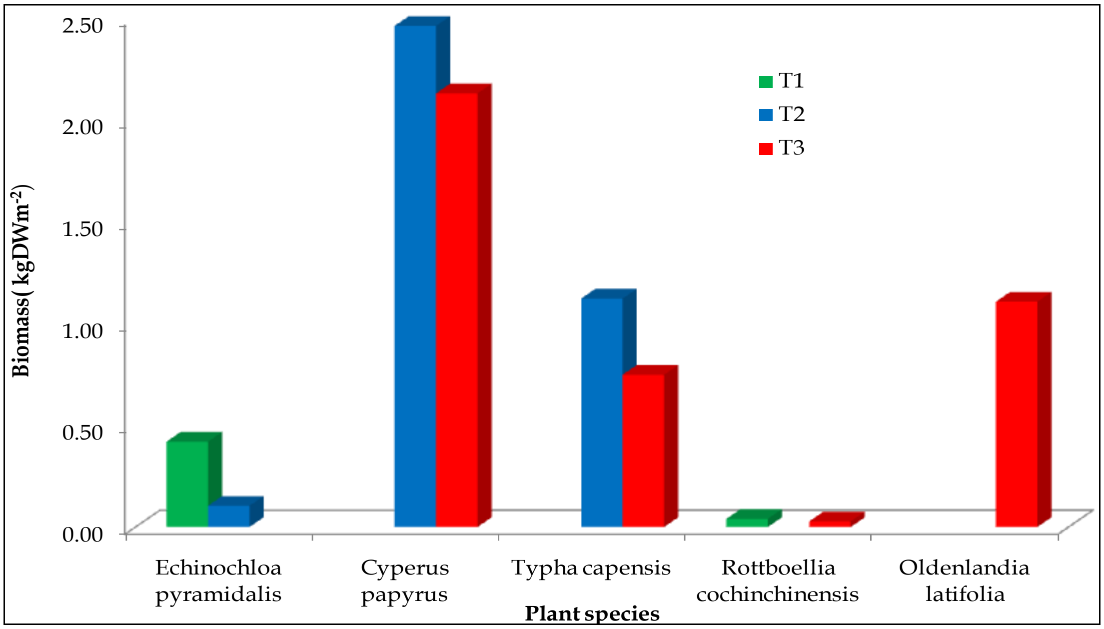

Figure 2. All most dominant plants biomass compared in the transects.

Table 5. Variation of plant biomass in the three transects.

Transect	Number of Plant Species	Biomass Means ($kgDWm^{-2}$)	Std. Dev.	Minimum ($kgDWm^{-2}$)	Maximum ($kgDWm^{-2}$)
T1	5	0.094	0.179	0	0.41
T2	5	0.072	0.106	0	0.25
T3	5	0.062	0.072	0	0.15

is 61.78% while the below-ground biomass is 38.22% of the total biomass. These findings appear to be in fairly close agreement with other earlier studies, where it has been reported that generally the above-ground organs of most natural wetland plants tend to constitute approximately 48 to 70% of the total plant biomass, and thus the below-ground biomass tends to constitute up to approximately 30 to 52% of the total biomass (Thompson and Hamilton, 1983). Also, in another study carried out by Mayo et al. (2014) in the Mara River Basin wetlands upstream of Lake Victoria in Tanzania, which unlike the Lubigi wetland do not directly receive wastewater effluents, the above-ground biomass production for *C. papyrus*, was relatively higher than the below-ground biomass production, accounting for 58.0 and 42.0% of the total biomass, respectively.

The statistical analysis was done using one-way ANOVA (Analysis of Variances) techniques, to test whether or not there is a statistically significant difference between the biomass of the plant species in the 3 transects. The variation of the minimim, maximum and standard deviations in the three transects is shown in Table 5. The general trend shows that mean and maximum plant biomass decreased from the inlet zone of the wetland towards the outlet zone. This suggests that more nutrients are available for plant growth near the wetland inlet than outlet zone.

To carry out one-way ANOVA analysis, it was hypothesized that the mean values of biomass in all three transects were equal at 5% significance level ($\alpha = 0.05$). The p-value was used to determine whether any of the differences between the group means was statistically significant at the chosen significance level ($\alpha = 0.05$). A p-value of 0.151 (Table 6) suggested that the differences between the mean biomass in the transects was not statistically significant.

Plant nitrogen content

The Lubigi wetland plants nitrogen contents data are presented in Tables 7, 8 and 9. The total nitrogen

Table 6. ANOVA analysis between and within groups.

Source of Variation	Sums of Squares (SS)	Degrees of Freedom	Mean Squares (MS)	F	Significance (P-value)
Between Groups	0.126	3	0.042	23.28	0.151
Within Groups	0.002	1	0.002		
Total	0.128	4	0.032		

Table 7. Plant Nitrogen contents in % dry weight.

Plant species	Plant part	T1	T2	T3	Means
Cyperus papyrus	Rhizomes+Roots	0.0	0.39±0.34	0.19±0.12	0.19±0.11
	Culms	0.0	0.00	0.004±0.004	0.001±0.001
	Umbels	0.0	0.65±0.41	0.48±0.22	0.38±0.19
	Total	**0.0**	**1.04±0.19**	**0.67±0.14**	**0.57±0.12**
Echinochloa pyramidalis	Roots	0.03±0.02	0.28±0.17	0.0	0.1±0.09
	Stems	0.35±0.18	0.0	0.0	0.12±0.12
	Leaves	0.72±0.45	0.62±0.5	0.0	0.45±0.23
	Total	**1.10±0.19**	**0.90±0.18**	**0.0**	**0.67±0.11**
Typha Capensis	Roots	0.0	0.03±0.03	0.08±0.08	0.04±0.02
	Stems	0.0	0.03±0.03	0.0	0.01±0.01
	Leaves	0.0	0.32±0.32	0.16±0.16	0.16±0.09
	Total	**0.0**	**0.38±0.09**	**0.24±0.05**	**0.21±0.05**
Rottboellia cochinchinensis	Roots	0.002±0.002	0.004±0.004	0.0	0.003±0.001
	Leaves	0.12±0.12	0.038±0.039	0.0	0.079±0.051
	Total	**0.122±0.06**	**0.042±0.017**	**0.0**	**0.082±0.035**
Oldenlandia lancifolia	Roots	0.0	0.0	0.028±0.02	0.01±0.01
	Stems	0.0	0.0	0.0	0.00
	Leaves	0.0	0.0	0.10±0.10	0.03±0.03
	Total	**0.0**	**0.0**	**0.13±0.03**	**0.13±0.03**

Table 8. Nitrogen content as a function of Below-Ground (BG) and Above-Ground (AG) plant organs in transects.

Plant species	T1		T2		T3	
	BG	AG	BG	AG	BG	AG
Cyperus papyrus	0.00	0.00	0.19±0.12	0.484±0.24	0.39±0.34	0.65±0.41
Echinochloa pyramidalis	0.03±0.02	1.07±0.19	0.28±0.17	0.62±0.31	0.00	0.00
Typha capensis	0.00	0.00	0.03±0.03	0.35±0.15	0.08±0.08	0.16±0.08
Rottboellia cochinchinensis	0.002±0.002	0.12±0.12	0.00	0.00	0.004±0.004	0.038±0.038
Oldenlandia lancifolia	0.00	0.00	0.00	0.00	0.02±0.02	0.10±0.05

contents vary in all the 5 most dominant plant species, and in their different organs. Figure 3 shows that the nitrogen content is highest in *E. pyramidalis*, followed by *C. papyrus* and *T. capensis. R. cochinchinensis* has the lowest nitrogen content. All the 5 most dominant plant species, had higher nitrogen contents in their above-ground organs, than in their below-ground organs. On average, the nitrogen content of the above-ground plants

Table 9. Determination of plants Nitrogen content in plant organs Below-Ground (BG) and Above-Ground (AG).

Plant species	Biomass (kgDWm^{-2})			Nitrogen Content (%DW)			Nitrogen Content (gm^{-2})		
	AG	BG	Total	AG	BG	Total	AG	BG	Total
Cyperus papyrus	0.55±0.48	0.46±0.23	1.01±0.05	0.22±0.14	0.19±0.11	0.41±0.12	121.0	87.4	208.4
Echinochloa pyramidalis	0.14±0.10	0.03±0.02	0.17±0.06	0.56±0.31	0.1±0.09	0.66±0.23	78.4	3.0	81.4
Typha capensis	0.21±0.16	0.05±0.03	0.26±0.08	0.17±0.10	0.04±0.02	0.21±0.07	35.7	2.0	37.7
Rottboellia cochinchinensis	0.023±0.015	0.005±0.003	0.028±0.009	0.038±0.038	0.004±0.004	0.042±0.017	0.9	0.0	0.9
Oldenlandia lancifolia	0.28±0.28	0.09±0.09	0.37±0.01	0.03±0.03	0.01±0.01	0.04±0.01	8.4	0.9	9.3
Means	0.24±0.09	0.13±0.08	0.37±0.17	0.20±0.09	0.07±0.03	0.27±0.12	48.89±22.57	18.66±17.19	67.54±37.91

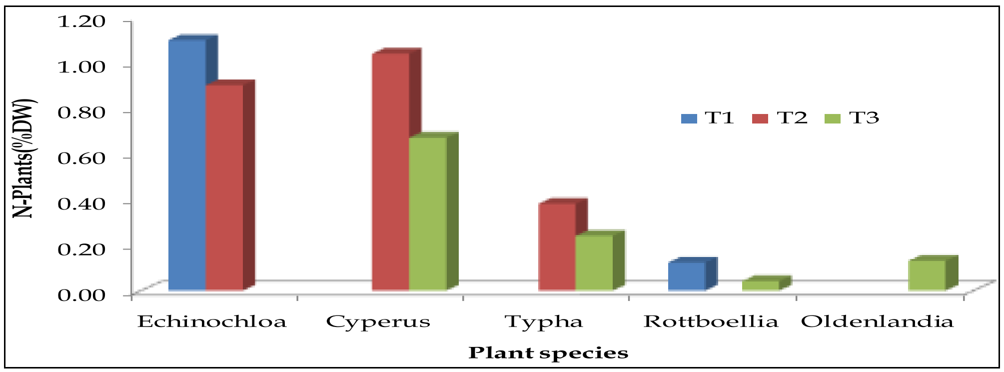

Figure 3. Nitrogen contents for all most dominant plants compared in transects.

organs is approximately 73.0%, and the nitrogen content for the below-ground plants organs is approximately 27.0% of the total plants nitrogen content. Therefore, the harvesting of these plants in a well-planned and timely manner, could make a considerable contribution to the removal of nitrogen from the wetland. Mayo et al. (2014) attributed this trend to the ability of the above-ground organs to develop inflorescence, their photosynthetic activities and their relatively higher biomass productions.

Differences in nitrogen contents in different plant organs, can be attributed to the process of nitrogen translocation, whereby nitrogen originally sequestered in mature organs is gradually recycled back to the juvenile and thus more metabolically active organs for their growth (Denny, 2008). For *C. papyrus*, Chale (1987) found the nitrogen contents of the various plant organs to be 8.4% in the rhizomes, 4.8% in the roots, 4.5% in the scales, 4.8% in the culms and 6.2% in the umbels, on dry weight basis. The rate of removal of nitrogen by plant uptake in a given wetland can be determined when the composition and the densities of the plants have been established (Mayo et al., 2014). From Table 9 the overall mean plants nitrogen content is 67.5±37.9

gNm^{-2} and this is a key essential input into the nitrogen transformation and removal model.

Sediment nitrogen content

The sediment nitrogen content in the Lubigi wetland was 0.16±0.12 g N/kg sediments in Transect T1 and 0.14±0.12 g N/kg sediments in Transect T2. However, deposition of nitrogen was more more intense at Transect T3 where 0.60±0.22 g N/kg sediments was observed. The mean content of nitrogen in the sediments was 0.30±0.15 g N/kg sediments, which is equivalent to about 157.5 $g.m^{-2}$. The sediments nitrogen contents in transects T1, T2, and T3 follow the same trend as exhibited by the plants densities in same transects. This observation can be attributed to the fact that plants densities determine the corresponding densities of their below-ground roots and rhizomes structures, which are responsible for the trapping of sediments, quantities of which determine the quantities of nitrogen and other nutrients sequestered in the sediments (Mayo et al*.,* 2014). In a study carried out by Mayo et al. (2014) in the Mara River Basin wetlands upstream of Lake Victoria in Tanzania, which unlike the Lubigi wetland do not directly receive wastewater effluents, the mean nitrogen content in the sediments was found to be 201.26±30.78 gNm^{-2}.

Conclusions

The Lubigi wetland is well-endowed with abundant vegetation, with a mean value of 10.19±4.69 plants/m^2.

The dominant plants species include *C. papyrus, E. pyramidalis*, *T. capensis, R. cochinchinensis, O. lancifolia, T. acuminate, P. scrobiculatum, Persicaria cordata* and *I. rubens*. These plants species are largely native wetland species, accounting for more than 60.0% of all the plants species recorded. The lack of showing up of colonising woody and/or early successional plants species, suggests that the Lubigi wetland is relatively stable with respect to vegetal cover. However, there is some emergence of invasive opportunistic plant species, which could distort the vegetal composition of the wetland with time. The overall mean plants and sediments nitrogen contents are 67.54±37.9 gNm^{-2} and 157.5 g/m^2, respectively, both of which are essential inputs into the nitrogen transformation and removal model, used in this research study. Based on all the foregoing conclusions, it is evident that the characteristics and macrophytes of the Lubigi wetland, play a vital role in the transformation and removal of nitrogen.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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