



## Plant communities as indicators of anthropogenic disturbance on a peri-urban tropical wetland of Lutembe Bay wetland system, Uganda

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### ABSTRACT

Wetland degradation linked to peri-urban anthropogenic pressures is a major threat to wetland biodiversity. However, little is known of the response of biodiversity to this disturbance. Biotic indicator species are useful for assessing the health and ecological integrity of wetlands. This study evaluated patterns of plant species richness and composition, and determined species characterizing each of three differently disturbed wetland sites of Lutembe Bay Wetland, a peri-urban Ramsar Wetland of International Importance and an Important Bird Area in Uganda. The study revealed that total nitrogen decreased following wetland degradation, but total phosphorous was not affected; pH values were <5.5, while OM content was low in the lightly and heavily (2.5–4.4%) degraded sites. While plant species richness did not differ among the sites, total species richness was higher in heavily disturbed, compared to lightly disturbed and relatively intact sites. Community composition differed significantly among the three sites. Indicator plant species were then identified which could be employed as a rapid assessment tool to infer the level of degradation in the sustainable management of Afrotropical wetlands by practitioners. Results show that continued unsustainable use of wetlands results in changes in soil properties and plant species composition, highlighting the need to restore anthropogenically disturbed parts of wetlands and to prevent further degradation of less degraded areas.

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Anthropogenic disturbance; biodiversity; degradation; ecotone; peri-urban wetland; plant species richness



## 1. Introduction

Globally, wetlands are considered an important and valuable asset to humanity because of their numerous ecosystem functions and values, such as wastewater filtration, nutrient retention, flood protection and storm protection, carbon sequestration and maintenance of wildlife habitats (Alikhani et al., 2021; Asumadu et al., 2023; Kaffashi et al., 2013; Saunders et al., 2012; Twesigye et al., 2011; USEPA, 2013). Anthropogenic disturbance particularly agriculture practices influence the quality and quantity of wetland species composition. Achieng et al. (2023) point out that very few studies focus on relationships between biodiversity and ecosystem change in Afrotropical wetlands except for reports from international organisations which tend to be generic, often with gaps in scientific evidence.

In Africa, various strategies established as efforts to preserve wetlands have continued to be challenged. Mkonda (2022) explains reasons for unsustainable management of Akagela wetland despite the various

strategies to conserve this vital ecosystem. Furthermore, Bosma et al. (2017) revealed different perceptions between different wetland resource users which pose challenges to sustainable wetland management. While papyrus harvesters, beekeepers, fishermen, wetland non-users, and hunters associate the largest livelihood benefits with a wetland conservation scenario, farmers and government officials perceive increased agricultural production in the wetland area to be more livelihood enhancing (Bosma et al., 2017). Similarly, Businge (2017) reported the main drivers of wetland degradation as agricultural activities, overharvesting of wetland resources and infrastructure development. The same study highlights socio-political dynamics and climatic changes as closely related to main drivers of wetland degradation.

In Uganda, wetlands cover about 11% of the total surface land area, and they provide a wide variety of biophysical and socio-economic functions (UNDP, 2016; Barakagira & de Wit, 2019). Despite their importance, however, in recent years, wetlands in Uganda

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have continuously come under increasing anthropogenic degrading pressures, and their coverage has been gradually shrinking due to drainage for agricultural development, excessive exploitation by local populations and infilling for construction of both residential and industrial development (Byamukama & Kiyawa, 2019; Finlayson, 2007; Kadoma et al., 2023; Ndiyoi & Wood, 2008; Zhang et al., 2006). These activities have, in many cases, drastically reduced the wetlands' capacity to perform ecological functions (Malick, 2004; Kabiri et al., 2020; Kakuru et al., 2013). For this reason, there is a need for studies on the anthropogenic degradation and restoration of tropical wetlands (Mehari, 2023; WRI, 2005). The Lutembe Bay is a typical Afrotropical wetland experiencing rapid and widespread degradation, conversion to other land uses and natural areas are increasingly becoming irreversible (Kadoma et al., 2023). Many sections of this peri-urban wetland have been converted to industrial use or have gradually been taken over by semi-slum residential housing and commercial floriculture farmers.

Although there is an urgent need to prevent wetland loss and degradation in this biodiversity hotspot, the effects of anthropogenic degradation on physico-chemical soil properties and patterns of plant species communities within the Lutembe Bay Wetland have been under-studied, and standardized plant species to monitor their ecological conditions is lacking.

The present study assessed how wetland plant species richness and community composition vary among wetland sites with different intensities of disturbance on the transitory peri-urban Lutembe Bay Wetland. This study predicted that in response to the wetland degradation, the composition of plant communities will change as a result of differences in the species' colonization ability (Mohler et al., 2006) and changes in soil chemical properties and hydrological regimes (Engida et al., 2021;

Zhang, 2012, Zhang et al., 2023). Furthermore, the study assessed which wetland plant species are characteristic of each anthropogenically disturbed and relatively undisturbed/intact adjacent wetland sites. A rapid identification of these indicator species during a transect walk by wetland managers can form the basis of appropriate sustainable Afrotropical wetland management planning.

## 2. Materials and methods

Figure 1 illustrates a flow chart summarizing the research methodology. Details of the methodology follow in sections 2.1 to 2.4.

### 2.1. Study area

The research was performed in the Lutembe Bay Wetland, Uganda (Figure 2). The Afrotropical wetland (latitude 00° 10' N and longitude 32° 34' E) is situated in Wakiso District (central Uganda) in the sub-counties of Ssisa and Katabi, and in the parishes of Namulanda, Bweya and Kisubi. It covers about 98 ha (Kalema, 2005; WMD, 2015) and is located approximately 25 km south of Kampala (Uganda's capital city), at altitudes ranging from 1140 to 1160 metres above sea level. The mean annual rainfall is 1320 mm, though in many areas of the lake zone it ranges between 1750 and 2000 mm. Lutembe Bay is a Ramsar site (No. 1637) and an Important Bird Area (IBA). It is situated at the Murchison Bay (also known as the mouth of Lake Victoria), between Kampala and Entebbe urban areas where the Kinawataka Stream flows into Lake Victoria and has several tributaries draining into it from, for example, Lumpewo, Kisubi bay and Kachindo wetlands. This shallow area is almost completely cut off from the main body of Lake Victoria by *Cyperus papyrus* islands.

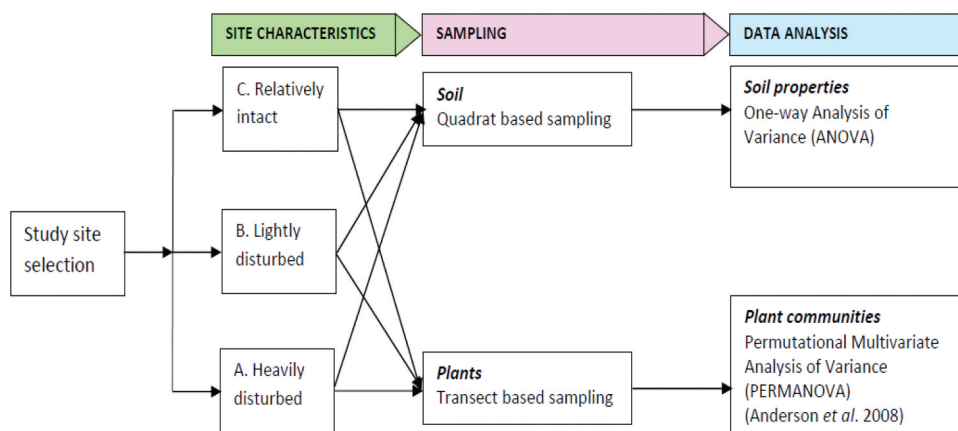
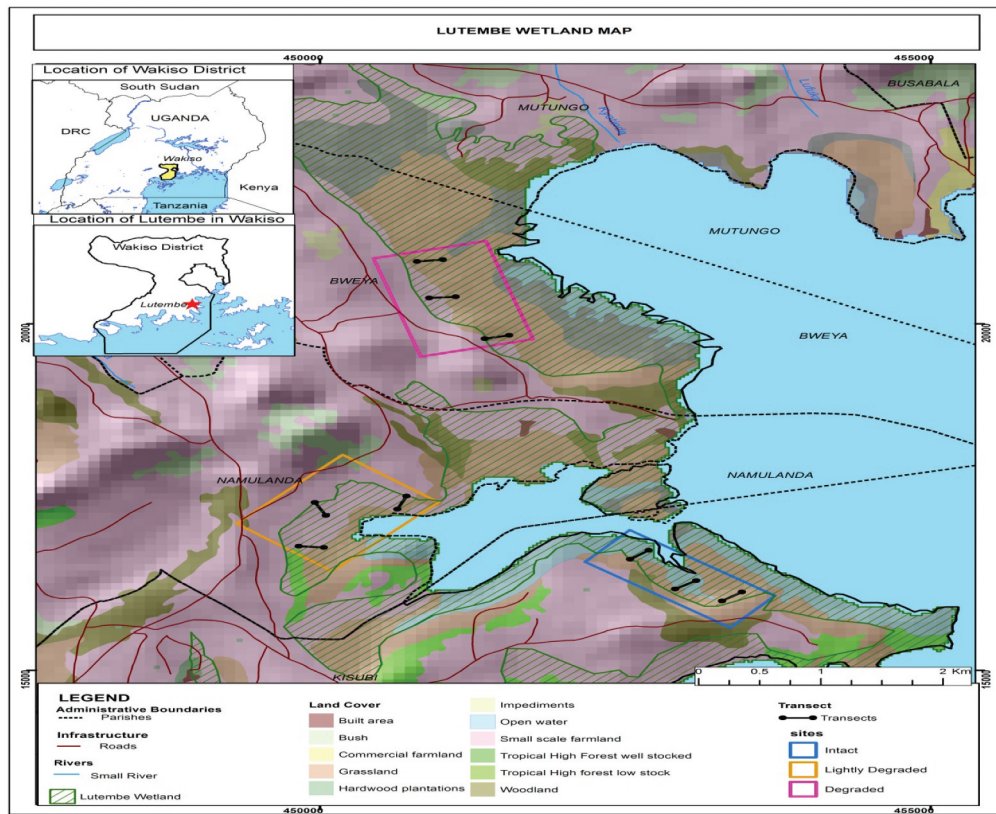


Figure 1. Flow chart of research methodology used in the study (authors construct).



**Figure 2.** Location of transects and study sites in the Lutembe Bay Wetland, Uganda (adapted from WMD, 2015).

Lutembe Bay Wetland has been affected by industrial and commercial developments and conversion of land for agriculture and settlements, and sand and clay mining. Some parts on the northwest of the landward side of Lutembe Bay Wetland have been recently cleared for horticultural farming, hence resulting in reduction in wetland cover, changes in wetland hydrology, pollution and sedimentation. With urban populations increasing, food production from the uplands cannot meet increasing food demand due to soil exhaustion and reduced fertility associated with the upland farming; thus, wetlands are seen as the most coherent environment in which to close this gap (Tijani et al., 2011).

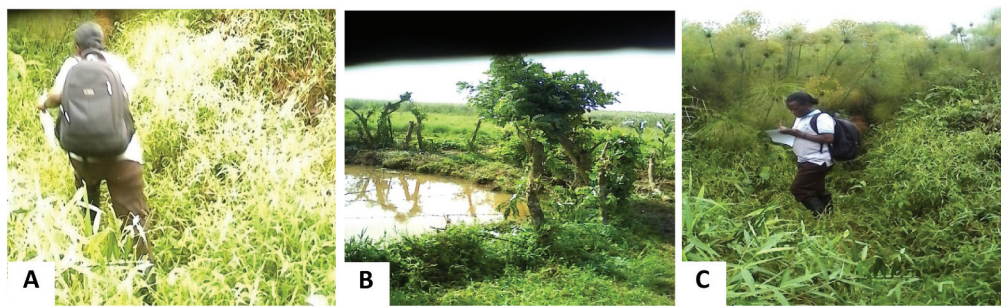
Although there is an urgent need to prevent wetland loss and degradation in this biodiversity hotspot, the effects of anthropogenic degradation on physico-chemical soil properties and patterns of plant species communities within the Lutembe Bay Wetland have been under-studied, and standardized plant species to monitor their ecological conditions is lacking. Since most studies published have been on wetlands either outside the Afrotropical realm (Behn et al., 2018), or require multiple variables not routinely assessed by wetland management field practitioners (Behn et al., 2018; Macfarlane et al., 2020), this is a common knowledge gap in Afrotropical wetlands. This study was designed to

address the knowledge gap, providing wetland managers with indicator plants to rapidly infer the level of degradation of a wetland for evidence-based management.

## 2.2. Site selection

Soils and plant species were sampled from three differently disturbed wetland sites, i.e. the lightly disturbed located in Namulanda Parish, heavily disturbed in Bweya Parish and relatively intact site in Kisubi Parish (Figure 3). These sites were identified based on the topographic map and Google Earth remote sensing imagery of Lutembe Bay Wetland.

In the context of this study, the definition of wetland degradation followed Harding (2005) and was based on the percentage cover of wetland perimeter with native and exotic vegetation plant species. A heavily disturbed wetland was defined as a wetland with <30% of native vegetation cover and with  $\geq 75\%$  of exotic species (Harding, 2005). A lightly or moderately disturbed wetland was defined as a wetland having between 30% and 75% native vegetation cover with few exotics, whereas a 'relatively intact wetland' was defined as a permanent wetland with  $\geq 75\%$  of native vegetation cover. An ecotone was defined herein as a wetland area within the 200 m boundary



**Figure 3.** (A) Heavily disturbed with food crop cultivation, (B) lightly disturbed with a fishpond, and (C) relatively intact wetland of Lutembe Bay (author shown in photos for scale).

of the low water mark (The Uganda National Environment-Wetlands, River Bank and Lake Shores Management regulations, No. 3/2000, under section 107 of the National Environmental Act Cap 153).

### 2.3. Vegetation and soil sampling

In each study site, three transects of 100 m long were established. Six plots (quadrats) of 2 m × 2 m were laid systematically on alternating sides along each transect, separated by a distance of 16 m, resulting in 18 plots per site. Within each quadrat, the plant species occurring were identified and recorded. The majority of the plant species were identified in the field by a qualified botanist, and for a few cases the voucher specimen was collected and identified at the Makerere University Herbarium. The plant species and family names were confirmed using the online database Tropicos ([www.tropicos.org](http://www.tropicos.org)) and the APG IV (2016) respectively.

Samples of soil were systematically collected from three quadrats, i.e. from the first, third and sixth quadrats along each transect. Soil samples were scooped from a depth of 10 cm using a 2-cm-diameter soil auger. The samples from the three plots were thoroughly mixed to yield one composite sample per transect (resulting in nine soil samples, three samples per study site). Samples were air-dried for 48 h to halt biological transformation, ground with a pestle and mortar, and sieved through a 2-mm-mesh screen to remove coarse debris and stones. The air-dried soil sample from each transect were analysed for pH (measured by a digital pH meter in a suspension of 1:2.5 soil:water ratio), particle size or texture (Hydrometer method), organic matter (OM; potassium dichromate wet acid oxidation method), N (Total N by Kjeldahl method digestion), Average available P (Bray P1 method) and the exchangeable bases (Al, K, Na by Flame Photometry; Ca and Mg by Atomic Absorption Spectrophotometry). The soil analyses were conducted at the Soil Science Laboratory of Makerere University, Kampala.

### 2.4. Data analysis

One-way analysis of variance (ANOVA) with Tukey's HSD test was used to determine the statistical significance of locations on soil physico-chemical properties. To assess sample completeness and to compare patterns of total wetland plant species richness among the three study sites (heavily disturbed, lightly disturbed, and relatively intact), we generated sample-based species accumulation plots (and their 95% confidence intervals) with Estimate S 9.1 (Colwell, 2013). For each study plot, the number of species per plot (species density) was calculated with PRIMER-E, version 6 (Clarke & Gorley, 2006). Differences among the three sites in species density were tested with one-way ANOVA followed by Tukey post-hoc tests with IBM SPSS Statistics, Version 23 (IBM Corporation, Armonk, NY, USA).

The study employed a Permutational Multivariate Analysis of Variance (PERMANOVA) + routine of program Primer-E, with distance Jaccard Similarity Index (Anderson et al., 2008) to determine whether there were differences in plant communities among the three wetland sites. PERMANOVA was conducted with 999 random permutations using method 'unrestricted permutation of raw data' and Type III sums of squares. The Non-metric MultiDimensional Scaling (NMDS) ordination was used to visualize the patterns in plant community composition among the three study sites. NMDS was performed using species presence-absence per site matrix and the Jaccard Index similarity matrix. To assess the variance represented by each axis, we calculated the coefficient of determination (expressed as a percentage) between distances in the ordination space and distances in the original space using the Jaccard similarity matrix (McCune & Grace, 2002). A similarity percentages routine (SIMPER, in PRIMER-E, version 6 (Clarke & Warwick, 2001)) was used to identify plant species that contributed most to the average dissimilarity between paired sites.

To identify wetland plant species that characterize each of the sites, calculations were based on a simplified indicator species analysis based on binary (presence-absence) data (Bakker, 2008), using the formula proposed by Dufrêne and Legendre (1997) as follows:

$$\text{Indicator species (IV}_{ij}) = A_{ij} \times B_{ij} \times 100$$

Where  $A_{ij}$  is the positive predictive value of a species (also called specificity) calculated as  $= n_{ij}/n_i$ , where  $n_{ij}$  is the number of samples in group  $j$  occupied by species  $i$ ,  $n_i$  is the total number of samples occupied by species  $i$ .  $B_{ij}$  is the relative frequency of the species, and is calculated from the formula  $= n_{ij}/n_j$ , where  $n_{ij}$  is the number of samples in group  $j$  occupied by species  $i$ , and  $n_j$  is the total number of samples in group  $j$ . Indicator Values (IV) range between 0 and 1, with higher values for stronger indicators. Only species with  $IV > 0.25$  were considered good indicators (Dufrêne & Legendre, 1997).

### 3. Results

#### 3.1. Soil physico-chemical properties

Table 1 shows the soil pH range and the mean values of the nutrients for the three wetland habitat sites and Table 2 shows the actual values of soil parameters. Results were compared with the critical levels recommended by Okalebo et al. (2002). The pH values significantly differed only marginally ( $p = 0.046$ , Table 1) among the three wetland sites. The soil pH of all the sites was less than 7 and ranged from 4.6 in the relatively intact wetland site to 5.9 in the heavily degraded site. The pH values at the relatively intact wetland site were within the recommended range (5.5-6.5) while for the heavily degraded site all the pH values were within the recommended range. However, for the lightly degraded site, all the pH values were generally below the recommended range.

The nitrogen content showed a highly significant difference ( $p = 0.024$ ) among the three wetland sites. The total nitrogen content ranged from 0.15% in the heavily degraded wetland to 0.25% in the lightly degraded wetland. A pairwise comparison indicated that there was no significant difference in the mean values between the relatively intact and lightly degraded sites. However, the lightly degraded site recorded a higher nitrogen content than the heavily degraded site ( $p < 0.05$ , Tukey HSD). Generally, the nitrogen content was slightly above the recommended critical value of  $>0.2\%$  in the relatively intact wetland, whereas it was below the recommended levels in both the heavily degraded and lightly degraded sites (Table 2). There were no significant differences in the mean values of

Sand, Clay, Sodium, Magnesium, Potassium, Calcium and average Phosphorous among the three wetland sites (Table 2). All the transects in the three sites had below the recommended Potassium levels ( $>3$  moles/kg) in the soil. The results revealed a similar trend for Calcium, Magnesium and Sodium. However, for Phosphorous, the values were above the recommended levels of  $>15$  ppm in the heavily degraded site. In the relatively intact site, Phosphorous was generally low, i.e. below the recommended level of  $>15$  ppm. The Phosphorous concentration in the rest of the sites was above the critical limit of  $>15$  ppm (Table 2). The Organic Matter content varied significantly among the three sites ( $p = 0.022$ ). The mean values of Organic Matter content ranged from 4.4% in the lightly degraded site to 2.5% in the heavily degraded site, respectively. The Organic Matter content in both the lightly and heavily degraded sites was below the recommended level of 3%, but it was above the recommended level (3%) in the relatively intact wetland. The mean values for silt in the heavily degraded sites were significantly higher than in the lightly degraded and relatively intact wetland sites (Table 1).

#### 3.2. Wetland plant communities and potential indicator species

A total of 114 plant species, representing 33 families, were sampled in the 54 plots (Table A1 in Appendix). The species accumulation curves of the three study areas nearly reached asymptotes for all the three sites (Figure 4). Based on the eighteen samples of rarefied species richness (the largest shared number of plots across study areas) and their 95% confidence interval (CI), the total species richness was significantly higher in the heavily disturbed and in the lightly disturbed wetland sites compared to the relatively intact wetland (Figure 4). However, there was no significant difference in the plant species density among the three wetland sites (one-way ANOVA:  $F_{2, 51} = 2.2$ ,  $p = 0.119$ ).

The community composition of plants differed significantly among the three wetland sites (PERMANOVA, pseudo- $F_{2,51} = 7.8$ ,  $p = 0.001$ , stress = 0.18) as illustrated by the NMDS ordination (Figure 5), and wetland site explained 38% of the variation in communities of plants. The first two axes of this ordination accounted for 35% of the variation (axis 1 = 23%, axis 2 = 12%). According to the pair-wise tests, all wetland sites differed from each other significantly ( $p < 0.001$ ). From SIMPER analysis, three plant species that made the strongest contributions to differences in the species composition between the heavily disturbed and lightly disturbed wetland sites were *Bidens pilosa* (4.9%),

**Table 1.** Soil pH range and statistical significance of the effects of sites on soil properties based on one-way ANOVA (ns = not significant; s\* = significant with  $p < 0.05$ ; s\*\* = significant with  $p < 0.01$ ). Values are means  $\pm$  SE

Habitat type	Soil pH range	Organic Matter %	Average P ppm	Ca me/100g	K me/100g	Mg me/100g	Na me/100g	N %	Silt %	Clay %	Sand %
Heavily degraded	5.6 – 5.9	2.51 $\pm$ 0.1a	30.84 $\pm$ 6.4a	5.87 $\pm$ 0.2a	0.55 $\pm$ 0.07a	2.27 $\pm$ 0.2a	0.13 $\pm$ 0.02a	0.15 $\pm$ 0.01a	18.67 $\pm$ 2.4a	33.33 $\pm$ 0.7a	48.0 $\pm$ 2.3a
Lightly degraded	4.8 – 5.6	4.44 $\pm$ 0.6b	20.41 $\pm$ 11.2a	4.07 $\pm$ 0.1a	0.97 $\pm$ 0.14a	1.94 $\pm$ 0.3a	0.25 $\pm$ 0.06a	0.25 $\pm$ 0.06b	8.67 $\pm$ 0.7b	40.0 $\pm$ 2.3a	51.3 $\pm$ 2.9a
Relatively intact	4.6–5.1	2.61 $\pm$ 0.2a	8.23 $\pm$ 7.0a	4.50 $\pm$ 0.9a	0.57 $\pm$ 0.05a	2.05 $\pm$ 0.6a	0.18 $\pm$ 0.09a	0.18 $\pm$ 0.09ab	9.33 $\pm$ 3.6b	28.67 $\pm$ 7.7a	62.0 $\pm$ 8.7a
Significance	ns	s*	ns	ns	ns	ns	ns	s*	s**	ns	ns

**Table 2.** Soil analysis results in the three study wetland sites (mean values from transects)

Wetland sites	pH	OM %	N %	P ppm	Na cmol/kg	K cmol/kg	Ca cmol/kg	Mg cmol/kg	Sand %	Silt %	Clay %	Class
Heavily degraded	5.80	2.51	0.15	30.84	0.13	0.55	5.87	2.27	48.0	18.7	33.3	Sandy Clay Loam
Lightly degraded	5.06	4.44	0.26	20.42	0.10	1.07	4.07	1.94	51.3	8.7	40.0	Sandy Clay
Relatively intact	5.07	2.61	0.18	8.23	0.14	0.57	4.50	2.05	62.0	9.3	28.7	Sandy Clay Loam
Critical Levels*	5.5–6.5	>3	>0.2	>15	–	>300	>2400	>180	–	–	–	–

\*Okalebo et al. (2002).

*Commelina benghalensis* (4.2%) and *Cyperus papyrus* (4.0%). *Pteridium aquilinum* (4.6%), *Cyperus papyrus* (3.8%) and *Leersia hexandra* (3.7%) contributed most to the observed differences between the lightly disturbed and relatively intact sites. The plant species that made the strongest contributions to differences between the heavily disturbed and relatively intact sites were *Bidens pilosa* (5.1%), *Pteridium aquilinum* (4.1%), *Commelina benghalensis* (3.9%) and *Cyperus papyrus* (3.8%).

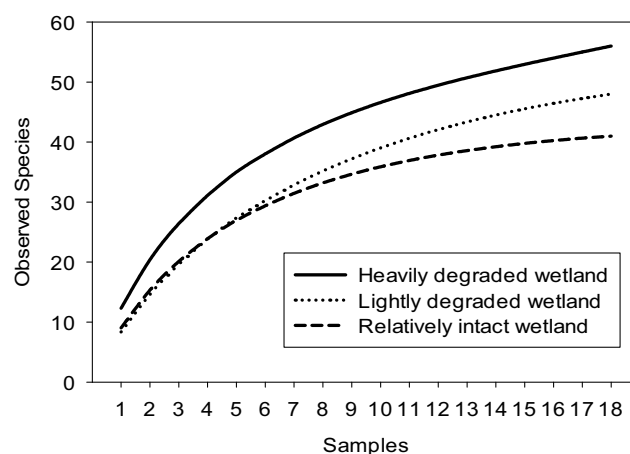
Dufrêne-Legendre Indicator species analysis showed that three species, namely: *Cyperus papyrus* (indicator value, IV = 0.33), *Pultenaea setulosa* (0.33) and *Fuirena umbellata* (0.25) (13% of total indicator species in all the sites) characterized the lightly disturbed wetland site (Table 1). Thirteen plant species (57% of the total indicator species) characterized the heavily disturbed site; the strongest indicators included *Bidens pilosa* (0.69), *Commelina benghalensis* (0.67) and *Ageratum conyzoides* (0.52) (Table 1). Others included: *Euphorbia heterophylla* (0.45), *Phragmites mauritanus* (0.41), *Digitaria abyssinica* (0.34), *Amaranthus hybridus* subsp. *cruentus* (0.33), *Kyllinga alba* (0.33), *Leersia hexandra* (0.31), *Adenostemma caffrum* (0.28), *Cyperus luteus* (0.28), *Glycine wightii* (0.28) and *Cyperus cyperoides* (0.27) (Table 1). Seven species (30% of the total indicator species), namely, *Pteridium aquilinum* (0.52), *Spermacoce latifolia* (0.39), *Miscanthus violaceus* (0.30), *Cyphostemma adenocaulum* (0.29), *Cyperus papyrus* (0.28), *Pentarrhinum insipidum* (0.28) and *Phyllanthus niruri* (0.28) characterized the relatively intact wetland site (Table 1).

## 4. Discussion

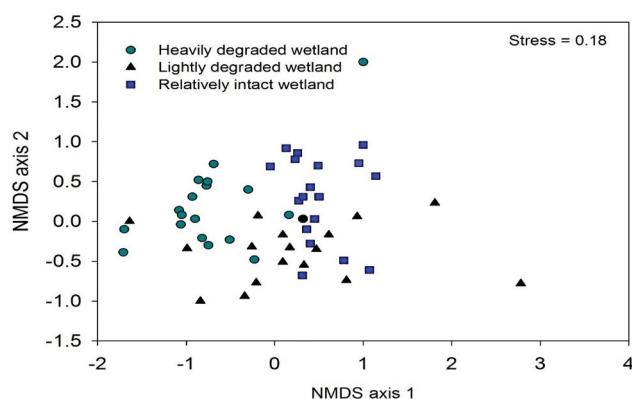
### 4.1. Effect of degradation on soil physico-chemical characteristics

The lower values of OM and the rest of the soil parameters tested in the three wetland sites could be due to the presence of human activities (in the relatively degraded and heavily degraded sites) or past human activities in the relatively intact wetland. The impact of human activities, especially cultivation, has also been reported in the Lubigi Wetland and elsewhere

(Kadoma et al., 2023; Omagor & Barasa, 2018; Nyombi, 2008). Clearing of the wetland vegetation exposes the land to solar radiation resulting in increased temperatures, groundwater loss, and eventually rapid decomposition of organic matter (Salimi et al., 2021). In agreement with results of this study, a decrease in organic matter content was similarly observed under conversion of salt marshes to dry lands in a similarly



**Figure 4.** Sample-based rarefaction curves for the three wetland sites in the Lutembe Bay Wetland, Uganda. Samples represent total plant species recorded in each quadrat.



**Figure 5.** Non-metric MultiDimensional Scaling (NMDS) ordination of plant communities using species presence-absence data and a Jaccard distance matrix among the three wetland sites in the Lutembe Bay Wetland in Wakiso, Uganda. Each point is a single plot ( $n = 18$  for each wetland site).

degraded environment elsewhere (Li et al., 2022; Mirabito & Chambers, 2023). In addition, several previous studies (Asongwe et al., 2016; Głowacz & Niżnikowski, 2018; Hailu et al., 2020; Osinuga & Oyegoke, 2019) have shown that replacement of natural vegetation with agriculture or grazing often leads to destabilization of soils. Consequently, various forms of anthropogenic habitat transformation in the heavily degraded wetland might explain the high sediment/silt inputs through increased surface runoff flows and erosion during rain events. Overall, the wetland degradation is consistent with results of the significant change in the percentage of silt among the three sites (Table 2).

Results in a pH range of 4.6 to 5.9 reflect a suitability for maximum phosphorus availability to plants, soil moisture content, Phosphorus-absorbing capacity of soils and the clay contents (Tisdale and Rucker 1964 in Okalebo et al., 2002). Hence, total nitrogen decreased markedly following wetland degradation, but total phosphorous (an indicator of soil fertility) was not affected. The total Nitrogen (Table 2) was generally low to medium following the ratings provided by Landon (1984), where values below 0.2% are low, between 0.2% and 0.5% medium, above 0.5% high. The total nitrogen content was low in the relatively intact and the heavily degraded but moderate in the lightly degraded sites. The low to moderate Nitrogen content indicates that the soils are very poor. These results are consistent with those of Li et al. (2014) and Ye et al. (2022), in coastal wetlands of northern China, where long-term reclamation significantly decreased total nitrogen at the surface layer (0–30 cm) but had no significant effect on total Phosphorous. The soil storages of total Nitrogen and total Phosphorous are a counterbalance of inputs (such as productivity and fertilizer) and outputs (e.g. loss of mineralization and harvest) during a certain period. The rate of inputs and outputs in soils is sensitive to environmental changes and human disturbances.

Wetland degradation substantially alters the soil environmental conditions by breaking the balance of inputs and outputs. Thus, the decrease in total nitrogen observed in this study suggests that the outputs were much larger than inputs. The reasons for the identified difference in total phosphorous among the three wetland sites can be attributed to application of fertilizers during cultivation of crops, especially in the heavily degraded and lightly degraded wetland sites. Additionally, phosphorous has poor mobility and is easily fixed in the soil when the pH is high or low. The input and output of Phosphorous in the soil is usually a result of fertilizer application and crop harvesting, respectively (Jamal et al., 2023; Lu et al., 2020). Thus,

results of the difference in the impacts of wetland degradation on total Phosphorous may be explained by fertilizer application and crop harvesting in the wetlands.

#### **4.2. Effect of degradation on wetland plant communities and identification of indicator species**

The results indicate that wetland degradation significantly increased the total plant species richness. This finding tends to suggest that following degradation, several new species emerge as secondary vegetation. This result coincides with a study in South-Bench district, Southwest Ethiopia (Mulatu et al., 2014), where a higher number of species (48 species) were recorded in cultivated wetland site than in the uncultivated sites (29 species). According to Tijani et al. (2011), emergence of secondary vegetation introduces several other new species into the wetland ecosystem. These new species mostly emerge after human activities such as farming, brick making, construction, and other practices that result into clearance of native vegetation. Like Nyombi (2008), Omagor and Barasa (2018) reported that after several seasons of cultivation in the Lubigi Wetland (another tropical wetland in Uganda), several weeds such as *Bidens pilosa* and *Commelina benghalensis* subsequently emerged. Furthermore, a new grass species *Vossia cuspidata* also emerged due to the altered hydrology (i.e. fluctuation in water level, depths and duration of water detention) of the wetlands. Species richness may increase tropical wetland plant community resilience after disturbance (Carvalho et al., 2013), and this will need to be studied further in the Lutembe Bay Wetland. However, one major limitation of this study was that only one observation site was sampled for each wetland degraded site. Nevertheless, our observation sites demarcated were large enough and were well sampled. According to Hulbert (1984), in studies involving very large-scale systems (i.e. whole wetland system) such as this study when replication is costly, experiments involving unreplicated sites may be the only option.

Additionally, the results provide evidence that anthropogenic wetland degradation can lead to changes in wetland plant species composition. Such compositional differences could be due to differences in the species-specific traits (Suding et al., 2008; Wang et al., 2022); for example, the recolonization efficiency of individual plant species, and the extent and degree of degradation among the sites. These results are consistent with others (Chen et al., 2019; Hotaiba et al., 2023; Imdad et al., 2023; Li et al., 2014; Mohler et al., 2006) who present evidence that wetland vegetation types and species compositions can be used to assess ecosystem health and the wetland's ability to fulfill ecological functions. Thus, impacts on the

hydrological regime—especially changes in water level, flood frequency and duration mainly through digging of drainage channels and reduction in groundwater—can, in turn, affect wetland vegetation (Engida et al., 2021; Phethi & Gumbo, 2019; Zhang et al., 2023), and wildlife habitats (Hatamkhani & Moridi, 2023). In conjunction with all the above, studies by Vesselly et al. (2022) in Uganda, and Kalema (2008) in Africa's Sio-Siteko trans-boundary wetland ecosystem between Kenya and Uganda, noted significant variations in the composition of plant communities across encroached and intact wetlands, including those that were within the same locality.

Finally, the results showed that different wetland sites in Lutembe Bay are characterized by different specific wetland plant species, which could be employed in future wetland management, especially in Afrotropical areas. Applying this finding to rapidly assess a wetland and infer the level of degradation for evidence-based management is a new observation. The heavily disturbed site was characterized by early successional wetland annuals such as *Bidens pilosa*, perennial species *Commelina benghalensis* and the introduced/invasive *Ageratum conyzoides*, agreeing with results from studies in other wetlands (e.g. Napaldet & Buot, 2019; Twesigye et al., 2011). Meanwhile, the relatively intact and lightly disturbed sites were characterized by native perennial emergent macrophyte sedges, *Cyperus papyrus* and *Miscanthidium violaceum*, which are known to dominate in permanently flooded swamps in tropical Africa (Kayima & Mayo, 2018; Saunders et al., 2012; Twesigye et al., 2011).

## 5. Conclusion and policy implications

The present study has revealed that continued unsustainable wetland degradation can lead to changes in soil properties and plant species composition, emphasizing the need to restore the anthropogenically disturbed parts of the wetlands and to prevent further degradation of less degraded areas. Differently disturbed wetland sites in Lutembe Bay are characterized by different specific wetland plant species, which could be employed as indicator species in future sustainable wetland management, especially in Afrotropical areas.

While most of the soil properties (pH, OM, N, P, Na, K, Ca and Mg) were identified to be below or within the recommended ranges; the most affected wetland study site was the 'heavily degraded' which confirms a correlation between wetland degradation and loss in soil nutrient status. Where there was observed degradation of the natural wetland, there was also evidence of cultivation of crops; this implies that the degradation was

a result of human activities rather than natural causes. The study highlights that anthropogenic disturbance is one of the main reasons for wetland degradation.

Based on the findings, strategic restoration efforts of wetlands can be undertaken. Information generated by this study can enrich a Wetland Information System to be useful in the formulation of scientifically sound management conservation strategies based on the rapid identification of indicator species to infer and categorize degradation status. Similar approaches can be used for other Afrotropical wetlands for which information is lacking.

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## Data availability statement

All related data is contained within the article.

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## Appendix

**Table A1.** Wetland plant species and their Dufrêne and Legendre's (1997) indicator value indices (IndVal) in each study site in the Lutembe Bay Wetland, Uganda. Indicator plant species in each wetland site are highlighted in bold.

Wetland disturbance category	Family	Species	IndVal	Ecological action
<b>Heavily disturbed site</b>	Acanthaceae	<i>Asystasia gangetica</i>	0.08	Native perennial
	Acanthaceae	<i>Dyschoriste radicans</i>	0.17	Native perennial
	Amaranthaceae	<i>Achyranthes aspera</i>	0.17	Introduced/invasive perennial
	<b>Amaranthaceae</b>	<b><i>Amaranthus hybridus</i> L.</b>	<b>0.33</b>	<b>Native annual</b>
	Apiaceae	<i>Centella asiatica</i>	0.06	Native perennial
	<b>Asteraceae</b>	<b><i>Adenostemma caffrum</i></b>	<b>0.28</b>	<b>Native perennial</b>
	<b>Asteraceae</b>	<b><i>Ageratum conyzoides</i></b>	<b>0.52</b>	<b>Introduced/invasive annual</b>
	<b>Asteraceae</b>	<b><i>Bidens pilosa</i></b>	<b>0.69</b>	<b>Native annual</b>
	Asteraceae	<i>Melanthera scandens</i>	0.07	Native perennial
	Convolvulaceae	<i>Dichondra repens</i>	0.06	Native perennial
	<b>Commelinaceae</b>	<b><i>Commelina benghalensis</i></b>	<b>0.67</b>	<b>Native perennial</b>
	Convolvulaceae	<i>Ipomoea rubens</i>	0.01	Native perennial
	Cyperaceae	<i>Abildgaardia hispidula</i>	0.08	Native annual or perennial
	Cyperaceae	<i>Abildgaardia ovata</i>	0.21	Introduced/invasive perennial
	<b>Cyperaceae</b>	<b><i>Cyperus cyperoides</i></b>	<b>0.27</b>	<b>Native, pioneer perennial</b>
	Cyperaceae	<i>Cyperus dives</i>	0.03	Native perennial
	Cyperaceae	<i>Cyperus esculentus</i>	0.13	Native perennial
	<b>Cyperaceae</b>	<b><i>Cyperus luteus</i></b>	<b>0.28</b>	<b>Native perennial</b>
	Cyperaceae	<i>Cyperus papyrus</i>	0	Native perennial
	Cyperaceae	<i>Cyperus smithii</i>	0.17	Native perennial
	Cyperaceae	<i>Fuirena umbellata</i>	0.08	Native perennial
	<b>Cyperaceae</b>	<b><i>Kyllinga alba</i></b>	<b>0.33</b>	<b>Native perennial</b>
	Cyperaceae	<i>Otomeria elatior</i>	0.17	Native perennial
	Cyperaceae	<i>Scleria distans</i>	0.13	Native annual or perennial
	<b>Euphorbiaceae</b>	<b><i>Euphorbia heterophylla</i></b>	<b>0.45</b>	<b>Native annual</b>
	Fabaceae	<i>Aeschynomene cristata</i>	0.03	Native annual or perennial
	Fabaceae	<i>Centrosema pubescens</i>	0.01	Native perennial
	Fabaceae	<i>Cyphostemma adenocaulis</i>	0.01	Native perennial
	<b>Fabaceae</b>	<b><i>Glycine wightii</i></b>	<b>0.28</b>	<b>Native perennial</b>
	Fabaceae	<i>Indigofera arrecta</i>	0.17	Native perennial
	Fabaceae	<i>Triumfetta rhomboidea</i>	0.02	Annual herb or perennial shrub
	Malvaceae	<i>Urena lobata</i>	0.06	Native perennial
	Menispermaceae	<i>Stephania abyssinica</i>	0.22	Native perennial
	Onagraceae	<i>Ludwigia stolonifera</i>	0.06	Native perennial
	Oxalidaceae	<i>Biophytum petersianum</i>	0.06	Native annual
	Oxalidaceae	<i>Oxalis latifolia</i>	0.22	Native perennial
	Phyllanthaceae	<i>Phyllanthus amarus</i>	0.22	Introduced/invasive annual
	Poaceae	<i>Brachiaria brizantha</i>	0.06	Native perennial
	Poaceae	<i>Cynodon dactylon</i>	0.17	Native perennial
	<b>Poaceae</b>	<b><i>Digitaria abyssinica</i></b>	<b>0.34</b>	<b>Native perennial</b>
	Poaceae	<i>Eleusine indica</i>	0.18	Native annual
	Poaceae	<i>Eragrostis pilosa</i>	0.06	Native annual
	Poaceae	<i>Eragrostis tenuifolia</i>	0.06	Native perennial
	Poaceae	<i>Imperata cylindrica</i>	0.06	Native perennial
	Poaceae	<i>Leersia hexandra</i>	0.31	Native perennial
	Poaceae	<i>Panicum maximum</i>	0.22	Native perennial
	Poaceae	<i>Paspalidium geminatum</i>	0.17	Native perennial
<b>Poaceae</b>	<b><i>Phragmites mauritianus</i></b>	<b>0.41</b>	<b>Native perennial</b>	
Poaceae	<i>Setaria homonyma</i>	0.22	Native annual	
Poaceae	<i>Setaria sphacelata</i>	0.06	Native perennial	
Poaceae	<i>Setaria verticillata</i>	0.06	Introduced/invasive annual	
Poaceae	<i>Sorghum arundinaceum</i>	0.06	Native pioneer annual or perennial	
Poaceae	<i>Sporobolus pyramidalis</i>	0.01	Native perennial	
Polygonaceae	<i>Oxygonum sinuatum</i>	0.17	Native annual	
Polygonaceae	<i>Persicaria salicifolia</i>	0.01	Native annual	
Typhaceae	<i>Typha domingensis</i>	0.05	Native perennial	
<b>Lightly disturbed site</b>	Acanthaceae	<i>Asystasia gangetica</i>	0.01	Introduced/invasive perennial
	Amaranthaceae	<i>Amaranthus dubius</i>	0.06	Introduced annual
	Asteraceae	<i>Ageratum conyzoides</i>	0.02	Native annual
	Asteraceae	<i>Aspilia africana</i>	0.17	Native perennial
	Asteraceae	<i>Bidens pilosa</i>	0.03	Native annual
	Asteraceae	<i>Conyza bonariensis</i>	0.06	Native annual or short-lived perennial
	Asteraceae	<i>Crassocephalum picridifolium</i>	0.04	Native annual or perennial
	Asteraceae	<i>Crassocephalum vitellinum</i>	0.22	Native annual or perennial
	Asteraceae	<i>Erlangea tomentosa</i>	0.06	Native perennial
	Asteraceae	<i>Galinsoga parviflora</i>	0.11	Native annual
	Asteraceae	<i>Melanthera scandens</i>	0.12	Native perennial
	Convolvulaceae	<i>Hewittia sublobata</i>	0.17	Native perennial
	Convolvulaceae	<i>Ipomoea acuminata</i>	0.11	Introduced/invasive perennial
	Convolvulaceae	<i>Ipomoea rubens</i>	0.17	Native perennial
	Costaceae	<i>Costus afer</i>	0.11	Native perennial

(Continued)

**Table A1.** (Continued).

Wetland disturbance category	Family	Species	IndVal	Ecological action
Relatively intact site	Cyperaceae	<i>Abildgaardia hispidula</i>	0.15	Native perennial
	Cyperaceae	<i>Bulbostylis barbata</i>	0.11	Introduced pioneer
	Cyperaceae	<i>Cyperus cyperoides</i>	0.01	Native perennial
	Cyperaceae	<i>Cyperus distans</i>	0.15	Native annual or perennial
	Cyperaceae	<i>Cyperus dives</i>	0.24	Native perennial
	Cyperaceae	<i>Cyperus esculentus</i>	0.18	Native perennial
	<b>Cyperaceae</b>	<b><i>Cyperus papyrus</i></b>	<b>0.33</b>	Native perennial
	Cyperaceae	<i>Cyperus tenuiculmis</i>	0.06	Native perennial
	Cyperaceae	<i>Cyperus nitidus</i>	0.02	Annuals or perennial
	Cyperaceae	<i>Cyperus tenu</i>	0.17	Native annual or biannual
	<b>Cyperaceae</b>	<b><i>Fuirena umbellata</i></b>	<b>0.25</b>	<b>Native perennial</b>
	Cyperaceae	<i>Scleria achtenii</i>	0.13	Native perennial
	Dennstedtiaceae	<i>Pteridium aquilinum</i>	0.08	Native perennial
	Euphorbiaceae	<i>Euphorbia heterophylla</i>	0.01	Annual native
	Fabaceae	<i>Centrosema pubescens</i>	0.13	Native annual or perennial
	Fabaceae	<i>Eriosema psoraleoides</i>	0.06	Native perennial
	<b>Fabaceae</b>	<b><i>Pultenaea setulosa</i></b>	<b>0.33</b>	<b>Introduced annual</b>
	Fabaceae	<i>Triumfetta rhomboidea</i>	0.07	Native annual herb to perennial shrub
	Melastomataceae	<i>Dissotis mossambicensis</i>	0.11	Native perennial
	Onagraceae	<i>Ludwigia abyssinica</i>	0.1	Native annual, occasionally perennial
	Poaceae	<i>Digitaria abyssinica</i>	0.01	Native perennial
	Poaceae	<i>Eleusine indica</i>	0.01	Native annual
	Poaceae	<i>Leersia hexandra</i>	0.2	Native perennial
	Poaceae	<i>Miscanthus violaceus</i>	0.02	Native perennial
	Poaceae	<i>Panicum repens</i>	0.11	Native perennial
	Poaceae	<i>Paspalidium geminatum</i>	0.01	Native perennial
	Poaceae	<i>Rottboellia cochinchinensis</i>	0.06	Native annual
	Poaceae	<i>Sorghum arundinaceum</i>	0.06	Native pioneer annual or perennial
	Polygonaceae	<i>Persicaria pulchra</i>	0.01	Native perennial
	Polygonaceae	<i>Persicaria salicifolia</i>	0.02	Native perennial
	Pteridaceae	<i>Pteris catoptera</i>	0.11	Native perennial
	Pyridae	<i>Pyura stolonifera</i>	0	
	Typhaceae	<i>Typha domingensis</i>	0.05	Native perennial
	Zingiberaceae	<i>Aframomum angustifolium</i>	0.11	Native perennial or annual
	Acanthaceae	<i>Asystasia gangetica</i>	0.04	Introduced/invasive perennial
	Amaranthaceae	<i>Cyathula officinalis</i>	0.15	Introduced perennial
	<b>Apocynaceae</b>	<b><i>Pentarrhinum insipidum</i></b>	<b>0.28</b>	<b>Native perennial</b>
	Asteraceae	<i>Crassocephalum picridifolium</i>	0.15	Native perennial
	Asteraceae	<i>Enhydra sessilifolia</i>	0.17	
	Asteraceae	<i>Melanthera scandens</i>	0.04	Native perennial
	Commelinaceae	<i>Commelina africana</i>	0.06	Native perennial
	Convolvulaceae	<i>Ipomoea rubens</i>	0.03	Native perennial
	Cucurbitaceae	<i>Momordica foetida</i>	0.11	Native perennial
	Cucurbitaceae	<i>Mukia maderaspatana</i>	0.22	Native perennial
	Cyperaceae	<i>Abildgaardia hispidula</i>	0.08	Native annual or perennial
	Cyperaceae	<i>Cyperus cyperoides</i>	0.02	Native annual
	Cyperaceae	<i>Cyperus distans</i>	0.1	Native annual
	Cyperaceae	<i>Cyperus dives</i>	0.06	Native perennial
	Cyperaceae	<i>Cyperus nitidus</i>	0.07	Native annual or perennial
	<b>Cyperaceae</b>	<b><i>Cyperus papyrus</i></b>	<b>0.28</b>	Native perennial
	Cyperaceae	<i>Scleria achtenii</i>	0.01	Native perennial
	Cyperaceae	<i>Scleria distans</i>	0.01	Native perennial
	Cyperaceae	<i>Scleria racemosa</i>	0.11	Native annual
<b>Dennstaedtiaceae</b>	<b><i>Pteridium aquilinum</i></b>	<b>0.52</b>	<b>Native perennial</b>	
Fabaceae	<i>Aeschynomene cristata</i>	0.2	Native to short-lived perennial	
<b>Fabaceae</b>	<b><i>Cyphostemma adenocaulis</i></b>	<b>0.29</b>	<b>Native perennial</b>	
Fabaceae	<i>Desmodium salicifolium</i>	0.11	Native perennial	
Onagraceae	<i>Ludwigia abyssinica</i>	0.04	Native annual or perennial	
<b>Phyllanthaceae</b>	<b><i>Phyllanthus niruri</i></b>	<b>0.28</b>	<b>Native perennial</b>	
Poaceae	<i>Digitaria longiflora</i>	0.06	Native perennial	
Poaceae	<i>Leersia hexandra</i>	0.23	Native perennial	
Poaceae	<i>Melinis repens</i>	0.11	Native pioneer perennial	
<b>Poaceae</b>	<b><i>Miscanthus violaceus</i></b>	<b>0.30</b>	<b>Native perennial</b>	
Poaceae	<i>Panicum repens</i>	0.11	Native perennial	
Poaceae	<i>Paspalidium geminatum</i>	0.17	Native perennial	
Poaceae	<i>Phragmites mauritiana</i>	0.02	Native perennial	
Poaceae	<i>Sporobolus pyramidalis</i>	0.13	Native perennial	
Polygonaceae	<i>Persicaria pulchra</i>	0.23	Native annual	
Polygonaceae	<i>Persicaria salicifolia</i>	0.22	Introduced/invasive annual	
Polygonaceae	<i>Polygonum lineare</i>	0.17	Introduced perennial	
Rubiaceae	<i>Oldenlandia corymbosa</i>	0.22	Native annual	
<b>Rubiaceae</b>	<b><i>Spermacoce latifolia</i></b>	<b>0.39</b>	<b>Introduced annual or perennial</b>	
Smilacaceae	<i>Smilax kraussiana</i>	0.06	Native perennial	
Solanaceae	<i>Physalis micrantha</i>	0.06	Native annual	
Typhaceae	<i>Typha domingensis</i>	0.09	Native perennial	