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Effects of water level on plant characteristics in a restored wetland and referenced natural wetland in Wakiso, Uganda

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Wetland restoration success is dependent on the likeness of both structure and function of the restored wetland systems comparable to reference sites. Assessing the success of restoration is reliant on the monitoring and evaluation of the restored system overtime as was done with Nakyesanja, a restored wetland, and Kiryagonja, a referenced natural wetland in Wakiso District, Uganda. The objectives of this study were to determine plant characteristics (species abundance, diversity, height and phytomass) in the wetlands and evaluate the effect of water level on plants establishment and phytomass accumulation. Two transects were established in each wetland with five plots measuring 1×1 m^2 on each transect. Plant species were identified in the plots while papyrus was measured and harvested. The water level was also measured in each plot. No significant difference was detected in the above ground phytomass of C*yperus papyrus* L*.* in the restored and the natural wetlands (p = 0.202). The restoration process has caused papyrus plants to accumulate productivity similar to the natural level. No significant difference was also observed in the heights of papyrus (p = 0.232). This indicated that the restoration methodology was effective on plants growth; making plants acquiring heights as their counterparts in the natural wetland. Uneven water distribution affected the growth and distribution of plants in the restored wetland. Areas of high water level got colonized with typical wetland species while areas with low water level got colonized by opportunistic plants. However, the water level was positively correlated (R^2 = 0.485, p = 0.042) with species diversity in the natural wetland making waterlogging the key determinant of macrophytic plants establishment in a natural environment. Periodic study is therefore recommended to monitor the success of the wetland restoration overtime.

Key words: Abundance*, Cyperus papyrus* L., diversity, plant species, restoration, water level, wetlands.

INTRODUCTION

Wetlands provide a large array of ecosystem services   defined as the benefits people derive from nature

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including filtering pollutants, and regulating water flows such as groundwater recharge, water availability during the dry season and minimizing flood impacts. Additionally, they supply riparian communities with basic needs such as water, construction materials, and fuel. They are used for farming, fishing, and livestock grazing. In Uganda, wetlands provide a wide range of tangible and non-tangible benefits to various communities (MWE, 2009). Over 80% of the people living adjacent to wetland areas in Uganda directly use wetland resources for their household food security needs (Turyahabwe et al., 2013). Most of the wetlands closer to urban centers have been degraded with many lost as a result of urbanization that has led to wetland reclamation which has become a key issue of discussion in natural resource governance in Uganda (Emerton et al., 1998).

The Ramsar convention defined restoration in its broadest sense, including activities that promote a return to previous conditions as well as those that improve the functioning of a wetland without necessarily seeking to return to its pre-disturbance condition (Ramsar, 2010). Restoring lost or degraded wetlands represents a valuable and cost-effective opportunity for society to recover and enhance benefits for human health and wellbeing including reduced risk from storms and other extreme events, improved food and water security, and the capacity to mitigate and adapt to climate change. Wetlands are restored for a number of purposes, including habitat replacement, water-quality enhancement, and flood minimization (Mitsch and Gosselink, 2000). Wetland restoration is needed to counteract the loss and degradation of wetland ecosystems and their benefits in many countries (Acreman et al., 2007). The catalysts for initiating wetland restoration activities are present at a number of levels, from obligations under international treaties to local opportunities and community-based initiatives. Wetland restoration has a role to play in meeting the Sustainable Development Goals, especially with regard to the environmental sustainability objectives, and also for achieving the targets under the United Nations Framework Convention on Climate Change by reducing emissions and enhancing carbon stocks in forested wetland ecosystems (Hassan et al., 2014). Experience has shown that where wetlands are degraded, poverty generally increases, escalating pressures on the remaining wetland resources and leading to further wetland degradation and poverty (Kumar et al., 2011).

A common goal of wetland restorations is creating plant diversity. There are natural wetlands that do not contain high diversity, such as those dominated by a limited number of sedge or bulrush species. Most wetland types exhibit a high degree of diversity. Often the diversity of a wetland prior to disturbance will not be equal in a restoration, but a goal of establishing a moderately diverse plant community is a first step in this direction. Restoring a diverse wetland will often provide quality habitat for a large number of species (Shaw, 2000).

In Wakiso, Uganda, a restoration order was issued for an urban degraded wetland, Nakyesanja, and implemented by the Kawanda Secondary School with engineers from the National Environmental Management Authority (NEMA) providing technical expertise. As part of directive, NEMA mandated that actions should be taken to restore the hydrology of the system and so the technicians redirected water to the restore site from upstream and open channels within the wetland to ensure distribution across the system. Papyrus was planted and used to facilitate restoration process in the wetland because of their ability to support soil structure through their thick root mat, and also their assistance to soil nourishment by their cover preventing direct sunlight as well as decay of dead leaves and other plant parts. Bulk of wetlands studies in Uganda has focused on natural pristine wetlands and constructed wetlands use for wastewater treatment (Kansiime et al., 2007). This study focused on determining the effect of wetland water level in establishing aquatic macrophytes in a restored wetland and compared that with a referenced undisturbed wetland. Giving that vegetative diversity has been the most commonly used measurement of wetlands restoration success (Ray et al., 2012), this study in addition to water level measurement focused on plant species diversity, relative abundance, height and phytomass accumulation. This research on a restored wetland will change the dynamics by adding to the current body of knowledge, and by monitoring the wetland from time to time Nakyesanja wetland could serve as a model of wetland restoration for wider dissemination in Uganda and maybe beyond.

MATERIALS AND METHODS

Description of the study areas

The wetlands studied, both restored and natural, are located in Wakiso District in Uganda on the outskirt of Kampala. The restored wetland, Nakyesanja, lies directly opposite Kawanda Secondary School in Nabweru sub-County at the following coordinates 32°32' 3.066''N and 0°24' 14.7132''E. The reference natural wetland, Kiryagonja, is located in Gombe sub-County at the following coordinates 32°29' 33.126''N and 0°30' 54.5184''E. The estimated terrain elevation above sea level for both Nakyesanja and Kiryagonja wetlands are 1160 and 1150 m, respectively (Figure 1).

Plant sampling and data collection

Two transects of 100 m long each were established 2 m from the outer edge of the natural and restored wetland. Five plots of 1 × 1 m^2 size, 25 m apart from each other, were measured on each transect. Aboveground papyrus parts (culms and umbel) were harvested from all the plots. All the culms and umbel from each 1 m^2 plot were cut into small units and put in plastic bags and their fresh weight determined on site. After determining the fresh weight from a given plot, a mixed sub-sample of 1 kg (of both culms and umbel) was then transported to the soil science laboratory at Makerere University. After drying to constant weight, the dry
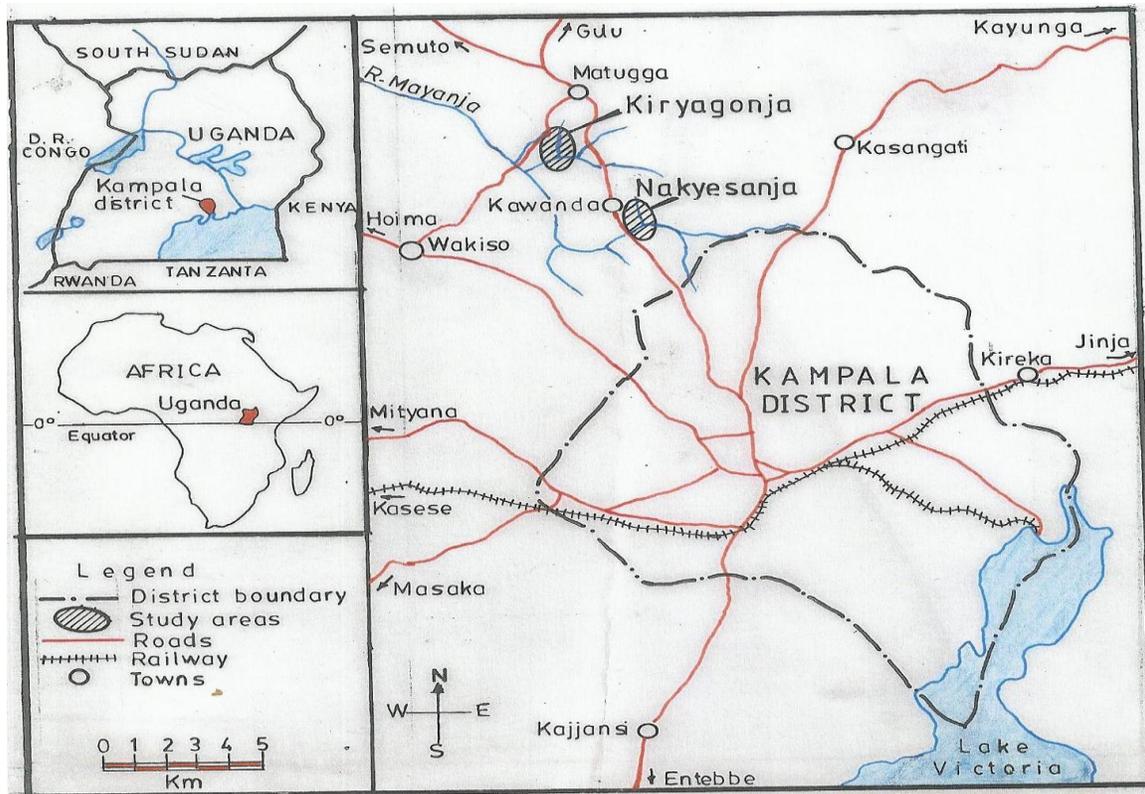
Figure 1. Map of the study areas showing the location of Nakyesanja and Kiryagonja Wetlands.

weights were then determined on the same scale used in the field. The ratio of wet weight to dry weight was used to calculate the phytomass density (kg m^{-2}) in given plots in the restored and natural wetlands.

The heights of papyrus plants harvested were recorded using a tape measure from sheath to base of umbel. The average heights of papyrus in each plot was computed and considered as the height of papyrus at a given wetland site.

Water level measurement and species identification

The water level in each plot was measured by using a calibrated auger in both restored and natural wetlands. Auger pits were dug in 10 plots in each wetland reaching the water table. The calibrated auger was partitioned into 10 cm segments using a tape measure. The auger was then placed back in the pits and observed to see where it reached the water table in each pit. Those observations were then recorded as the water level.

Plants species were identified in the same 1 m^2 plots used for phytomass assessment. This was done before the papyrus was harvested. Plant species were identified on site with the help of a botanist. Species that were not identified in the field were collected and attached on newspapers, used as plant press, using a scotch tape and taken to the herbarium at the Department of Botany, Makerere University for identification. The species names were confirmed using the International Plant Names Index (IPNI).

Data analysis

The relative abundance (RA) of the plant species was captured

Table 1. Categories of upper ranges on the DAFOR scale used to score species.

Dominant	100%
Abundant	75%
Frequent	50%
Occasional	25%
Rare	10%

using the DAFOR Scale (Scaglia et al., 2008). The DAFOR Scale enables one to determine relative abundance of species in a habitat by designating assigned percentage to species that are dominant, abundant, frequent, occasional and rare (Kent and Coker, 1992) (Table 1).

The RA of a species was calculated by dividing the sum score of that species in all 10 plots by the total score of all species in each wetland community. The relative abundance was then used to compute the species diversity using Shannon Index (H):

$$H = - \sum (P_i \times \ln P_i),$$

where (P_i) is the relative abundance of species "i" in the community (Thompson et al., 2005).

Sorensen's Coefficient of Similarity was used to determine the pattern of species turnover among successive communities. Its coefficient value ranges from 0 (complete dissimilarity) to 1 (total similarity). Floristic similarity was calculated by the following formula (Krebs, 1999).
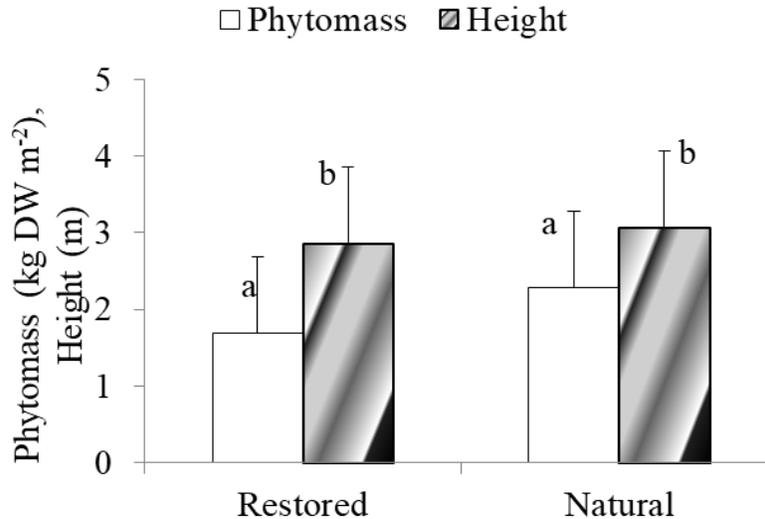
Figure 2. Mean phytomass and heights of C*yperus Papyrus* L. in a restored and natural reference wetland. Graphs with the same letters are not statistically significant. Bars represent standard error of the mean (n=20). DW = Dry Weight, m = meters.

$$Sc = [2a/(2a+b+c)] \times 100.$$

where Sc = Sorensen's similarity index, a = number of species common to both wetlands, b = number of species unique to the restored wetland, c = the number of species unique to the natural wetland.

GenStat 15th Edition for Windows was used for data analysis. All statistics were computed at a 95% confidence level $p \leq 0.05$. One way analysis of variance (ANOVA) was used to compare the parameters in both restored and natural wetlands. The parameters were phytomass density, species diversity, abundance, water level and plant height. Simple linear regression was also used to find the relationship between water level and plant characteristics (abundance, diversity, phytomass and heights) in both restored and natural wetlands.

RESULTS

Papyrus phytomass and height

The mean aboveground phytomass in the restored and natural wetlands were 1.69 ± 0.32 and 2.29 ± 0.35 kg DW/m^2, respectively (Figure 2). Papyrus was not found in two plots of the restored wetland. The papyrus planted during restoration appears to not have survived and those plots have been overtaken by other macrophytic plants.

The mean value of *Cyperus papyrus* heights in the restored wetland was 2.86 ± 0.24 m and the natural wetland was 3.07 ± 0.25 m (Figure 2).

Water level variation in the wetlands and relationship with plant characteristics

The mean water level was closer to the surface along transects of the natural wetland as compared to the restored wetland (Figure 3). Comparison of water level within transects in the restored showed significant difference (p = 0.050) while water level within transects of the natural wetlands did not show significant difference (p = 0.771). The overall comparison of water levels between the restored and natural wetlands showed significant difference (p = 0.001).

There were moderate positive correlation and significant relationship of species diversity to water level (R^2 = 0.485, p = 0.042) in the natural wetland. The regression analysis to establish the relationships between water level and other plant characteristics in the two wetlands were not statistically significant. These results indicated that the restoration process was not yet effective on water distribution across the wetland. Typical aquatic macrophytes colonized areas of high water level (37-45 cm away from the surface) in both restored and natural wetlands but areas of low water level (55-60 cm away from the surface) were colonized by others opportunistic plants that could survive fluctuating water conditions (Table 2).

The common and unique plant species in the restored and natural wetlands

The common species in the restored and natural wetland are shown in Table 3. The total number of species identified in the restored wetland was 57 belongs to 47 genera and 27 families. In the natural wetland, 43 species were identified belonging to 37 genera and 22 families. The species unique to each wetland type is shown in Table 4. There were 36 species found to be
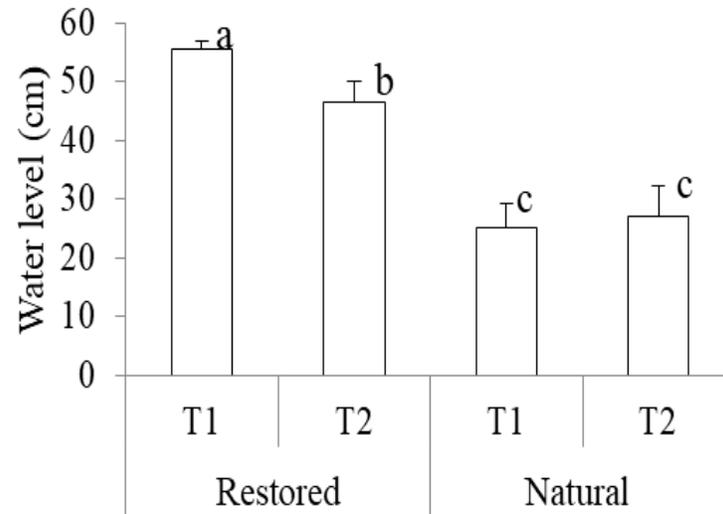
Figure 3. Mean water levels changes along transects in the restored and natural wetlands. Graphs with the same letters are not statistically different. Bars represent standard error of the means (n=20). Water level was measured from the surface downward. T1 and T2 indicate transects 1 and 2 in both wetlands.

Table 2. Summary regression statistics of water level and plant characteristics in the wetlands.

Description of the characteristics	Wetland Type	R	R^2	P- Value	SE
Water level and plant height	Restored	0.170	0.020	0.660	0.815
	Referenced Natural	0.531	0.289	0.141	0.767
Water level and phytomass	Restored	0.082	0.004	0.832	1.098
	Referenced Natural	0.502	0.223	0.167	1.086
Water level and diversity	Restored	0.314	0.029	0.409	0.199
	Referenced Natural	0.682	0.485	0.042	0.330
Water level and richness	Restored	0.237	0.056	0.508	4.028
	Referenced Natural	0.114	0.013	0.753	5.162

unique to only the restored wetland while 22 species were found to be unique to only the natural wetland. The most abundant species in the restored wetland was *C. papyrus* L. followed by *Ipomea cairica* L. and *Panicum trichocladum* Hack. ex K. Schum. The most abundant species in the natural wetland were *C. papyrus* L., followed by *Leersia hexandra* Sw. and *Christella dentata* Forssk. There were 21 species common to both wetlands. Majority of the common species (14) were more abundant in the restored wetland. Sorensen's Coefficient of Similarity calculated the similarity of the both wetlands to be 45% similar and dissimilarity to be 55% indicating the communities were more dissimilar in floristic composition.

DISCUSSION

C. papyrus phytomass in the restored and referenced natural wetlands

The average phytomass of papyrus in both studied wetlands was within the range (1.4 - 4.95 kg/m²) reported in literature for East and Central African wetlands (Chale, 1985; Muthuri et al., 1989). However, the values were relatively lower compared to previous studies (Kansiime et al., 2003; Kansiime et al., 2005; Kipkemboi et al., 2002). This could have been as a result of zero interaction between papyrus plants and wastewater supply. Perbangkhem and Polprasert (2010) found out

Table 3. The relative abundance of common plant species in the restored and natural wetland.

No	Species	Relative abundance in wetlands	
		Restored	Natural
1	*Acanthus polystachius* Delile	0.010	0.007
2	*Bothriocline longipes* (Oliv. and Hiern)	0.020	0.005
3	*Bridelia micrantha* (Hochst.) Baill.	0.005	0.030
4	*Commelina benghalensis* L.	0.020	0.005
5	*Crassocephalum vitellinum*(Benth.) S.Moore	0.026	0.005
6	*Cyperus distans* L.f.	0.026	0.005
7	*Cyperus papyrus* L.	0.164	0.179
8	*Gynura scandens* O.Hoffm.	0.010	0.009
9	*Hibiscus diversifolious* Jacq.	0.031	0.010
10	*Ipomoea cairica* L.	0.082	0.042
11	*Ipomoea whitei*	0.015	0.020
12	*Leersia hexandra* Sw.	0.026	0.114
13	*Ludwigia abyssinica* A.Rich.	0.015	0.045
14	*Momordica feotida* Schumach.	0.005	0.002
15	*Panicum trichocladum* Hack. ex K. Schum.	0.063	0.035
16	*Persicaria setosula* (A. Rich.) K.L. Wilson.	0.010	0.035
17	*Stephania abyssinica* (Quart.-Dill. and A.Rich.)	0.041	0.040
18	*Tragiabrevipes* Pax	0.005	0.002
19	*Triumfetta macrophylla* Schumann	0.015	0.005
20	*Vernonia amygdalina* Delile	0.022	0.010
21	*Zehrenia scabra*	0.036	0.016

that papyrus planted in or supplied with wastewater reach the ultimate growth rate more rapidly than those in the natural state. Kansiime et al. (2003) also reported that *C. papyrus* growing in the main path of wastewater were healthier, exhibiting long and thick culms, long umbel and dark green shoots; while those not under the influence of wastewater were stunted and yellowish green in color. In the natural wetland, over-harvesting could have been another factor responsible for the low phytomass productivity as women were seen frequently harvesting papyrus culms and umbel for commercial purpose. The phytomass productivity in both restored and natural wetlands was in the same measure as reported by Mugisha et al. (2007) while working on re-growth papyrus in Uganda found their productivity to be 1.16 and 2.24 kg DW/m^2 in Nakivubo and Kirinya wetlands, respectively and attributed that to the frequency of cutting affecting re-growth.

In the restored wetland, productivity of papyrus was higher in areas of high water level but lower in areas of low water level. Productivity at areas where water level was close to the surface (37 - 45 cm) phytomass accumulation was as high as 2.8 kg DW/m^2. Other areas with water level relatively farther away from the surface (55 - 60 cm), the phytomass accumulation dropped to 1.8 kg DW/m^2. However, these results were not sufficient to draw a conclusion that water level was a key factor determining the growth and distribution of aquatic

macrophytes especially papyrus in this study. Serag (2003) indicated that the optimum conditions for papyrus growth are the presence of adequate fresh water current, continuous flooding of the root system, and change in the hydrological regime especially water current and flooding.

Species diversity, relative abundance and water level

The study found out that the restored wetland was relatively higher in diversity with plant species as compared to the referenced natural wetland. This finding may be attributed to colonization of the restored wetland edges or landward areas by opportunistic plants where the water level was far from the surface. Species tolerant to flooding for short periods became established without problems on the edge of the restored wetland where there was occasional flooding with freshwater. Another factor contributing to the establishment of species in the restored wetland was the microtopography that existed in the wetland, creating microhabitats favoring species with different levels of tolerance to inundation (Piedade et al., 2010). The relative lower species diversity in the referenced natural wetland may also have been a result of the waterlogged condition (Brock et al., 2005) which most likely is tolerated by only macrophytic plant species. Lower diversity in the natural wetland could also be as a result of little or no disturbance (Tao et al., 2008). The

Table 4. The unique species in the restored and natural wetland.

No	Species unique to restored wetland	Species unique to natural wetland
1	*Achyranthes aspera* L. (Latjeera)	*Brachiaria decumbens*
2	*Adenostema cafrum* DC	*Christella dentata* Forssk
3	*Aeschynomene indica* L.	*Cissamperos mucronata* L
4	*Aframomum unguistifolia* K.Schum	*Commelina diffusa* Burm.f.
5	*Aspiria africana*	*Cordia* sp
6	*Aspiria kotshyana*	*Cyperus latifolious* Poir. Protologue
7	*Asystezia gangetica* L.	*Dichrostachys cinerea* Wight et Arn.
8	*Canavalia cathartica* Thouars	*Ficus vallis* chaude, Olam,
9	*Centella asiatica* L.	*Hibiscus sabdariffa* L.
10	*Cissus petiolata* Hook.f.	*Justicia* sp
11	*Clerodendrum johnstonii* Oliv	*Macaranga schweinfurnthii*
12	*Cynodon dactylon* (L.) Pers.	*Mondia whitei* (Hook.f.) Skeels
13	*Elephantopus scaber* L.	*Persicariastrigosa* (R.Br.) H.Gross APNI
14	*Eucalyptus* sp	*Peucedanum*sp
15	*Ficus natalensis* Hochst	*Phoenix reclinata* Jacq.
16	*Ficus* sp	*Polygonum* sp
17	*Glycine whitei*	*Rumex usambarensis* L.
18	*Hibiscus cannabinus* L.	*Sesbania sesban* L.
19	*Hoslundia opposite* Vahl	*Tabernaemontana crassa* Benth.
20	*Indigofera arrecta* L.	*Thumbergia alata* Bojer ex Sims
21	*Ipomea rubens* L.	*Urena robata* L.
22	*Ipomoea aquatica* Forssk.	*Waltheria indica* L.
23	*Lantana camara* L.	
24	*Mimosa pigra* L.	
25	*Ocium grantisimum* L.	
26	*Panicum maximum* Jacq	
27	*Pennisetum purpureum* Schumach.	
28	*Phyllanthus amarus*	
29	*Psidium guajava* L.	
30	*Rhynchosia stipulosa* A. Rich.	
31	*Setariasphacelata* (Schumach.) Stapf and C.E. Hubb.	
32	*Solanum mauritianum* Scop.	
33	*Solanum nigram* L.	
34	*Tridax procumbens* L.	
35	*Vernonia smithiana* Less	
36	*Virgina unguiculata* (L.) Walp.	

relative higher species diversity in the restored wetland could have also been a classic example of invasion by functionally different species following the changes in environmental filters like soil and water qualities (Mayfield et al., 2010). Stefanik and Mitsch (2012) reported high species diversity for younger restored site than mature site. Other studies have found that restored wetlands tend to have high species diversity during the monitoring period, but species diversity begins to decline with age (Gutrich et al., 2009; Balcombe et al., 2005).

The relative higher species abundance in restored wetland compared to natural wetland could have been because overtime the reference natural wetland tends to maintain and multiply only species that can withstand a waterlogged environment. This is consistent with Ho and Richardson (2013) who reported that the seasonal waterlogged conditions of restored marshes can preclude the establishment of many species that are water intolerant. The comparison of plant characteristics of restored wetland with natural wetland showed a general trend towards a mature community or ecosystem, which also has been observed in terrestrial systems (Comín et al., 2001). It is expected that with longer restoration time, species composition will increase in similarity and stability and reflect functional characteristics of a natural wetland vegetation community.

This study found out a non-significant relationship between the phytomass density and water level in the restored and referenced natural wetlands. The result of this study also concurs with Webb et al. (2012) who found inconsistent evidence to support the hypothesis that increased water level causes decrease in aboveground biomass.

Species composition in zones of the restored wetland

The middle of the restored wetland which had relatively higher water level was colonized with typical macrophytic vegetation, and those species were also common to the natural wetland. Edges of the restored wetland were established by opportunistic species. Species such as *Cynodon dactylon* were found on the landward because of its ability to survive on almost all soil types and being able to adapt to chemical stress (De Silva and Snaydon, 1995). *Achyranthes aspera* also found on the edges was established as a herb that grows in dry and seasonally flooded areas (Bussmann, 2006). Other species like *Asystasia gangetica, Hibiscus cannabinus, Indigofera arrecta* and *Panicum maximum* established at the edges because of their ability to adapt to a wide variety of conditions (Orwa et al., 2009; Akah et al., 2003; Oudtshoorn, 2002). However, exotic species like *Eucalyptus* species and *Solanum mauritianum* Scop*.* were planted by engineers on the edges of the restored wetland during the initiation phase to prevent erosion, act as a windbreak and also provide cover.

Conclusion

The restored wetland had similar plant height and phytomass of *Cyperus papyrus* L. as the natural wetland. In the restored wetland, areas with high water level got colonized with typical wetland species while areas of low water level favoured other species tolerant to fluctuating conditions. This variable condition caused the restored wetland to be more diverse and abundant in species composition than the natural wetland. The plant species associated with the restored wetland differed from the plant species found in the natural wetland but it is expected to start exhibiting resemblance similar to a natural condition if the water level becomes uniformed. It is recommended that future studies be undertaken on the development of soil properties, water quality and plant characteristics in Nakyesanja wetland in comparison to other wetlands with different hydrologic regimes to monitor the restoration progress over time.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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