

**INTERPRETING THE EFFECTS OF SAND MINING IN LWERA WETLAND  
USING LANDSCAPE METRICS AND TESTING A  
REHABILITATION APPROACH**

**BY**

**AKELLO GERTRUDE,  
15/U/14390/GMAG/PE**

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**DECLARATION**

I hereby declare that this dissertation is my original work and has never been presented to any other university for any other degree award.


Signed..........

Date.....1<sup>st</sup>/12/2018.....

**AKELLO GERTRUDE;**  
**15/U/14390/GMAG/PE**

**APPROVAL**

I hereby declare that this dissertation has been submitted with my approval.

Signature:  .....

Date: 03/12/18

**DR. JEROME SEBADDUKA LUGUMIRA**

Signature:  .....

Date: 3/12/2018

**ASSOC. PROF NABALEGWA MUHAMUD WAMBEDDE**

## **DEDICATION**

This thesis is dedicated to my family who have stood by me every step of the way.



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## **LIST OF ABBREVIATIONS AND ACRONYMS**

GIS	Geographic Information Systems
GoU	Government of Uganda
NEMA	National Environment Management Authority
NFA	National Forest Authority
UBOS	Uganda Bureau of Statistics
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

## ABSTRACT

Wetlands are one of the most valuable ecosystems but are fast getting degraded. Increasing threats of environmental degradation to wetlands has driven adoption of ecological rehabilitation as one of the tools for conservation. Rehabilitation has further been emphasized to compensate for the biodiversity values lost in carrying out development projects in fragile ecosystems. For a mined wetland at Lwera, an attempt was made to: (i) study the spatial patterns of wetland fragmentation using landscape metrics computed from satellite-based land cover classification, and (ii) test differences in establishment of the dominant wetland vegetation in the area (*Cyperus*, *Typha angustifolia* and *Phragmites*). To assess the mining footprint, the active mining wetland area was mapped and constrained around some area for landscape analysis using sensor data. To test a rehabilitation strategy, a northerly transect was selected with random intervals at pits where experimental pits were set. In each of the pits, six replicate plots were set up, that is, for each species two arrays of four platforms, one arranged parallel and the other conterminous at the edges. The platforms were each lined with perforated sisal bags anchored on supports at the platform corners. Rhizomes of the plants were then planted on the platforms where wetland soil material had been placed. The results of landscape analysis showed fragmentation of the wetland, mostly by mining activities. For instance, using a representative metric, namely vegetation patch number, it was shown that the number of patches under vegetation increased from 400 in 2016 to 620 in 2017 and then to 710 in 2018, depicting a discontinuous and patchy landscape and with this was a change in landscape structure. Further, the results on testing establishment of the native wetland species showed that the species rapidly established, but *Papyrus* was particularly more successful growing up to a shoot length of 94cm as compared to *Typha* (80.14cm) and *Phragmites* (64cm). It was also shown that the distance from the lake had a significant effect on establishment of the three species tested ( $P \leq 0.05$ ). The results were beneficial in reporting the effects of mining on the wetland and demonstrated the possibility of using remote sensing to quantify spatial changes in the wetland. It was however clear that expansion dynamics of the planted species cannot be studied in a short period of time which calls for a long term study.



## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background

Wetlands are one of the most valuable but fragile ecosystems in the world (Costanza et al., 1997; Pitchaiah & Pradesh, 2017). Their functions are diverse and range from climate regulation and biodiversity protection to socio-economic benefits (Zedler & Kercher, 2005 ; MEA, 2005). Critical services provided by wetlands include regulating atmospheric gases, sustaining native biota, sequestering carbon and maintaining water quality (Constanza et al., 1997; EPA, 2017). The benefits and values from this ecosystem are however undercut by increasing degradation, which is partly attributed to natural drivers related to climate change and manmade interruptions wholly due to poverty, historical land ownership, rapid population growth, industrialization, urban expansion and unplanned settlements (Zedler & Kercher, 2005; NEMA, 2006; Ramesh et al., 2017).

Global estimates indicate that over 50% of the world's original wetland cover has disappeared, although this varies between countries (Mitsch & Gosselink, 2000; Peck, 2007; Robertson & Section, 2015). In Uganda, wetlands cover approximately 11% (26,600 km<sup>2</sup>) of the country's total area (241,500 km<sup>2</sup>); a drop from 13% in 2000 (MWE, 2001; Mbeche & Bagyenda, 2016), which deviates from the mission of the international treaty for conservation and wise use of wetlands (Ramsar, 2010). The drop of wetland coverage is further complicated by unclear wetland boundaries and the legal definition of wetlands (MWE, 2012). The remaining wetlands face pressure from nutrient enrichment, hydrological alterations and invasive species of plants and animals.

Quite recently, wetlands with sand deposits have come under threat, occasioned by a growing construction industry (NEMA, 2014). Sand excavators in these wetlands employ various techniques, mostly involving massive excavations that leave large footprints of change on the landscape (NEMA, 2014). The resultant pits increase rates of evaporation, hence lowering the water table, and consequently impacting on plant communities around the wetland (Bradshaw, 1987). The pits also expose the water table to contamination, and the people living around the wetland to death by drowning (Young & Griffith, 2009; Global Witness, 2010). In addition, aquatic species like migrating fish (e.g. lung fish) are unable to spawn in open water, thus affecting their diversity (Fahrig, 2003). Vegetation removal and disturbance

of land surfaces also leads to increased sedimentation and turbidity of water sources (Mitsch & Gosselink, 2000), and removal of soil as over burden alters the topography, and consequently the water flow patterns of the mined area (Zedler, 2000).

Although a lot of progress has been reported in the development of rehabilitation of degraded lands (Zedler, 2003; Davidson, 2014), little has been reported on specific approaches applicable to disturbed wetlands hence calling for studies in wetland rehabilitation initiatives in the face of their increasing degradation (Stefanik & Mitsch, 2012). Often times, rehabilitation of mined landscapes is mostly unplanned and rarely based on appropriate science, so much so that it has been a failure as has been noted elsewhere (e.g. Zhang et al., 2009; Zedler & Callaway, 1999; Mateos et al., 2012; Stefanik & Mitsch, 2012). Observed wetland rehabilitation efforts in Uganda have focused on afforestation of the mined areas and fish farming, which sometimes fail and the areas are abandoned (Kaggwa et al., 2009).

Although legislation identifies protection of wetlands as key (NEMA, 2010), this is unsustainable in a country with growing demands for resources (such as sand and clay) given the ever growing population (UBOS, 2015). A robust and efficient rehabilitation method remains one of the most desired goal in wetland management, whether to mitigate the losses attributed directly to mining or as a way of increasing wetland coverage.

For disturbed wetland systems such as is the case with Lwera wetland, it is unlikely that native vegetation will reappear quickly if at all, in their former habitats without artificial establishment. In this study, attempts were made to understand the effect of mining on wetland structure, so as to give a basis for a proposed rehabilitation strategy where establishment of native species in abandoned mined pits was tested.

## **1.2 Problem Statement**

There is increasing mining of sand from wetlands driven by the growing construction industry in Uganda (UBOS, 2016). Although sand is a ubiquitous resource, its most valuable quality is found in fragile ecosystems such as wetlands (Marti, 2011; UBOS, 2015). This therefore means that more sand-bearing land is being exposed to mining and dereliction since most sand mines are illegal and mined areas are never rehabilitated. Lwera wetland in particular is under pressure from mechanized sand mining as excavation is often unplanned



and rehabilitation rarely conducted (Wetland policies, 1995; NEMA, 2009; Water and Environment Sector Performance Report, 2015). Without rehabilitation, the landscape poses several challenges; the resultant pits from sand extraction are death traps in addition to becoming habitats to invasive weeds that can easily cross to open lake and river systems.

While mines on drier areas can readily be restored following standard methods, this is difficult for wetland systems mined for sand as over-burden is shallow, hence limiting the possibility of re-filling (Ehrenfeld, 2000). Observed rehabilitation efforts in Lwera and other sand mining areas are therefore unsatisfactory due to absence of adequate baseline information and limited knowledge of corrective approaches, which would facilitate succession and systems recovery (Mitsch, 2003; Mitchell et al., 2013).

Further, there is limited knowledge and practices to borrow from to guide rehabilitation of inland eco-systems, such as the Lwera wetland. What is available is rehabilitation of riverine systems (Wilcox et al., 1999; Xu, Jiang, Liu, Fu, & Zhao, 2015), lake shorelines (Suding, 2004; Mitsch, 2007), and ocean beaches (Peichel, 1997), following disturbances related to mining activities. Moreover, most of the examples are drawn from environments other than the tropics (Zedler et al., 1999; Wilcox et al., 1999; Zedler, 2000; Hildebrand, Gumiero, Mant, Hein, Elso, & Boz, 2013). This study was intended to design a rehabilitation approach suitable for a lacustrine wetland disturbed by sand mining.

### **1.3 Objectives**

#### **1.3.1 General objective**

The overall objective of the study was to test a methodology for restoring functionality of mined wetlands.

#### **1.3.2 Specific objectives**

Specifically, the study sought to:

1. Characterize the spatial patterns of wetland fragmentation in Lwera.
2. Test difference in establishment of native wetland plants in Lwera (*Cyperus*, *Typha angustifolia* and *phragmites*).

#### 1.4 Research questions

Increasing threats of environmental degradation has driven adoption of ecological restoration as one of the tools for conservation (Convention on Biological Diversity, 2010). Rehabilitation has further been emphasized to compensate for the biodiversity values lost in carrying out development projects in fragile ecosystems (Maron et al., 2012). Against this background, the study was guided by the following questions;

- a) What is the average (i) pit depth and (ii) size of the sand mined pits in Lwera wetland?
- b) What has been the change in vegetation cover of the wetland between 2016-2018?
- c) What landscape metrics can be used to describe fragmentation in Lwera wetland?
- d) What aboveground and belowground plant functional traits are suitable to benchmark (i) establishment of plants and (ii) recovery of the wetland ecosystem in the sand mining areas?
- e) Which of *Cyperus*, *Typha angustifolia* and *Phragmites australis* is suitable for rehabilitation of pits based upon distance from the lake, following sand mining closure?

#### 1.5 Hypotheses

The study was premised on the following assumptions;

1. When used to assist wetland recovery, and for the same environmental conditions, the success rate of (a) *Cyperus* (b) *Typha angustifolia* and (c) *Phragmites australis* is not the same.
2. Wetland plant communities establish easily at pits nearer the lake shore than those far away.

#### 1.6 Significance of the study

Wetland coverage in Uganda has greatly declined due to a multiplicity of unsustainable human activities some of which expose them to near extinction (NEMA, 2014). As such, emphasis has been geared towards protecting existing ones and rehabilitating those that have been degraded. To that effect, the findings from this study would benefit several

stakeholders' particularly environmental regulators e.g. National Environmental Management Authority and the wetlands department in the Ministry of Water and Environment in Uganda.

Results from the study would help in the guidance of restoration of sites where sand mining has been permitted on decommissioning of the projects. Rehabilitation of the biotic community in mined areas improves the landscape conditions by vegetating the disturbed areas with native species. Papyrus for example, traps suspended solids within their extensive rhizome and root structures thus ideal for recovering landscapes that have been ravaged by open pits.

In addition, the study would aid researchers in landscape and restoration ecology by providing a basis for additional work in the areas of disturbance and restoration ecology, giving the opportunity to further observe system recovery after the completion of the campaign.

Besides, the selected species alongside other emergent macrophyte communities are very productive ecosystems with high rates of biomass accumulation (Jones, 1983; Muthuri & Johnes, 1997; Loiselle et al., 2006) resulting from their high primary productivity. The peat that results from the plants' decomposition is a source of energy in addition to other uses in the field of agriculture.

### **1.7 Scope**

The study was carried out in the sand mining areas of Lwera wetland in the districts of Kalungu and Mpigi. The study entailed characterization of the degree of disturbance in the selected sites and manipulation of plant establishment using native species (*Cyperus*, *Typha angustifolia* and *Phragmites australis*). Study activities lasted a period of two months from December, 2017 when the experimental pits were established.



## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Introduction

This chapter comprises a review of literature on wetland disturbances and the techniques that have been used to rehabilitate such lands.

#### 2.2 Common disturbances of wetland systems

A wetland disturbance is any relatively discrete event in time that disrupts ecosystem community or population structure and changes resources and substrate availability (Pickett & White, 1985, Beuel et al., 2016). Wetland system disturbances stem from imbalances in their processes initiated by natural catastrophes and extrusive human activities. The latter is of more concern as human activities can be guided and mitigated to reverse the disturbance (Laurence et. al, 2012). Common human disturbances are highlighted in literature as follows:

Roads and bridges constructed through wetlands often result in fragmentation of habitats and bring about effects to the system such as restriction of organisms (Mitsch & Gosselink, 1993; Mandle, 2015). Besides, pits adjacent to wetlands that are often constructed to excavate murrum negatively affect the water quality through increased turbidity and sedimentation. Road use and maintenance also accounts for disturbances in some wetlands; the use of rock salt for deicing roads can cause death to aquatic animal and plant life (Zentric, 1994).

Further, locating of sanitary landfills in wetlands alters its functionality (Kjeldsen et al, 2010). Continuous contamination from these landfills alters the hydrology of the wetland (Renou et al., 2008; Wong, 2018). Besides, dumping of industrial waste, sewage and household wastes in wetlands all result in massive degradation (Lambou et al., 1988). Also, metals and radio-nuclides naturally concentrate in wetland sediments and peat in heavy industrial locations (Owen, 1992 and Ruffins, 2015).

Agricultural activities particularly construction of irrigation channels, farm roads, dikes and levees often impact on functionality of wetlands (Laurance et al., 2012). Drainage and maintenance of channels under irrigation farming increases contamination of wetlands receiving irrigation drainage water (USEPA, 1995). Pesticides and other agro-chemicals from agricultural fields drain into wetlands as runoff and accumulate in aquatic organisms bodies

(Kennish, 1992). Intensive grazing in wetlands reduces plant diversity; preventing infiltration and increasing runoff (Kent, 1994). In addition, manure and urea result in high nutrient inputs.

Urbanization and associated population explosion is probably the biggest driver of wetland disturbances (Laurance et al., 2012). It directly impacts on wetland loss and degradation due to increases in pollutant inputs and heavy metals from the supra urban space and the resultant changes in species composition. Water quality, quantity and flow rates are greatly impacted on by activities in the urbanized area (Laurance et. al, 2012). Further, impervious surfaces prevent rain water from percolating into the soil, resulting in run off which carries sediments, organic matter, pet wastes, and fertilizers from lawns and gardens (Taylor et al., 1990 and USEPA, 1993). Impervious surfaces reduce ground water recharge within a watershed and water flow into wetlands (USEPA, 1993) thus affecting plant existence.

Urbanization is often accompanied by a growing construction industry which again depends on sand deposits mostly residing in wetlands (Azous & Horner, 2001). Even when sand mining is performed according to regulations, it still impacts the environment negatively (Laurance et. al, 2012). Wetlands mined for sand are significantly modified and transformed into open water habitat. Sand mining requires clearing of vegetation, drainage of the wetland, and creation of roads for equipment to access the sand (Young & Griffith, 2009 and Global Witness, 2010). These activities destroy the portion of the wetland selected for harvest and degrade adjacent areas (Lacki, 1992; Weider, 1993 and Kent, 1994). Removal of soil and overburden alters local topography which in turn disrupts local ground and surface water flow patterns (Hoering, 2008). The removal of vegetation and disturbance of land surfaces increases sedimentation rates with resultant increases in water turbidity (Global Witness, 2010). Access roads cause erosion in steep terrain and can block flow of water in areas of low relief resulting in formation of pits (Young & Griffith, 2009).

Disturbance impacts on vegetation development as the resultant landscapes are often patchy with modified spatial heterogeneity (White & Jentsch, 2001). It is therefore important to characterize these patches in terms of their sizes and distribution over time.



#### **2.4 Landscape metrics for disturbance studies**

Landscape metrics are the numerical indices that have been developed to quantify spatial characteristics of landscapes (McGarigal & McComb, 1995). The metrics provide an effective method of capturing landscape structure, be it at the patch, class or landscape level) and are thus used to compute fragmentation (McGarigal & McComb 1995; Kupfer 2012; Lausch et al. 2015). Habitat fragmentation involves continuous subdivisions of habitats into smaller areas or patches accompanied by a loss of habitat area (Liu et al., 2017). This reduction often impacts on the survival of species. Fragmentation closely relates with disturbance in as far as having a cause- effect relationship (Kearns et al., 2005). Disturbance can be measured from a variety of landscape metrics, especially with the availability of high resolution time series data (Rocchini, 2005).

Patch-level metrics define individual patches and are a basis for computation of several landscape metrics (McGarigal & McComb, 1995). Class metrics or indices on the other hand quantify the spatial configuration and amount of patches of a given type, and a thus a good indicator of the extent and fragmentation of individual patches in the landscape (Gbekor, 2008), while landscape-level metrics are summed over all patch types or classes for the full extent of the data (Gbekor, 2008). Interpretation of the metrics is thus dependent on the level chosen. The metrics are derived from information theory (O'Neill et al. 1988), fractal geometry (Krummel et al., 1987; Li, 2000), percolation theory (Gardner & O'Neill, 1991), mathematical morphology (Vogt et al., 2007), statistical measures of dispersion (Gertsev, 2004) and mechanics (Zhang et al., 2006), and can readily be computed in 'FRAGSTATS' software to facilitate their implementation (McGarigal & McComb, 1995; Remmel & Fortin, 2013).

Several studies document dependence of landscape metrics on scale (Uuemaa, et al., 2009), study area extent (Walz, 2011) and input data resolution (Rocchini, 2014). The metrics have been widely used in several studies for example, quantification of ecosystem services (Walz, 2011), assessment of land cover changes (Hoek et al., 2015) and inference of landscape functions (Li et al. 2015). Specifically, landscape metrics and spatial autocorrelation were used to assess the effect of earthquakes and typhoons on landscape patterns, and the results showed that the disturbances produced several fragmented patches (Lin et al., 2006). In another study, Roosaare (1982) used the indices to analyze landscape structure of Vormsi Island. Relatedly, Abdullah & Nakagoshi (2006) studied the coherence of landscapes, as well



as a study by Jing et al., (2015) on land cover structure and water quality. The wide application of landscape metrics can be attributed to the fact that their linkages to ecological processes are clear and can easily relate with fragmentation (Kupfer et al., 2006), in addition to the ease with which they can be computed using readily available data (Gbekor, 2008).

Further, it is reported that landscapes can be described using just a few components, the pool of which varies in different studies (Cushman et al., 2008). Selection of metrics is often necessary as some have similar or even the same interpretive value. For example, juxtaposition, contagion index and interspersion all originated from probability theory therefore, their mathematical similarity makes them redundant when used together to analyse the same landscape (Riitters et al. 1995). Also, some metrics exhibit statistical interactions with each other (Cushman et al., 2008). Selection in previous studies has been based on correlation grouping, regression with habitats and principal component analysis (PCA) (McGarigal & McComb, 1995; Plexida et al., 2014). Schindler et al. (2008) proposed a set of metrics related to area, shape and edge which can be used for establishing a landscape monitoring program. A similar study by Cushman et al. (2008) performed principal component analysis (PCA) and cluster analysis to identify independent components of landscape structure and found that there were eight universal and consistent combinations of metrics related to patch area, connectivity and isolation. The work of O'Neill et al (1988), also put to light a number of useful metrics broadly categorized under habitat subdivision, extent, isolation, connectedness and patch geometry metrics (McGarigal et al., 2002).

Habitat extent is a measure of landscape composition that represents areal coverage of the target habitat and can be computed using either number of patches (NP) or patch density (PD). The two metrics are however both dependent on habitat area and so can be used interchangeably (McGarigal & Mark, 2001; Gbekor, 2008).

Area and edge metrics compute patch sizes and the total edge created by the patches. Common metrics under this subdivision include patch area (AREA) and patch radius of gyration (GYRATE), which is a measure of the extent of a patch across a landscape (Li & Wu, 2004). Others include class area (CA) and percentage of landscape, which measures the area of each patch type or percentage of landscape of a particular patch type. Total edge (TE) or edge density (ED), on the other hand, is the total length (m) or density (m/ha) of edge of a particular patch type. (Lausch, 2015). Due to its direct interpretive ability, class area is used in the computation of several class and landscape metrics (Kupfer, 2012).

Shape metrics on the other hand, represent geometric complexity and compactness of patch shapes on the basis of perimeter-area relationships (Clarke, 1997; Kupfer, 2012). The common metrics in this category include shape index (SHAPE), which is a measure of the normalized ratio of patch perimeter to area, while contiguity index (CONTIG) computes patch shape based on the spatial connectedness of cells within a patch (Eetvelde & Antrop, 2009). Shape metrics are important because the interaction of patch shape and size has an influence on many ecological processes for example plant establishment in some systems (Hardt & Forman, 1989) where concave boundaries promote more growth as would convex ones.

Core area metrics describe the patch interior discounting for depth-of-edge effects along the boundary of every patch (Clarke, 1997). The metrics herein include, patch core area (CORE) which computes the area of the patch occupied by the core (Turner, 2005). Core area represents the area within a patch beyond some specified depth-of-edge effect distance. Core area integrates patch shape, size and edge distance into a single measure and smaller patches generally have less core area. Core area index (CAI) on the other hand computes the percentage of the patch that comprises the core area and total core area (TCA) is a computation of the total percentage of the class or landscape that is composed of the core (Herold et al., 2002). Core area determines the character and function of patches in a landscape i.e., a patch may be big enough but still not contain enough suitable core area to support species (McGarigal & Mark, 2001).

Contrast metrics compute the magnitude of contrast or difference between adjacent patch types along patch edges with respect to one or more ecological attributes. Metrics in this category include edge contrast index (ECON), which is the percentage of maximum contrast along an edge between two patches (McGarigal & Marks, 1995). Edge density (ED) is a measure of the total length of patch edge per unit of area in the landscape. Total edge contrast index (TECI) on the other hand quantifies edge contrast as a percentage of maximum possible for the landscape as a whole. The contrast between a patch and its neighborhood affects a number of ecological processes (Forman & Godron, 1986) in that organisms may not freely move across hard edges and this impact on landscape connectivity (Dunning et al., 1992). High contrast edges may prohibit or inhibit some organisms from seeking supplementary resources in surrounding patches (Gbekor, 2008).



Aggregation metrics compute the tendency of different patch types to be spatially aggregated and is thus a reflection of landscape texture (McGarigal et al., 2002). Metrics in this category include Contagion index (CONTAG) which is a measure of the extent to which patch types are aggregated or clumped as a percentage of the maximum possible value (Gbektor, 2008). Interspersion and juxtaposition indices (IJI) measure the extent to which patches are intermixed as a percentage of the maximum possible (Kupfer et al., 2006). Habitat fragmentation thus leads to a decrease in contagion and an increase in habitat disaggregation (Lande, 1987).

Aggregation metrics describe the degree of spatial isolation of patches. Aggregation is the degree of clumping of patch types and the corresponding metrics deal generally with the spatial distribution of patch type (dispersion), the spatial intermixing of different patch types (interspersion) and the tendency of patches to be relatively isolated in space (isolation). Metrics here include; mean nearest neighbor (MNN) which is a measure of the spacing between different patches in a cluster (McGarigal & Mark, 2001). This is always shorter for disturbed areas (Kupfer et al., 2006). This metric further defines the shortest straight-line distance (m) between a patch and its nearest neighbor in the landscape (McGarigal & Mark, 2001). The major limitation of the metric is that it yields absolute values and thus requires maps of known grain size and similar extent. It is however useful in assessing distances between remnant patches of original patches in highly disturbed areas (McGarigal & Marks, 1995).

While they continue to be used, the metrics have well documented limitations (Cardille et al., 2005). The interpretation of some is complicated because there are no general guidelines for their selection (McGarigal et al., 2002). Also, some metrics are unstable in making predictions at extreme conditions. That is, it is often difficult to characterize landscape structure at the class level when the focal class is either too rare or dominant or at a landscape level when a single class is dominant (Neel et al., 2004). Further, most shape complexity indices are derived on the basis of form of perimeter–area relationship and ignore the directional differences between patches (Gustafson, 1998; Zhang et al. 2006 ).The limitations can however be minimized through careful data manipulation, analysis and interpretation (Shao & Wu, 2008).

For this study, selection of the metrics was based on the need to use those with no special implementation problems such as high sensitivity to size and boundaries and also those that

cover the characteristics of interest without redundancy. On the basis of the above and from literature cited (McGarigal et al., 2002; Schindler et al., 2008; Cushman et al., 2008, Plexida et al., 2014), metrics selected included Class area, Number of patches, Edge and Percent cover of the landscape. Number of patches was selected because together with the patch sizes, are linked to changes in plant and animal populations (Gbekor, 2008). Also, class area affects the economic viability of the land cover in addition to impacting on the wildlife habitat. Metrics that compute area provide useful analysis as area strongly relates to species richness and abundance (Turner, 2005). Area, density and edge metrics therefore represent physical continuity of the landscape and can be used to explain a range of ecological processes for example, predation, changes in micro climate and competition along the edges (Leopold, 1933; Temple 1983; Wilcove 1985; Temple 1986; Noss 1988; Robbins et al. 1989). The metrics chosen therefore provide crucial information in the study of fragmentation.

### **2.3 Rehabilitation of degraded systems**

Rehabilitation from a mining perspective implies putting back the impacted land to a sustainable usable condition. This involves re-establishing ecosystem structure and function to its pre-disturbance state or replicating a desired reference ecosystem (Doley & Audet, 2013). The specific technique employed in restoration is dependent on the type of wetland to be created, existing size and the functions targeted (Richter & Stromberg, 2005). Passive restoration is preferred in smaller sites and in landscapes that have been less altered by man; where target species are common. For landscapes with a thick top soil and overburden layer, top soil containing the native seed species and useful microbes can be stockpiled and later returned to reconstruct pits and thus facilitate vegetation re-establishment (Doley & Audet, 2013). Mined landscapes can also be rehabilitated by spreading back top soil to a desired shape so as to allow for infiltration and facilitate weathering processes (Burger, 2011). This method of rehabilitation is the most common, but is inapplicable for landscapes with limited overburden and impractical for countries like Uganda where the law prohibits dumping.

For mined wetlands, plants have to be introduced artificially since the local species pools are often lost or reduced due to degrading activities of soil excavation (Zedler & Kercher, 2005). One way of doing this is borrowing from other restoration techniques, such as, floating islands (e.g. Wilcox et al., 1993; Burton, 2003), but instead use the islands as propagation platforms to grown colonies that will eventually cover the pits. The platforms should be set



up in patterns predicted to allow rapid takeover of the desired species so as to avoid invaders and ensure the use of plants that rapidly accumulate below-ground material while spreading the rhizomes to cover a larger area.

#### **2.4 Monitoring wetland plants recovery**

Predicting the path and final outcome of a rehabilitation project with certainty is difficult due to inadequate knowledge base and empirical data from a science that is just developing (Mitsch, 2012). Monitoring is thus carried out to ascertain the trajectories of the strategies. Most rehabilitation projects require longer time periods however the length of time can also be determined by the urgency required as stated in the objectives and practical limits to ecosystem recovery. For this study, the objective was to assess establishment of wetland plant species in the first four (4) months of implementation. It is important to note that complete wetland recovery takes time and, therefore, the results of this study were to be indicative of scenarios predictable based upon the facts.

In restoring wetland systems, the focus is to reproduce the structural and functional attributes of natural wetlands (Zedler et al., 2000). However, many efforts have not been successful when compared with the reference ecosystems (Suding, 2011; Wortley et al., 2013). Rehabilitation hence requires ongoing attention and adaptive management to be able to identify constraints to systems recovery and propose appropriate changes to site designs so as to achieve successful projects. Also, photo-points can often be used to provide a means of tracking changes in the vegetation establishment over time.

#### **2.6 Conceptual framework**

The conceptual model (Figure 2.1) was formulated on the basis of the definition, causes and effects of disturbances. The study focused on establishment of native species in the mined areas of Lwera wetland by supporting the growth of rhizomes following a hydrological gradient. The framework illustrates linkages between a degraded wetland system and interventions to restore wetland vegetation to achieve a stable wetland ecosystem.

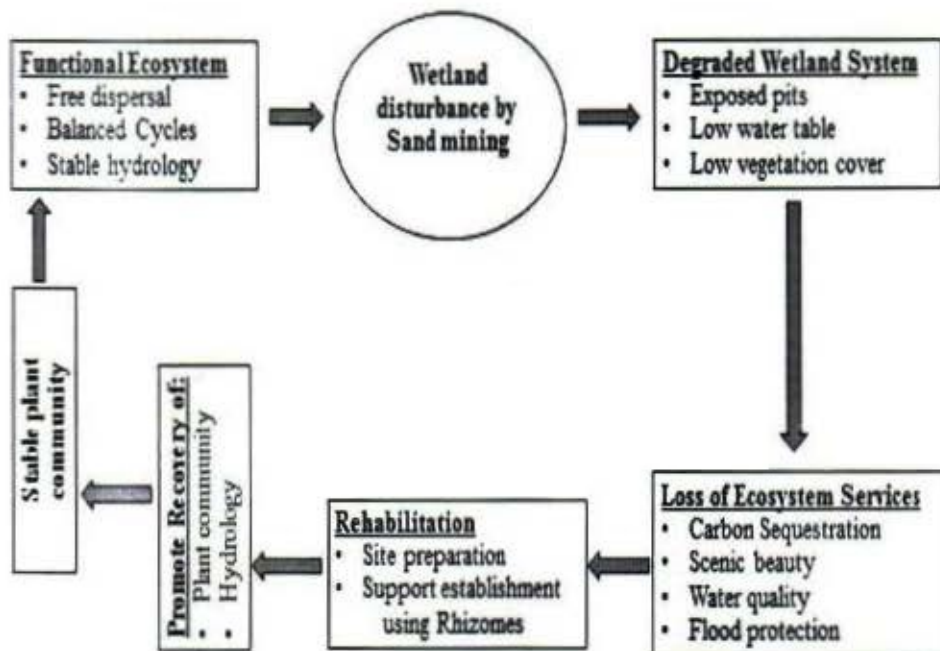


Figure 2:1 Conceptual Framework

## CHAPTER THREE

### METHODOLOGY

#### **3.1 Introduction**

This chapter presents background information about the study area and the methods employed in data collection and analysis. In addition, the Sample and Research designs adopted as well as limitations of the study are detailed in this chapter.

#### **3.2 Description of the study area**

##### **3.2.1 Location**

Geographically, Lwera wetland is located in the Lake Victoria catchment; stretching from  $0^{\circ}5'11''$  N to  $0^{\circ}17'$  S and  $31^{\circ}38'40''$  and  $32^{\circ}00'45''$  East. With an area of about  $237 \text{ km}^2$ , the wetland forms part of the greater Katonga wetland system bordering river Katonga and Lake Victoria and located in the districts of Mpigi and Kalungu (UBOS, 2012). The Kampala-Masaka highway crosses through the wetland and is the main access route to the wetland (Kalungu district local government, 2014).

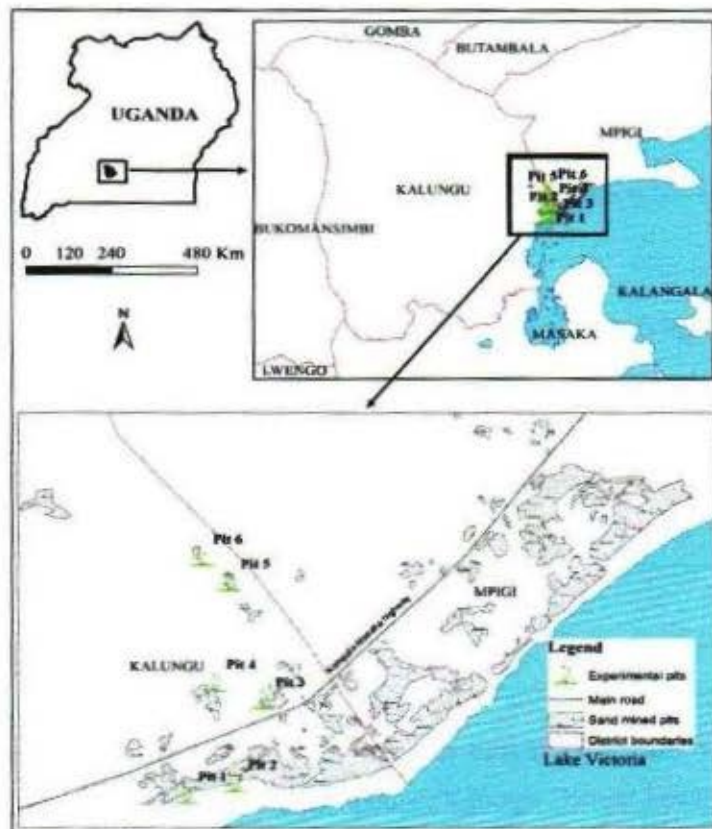


Figure 3.1: Location of Study Area.

### 3.2.2 Geology and soil

The study area is underlain by rocks of the Buganda -Toro system comprising of strongly metamorphosed and deformed quartzite, which form major geomorphological features in central southern Uganda. Much of the Wetland is underlain by lacustrine deposits that can be traced to the Pleistocene period (Geologic Survey of Finland, 2014). Beyond the wetland system are sedimentary deposits associated with river processes. The soils in the study area are mainly hydromorphic comprising mainly sodium minerals and ferallitic mainly sandy clay loams (Uganda government, 1967).



### **3.2.3 Geomorphology**

The relief of the study area is generally flat and low lying with cases of interfluvial broad-flat or rounded valleys and its altitude ranges between 900-1200m above sea level (Kalungu District Local Government, 2016).

### **3.2.4 Climate**

The study area falls under the Lake Victoria climate zone receiving rainfall throughout the year with two rainfall peaks from April-May and October-November. Two relatively low rainfall periods are experienced between December-March and June-July (NEMA, 2009). The climate in this zone is modified by maritime conditions i.e. proximity to Lake Victoria and location astride the equator (NEMA, 2010). Annual rainfall ranges between 1250-2000mm.

### **3.2.5 Drainage**

The wetland is bordered by Lake Victoria to the East and the main river draining the area is Katonga. The wetland is intermitently flooded.(Kalungu District Local Government, 2016)

### **3.2.6 Vegetation**

The vegetation of Lwera is partly permanent wetland vegetation terminating into seasonal wetlands. The dominant vegetation types include *Cyperus*, *Raphia*, *Phragmites australis*, *Typha angustifolia*, sedges and swamp grass (Huisings, 2009). The economic and subsistence benefits of these wetlands determine their vulnerability to becoming permanently degraded.

### **3.2.7 Land-use**

The main forms of land use in the study area include farming and sand mining (Kagwa, 2009). Both cash and food crops are grown i.e. bananas, potatoes, coffee and maize in addition to cattle rearing for milk and beef (UBOS, 2009 and Kalungu District Local Government, 2016).

## **3.3 Research design**

The study design was partly analytical based on archival information of satellite data of the area for which metrics were derived. Also, an experimental design was adopted where study

pits were set up at varying distance from the lake and planted species monitored for growth over time.

### **3.4 Sample Design**

To assess the mining footprint, the active mining wetland area was mapped and constrained for landscape analysis using sensor data obtained over four time steps (2010 as reference, 2016, 2017 and 2018). Google earth images of the wetland were used to digitize pits and selection of those for study done on the basis of distance from the lake. This was done to be able to track changes in condition and report the changes using metrics. To test a restoration strategy, a northerly transect was selected with random intervals at pits where experiments were set. At each of the study pits, experiments consisted of two different treatments; species, and distance from the lake. Each of the pits was considered a replicate (block) with a complete block design of the two treatments for each species. The total number of experimental units were 3 replicates x 3 species x 6 pits = 54. The initial point was randomly selected to include the pit closest to the lake following a hydrologic gradient.

#### **3.4.1 Experimental set-up**

At each of the six pits, six replicate platforms were established each having four rectangular arrays arranged i) parallel and ii) conterminous to one another, but at the edges. The platforms were each lined with perforated sisal bags anchored on wooden supports at the platform corners. The bags were set at 10cm below the water level to cater for a changing hydro period. Small rhizome sections (approximately 30cm) of *Cyperus*, *Typha* and *Phragmites* were collected from the virgin areas of the wetland and planted on the platforms using remnant wetland soil adjacent to the mined areas following a hydrological gradient from the lake shore.

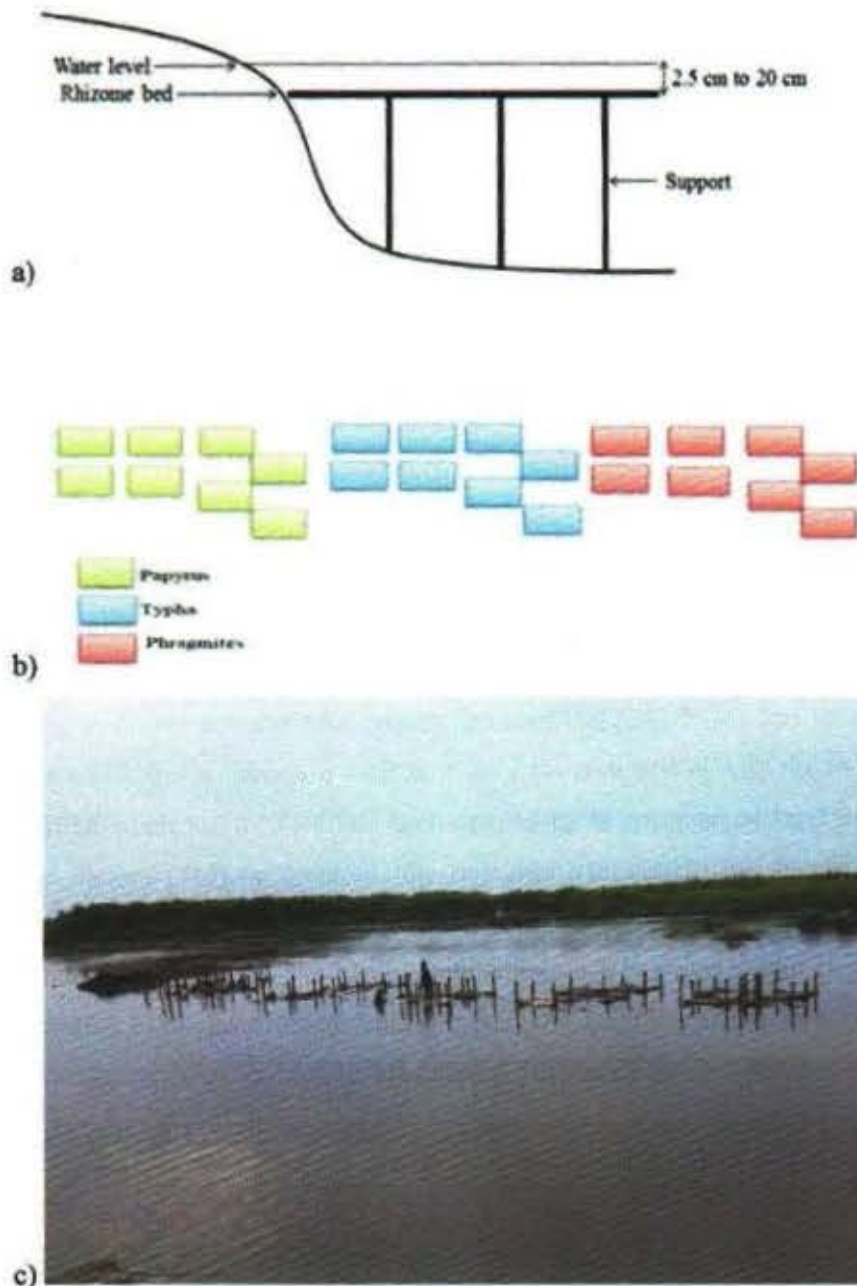


Figure 3.4: a) Experimental setup b) Schematic Layout of the Study Pits and c) Photograph... .. the Experimental Setup.

### 3.5 Data collection

The study involved collection of data on pit characteristics and plants used in the experiment. Further, data was also collected to aid identification of how species-specific mean trait values varied across pits and with time.



### 3.5.1 Characterizing disturbance of wetland due to mining

#### 3.5.1.1 Pits and surrounding environment characteristics

Prior to set up, experimental pits were geocoded and specific measurement of depth and width made based upon distance from the lake.

#### 3.5.1.2 Land cover classification data

This study used four sets of Ortho-rectified multispectral images that is, one Landsat 5 (30m) and three Sentinel 2A (10m) images to characterize the degree of disturbance of the wetland as a result of sand mining over time. The Landsat and Sentinel images were preferred owing to their high repetitive coverage and free accessibility. The images were downloaded from the USGS web portal (<http://glovis.usgs.gov/>). Images downloaded where those with cloud cover ranging from 0 – 15% and captured during the dry season (i.e. January). Prior to 2010, mining in Lwera wetland was largely artisanal (NEMA, 2016) and therefore, the Landsat image of 2010 was therefore used as a basis for comparison with the images of 2016, 2017 and 2018 when the wetland had been opened up to commercial sand mining. The Landsat image dataset (TM) acquired for the reference year (2010) had bands 3 (Red), 2 (Green) & 1 (Blue) and Sentinel 2A for the years, 2016, 2017 and 2018 had bands 4 (665nm), 3 (560nm) & 2 (490nm). The band combinations offer similar output in terms of reflectance and display of imagery. Image band combinations gainfully add value to image interpretation. The image specifications of the downloaded images are hereby shown in table 3.1 & 3.2.

**Table 3.1: Landsat 5 satellite imagery specifications**

Year	Path/Row	Date	Band Specifications
2010	171r080	28/01/2010	3 (Red), 2 (Green) & 1 (Blue)

**Table 3.2: Sentinel 2A satellite imagery specifications**

Year	Resolution	Date	Band Specifications
2016	10	1/01/2016	4 (665nm), 3 (560nm) & 2 (490nm).
2017	10	5/01/2017	4 (665nm), 3 (560nm) & 2 (490nm).
2018	10	5/01/2018	4 (665nm), 3 (560nm) & 2 (490nm).

In addition, point location data for the three land cover classes (vegetation, open water and sand fields) was collected using Google earth tools. A total of 600 sample points were generated for all the classes to generate a metric for training data.

### 3.5.2 Testing difference in establishment of the dominant wetland plant species

Data about number of roots, number of shoots, root length and shoot length were collected three times over a period of two months (Table 3.3). At every monitoring, the above traits were measured and recorded, and then translated into a proportion (only root length and shoot length) based upon a species maximum attainment of the trait at maturity (Table 3.4). Computation of proportions was necessary given that the period of monitoring was shorter than the life history of the selected species. This was intended to enable between-species comparison, but also, monitoring of development allowed determination of differences in establishment of the three plants, first generally, and second as a function of distance from the lake.

**Table 3.3: Dates when the experiment was set and monitoring done.**

Date	Activity
13 <sup>th</sup> /12/2017	Set up the experiment
3 <sup>rd</sup> /1/2018	First phase of monitoring
26 <sup>th</sup> /1/2018	Second phase of monitoring
18 <sup>th</sup> /2/2018	Third phase of monitoring

**Table 3.4: Summary of root and shoot dimensions**

Plant	Max_root length at maturity (cm)	Max_shoot length at maturity (cm)
Typha	70	80
Phragmites	300	64
Papyrus	360	94

In the absence of adequate resources, the monitoring period was restricted to two months and plant traits documented to track establishment of the selected species. Photo-point monitoring was also used to record changes in the structure and size of the established plants.



## **3.6 Data analysis**

### **3.6.1 Analysis of the degree of disturbance of the mined wetland**

#### **3.6.1.1 Pit dimension**

Data collected on pit dimensions were analyzed using descriptive statistical methods involving computations of means, minimum, maximum and deviations in the values. Analyses were done on pit depth, width and pit distance from the lake shore. The pit dimensions were obtained from field measurements and compared to compute mean estimates.

#### **3.6.1.2 Modeling Landscape disturbance due to sand mining activities**

The downloaded images were pre-processed for atmospheric, spectral and radiometric corrections using QGIS software version 3.0.3. Extraction and compositing of bands of interest then proceeded using ArcGIS 10.5. A polygon shape file delineating the boundaries of the study area was created and used to clip the processed images. The prepared datasets were then imported into R statistical software for land cover classification using randomForest. These were accompanied by point data shape file for the three classes to be modeled over the area. The modeling process involved use of a variable number of trees and the model with the smallest Out of Bag Error (OBB) was selected for classification of the land-cover classes. Land-cover classes of more or less homogeneous land-use aid in studies of land-cover change. To minimize classification errors, only three land-cover classes were used (vegetation, open water and sand fields) given that the classes are clearly separable both spatially and spectrally in addition to representing the dominant land-cover types in the area. The random Forest classification output for the four years was further processed in ArcGIS 10.5. The classification accuracy assesement was based on 600 training samples

#### **3.6.1.4 Computation of landscape metrics**

The products of land cover classification were used to compute landscape metrics in Fragstats 4.2 (A Spatial Pattern Analysis Program for Categorical Maps). The output images were first resampled to the 2010 Landsat 5 Image to harmonize the pixel resolution before computations for size, number and distribution of patches in the area over the study period.

The metrics selected were those that depict landscape disturbances resulting from sand mining activities. For example those that quantifies the number and size of the patches plus the edge dimensions. (McGarigal et al., 2002). Table 3.3 summarizes the selected metrics.

**Table 3.5: Landscape Metrics Selected for Fragmentation analysis**

<b>Metrics</b>	<b>Description</b>	<b>Units</b>
No. of patches (NP)	The number of patches of a particular type	None
Percentage of landscape (PLAND)	The sum of areas of all patches of particular types divided by the total landscape area ( $m^2$ ) X 100	Percent
Total class area (CA)	This is the sum of areas ( $m^2$ ) of all patches of a particular type divided by 10000 (10 for hectares)	Hectares
Total edge length (TE)	The sum of all perimeters within a landscape	Meters

### **3.6.2 Analysis of the difference in establishment of the dominant plant species**

#### **3.6.2.1 Above and belowground plant functional traits suitable to benchmark plant establishment**

Analyses were made on the variability of root and shoot traits at species and pit level. Boxplots were created where the traits were plotted verses distance from the lake to be able to identify patterns in the data. Species performance (shoot and length growth rate) in establishment was analyzed with the objective of providing reliable estimates of growth rates. Patterns of variation of the field collected data were tested for significant effects of independent wetland variables (i.e. treatment types and landscape placement) on the dependent vegetation indices. Initial growth estimates was presented for a period of two months and used to project growth in order to make predictions about the potential for establishment.



**Table 3.6: Summary of the response variables obtained from plant measurements**

<b>Response variables</b>	<b>Description</b>
Shoot number	Count of new shoots post treatment
Shoot length	Maximum length of post treatment shoot measured from the stolon
Root number	Count of new roots post treatment
Root length	Maximum length of post treatment root measured from the rhizome

The significance of pit depth on plant establishment was also determined and differentials in success rates of the individual species documented. A 95% confidence interval was the significance threshold for all the tests. The software packages R, version 3.03 (R Core Team, 2014) was used for all the statistical analyses.

### **3.6.2.2 Above and belowground plant functional traits suitable to benchmark recovery of the system**

The main goal of the study was to observe plant establishment for a sustained period of time to be able to report on the recovery of the system. This was however not possible in the absence of time and finances. The study was therefore restricted to comparing success in establishment of the three dominant plant species in the area and so an analysis of the recovery of the system could not be attained.

### **3.6.2.3 Suitability of *Cyperus*, *Phragmites* and *Typha* in rehabilitation of the pits based upon distance from the lake**

For each pit, functional trait data (e.g shoot length, root length, number of shoots and number of roots) was averaged over the monitoring period to create a data matrix used to derive means for each of the plants for the entire study period. Distance from the lake as the main factor under investigation was used to classify the different pits selected. Plant responses at pit level were assessed using a Generalized Linear Mixed Model so as to examine how species traits differed with time. Further, a discriminant analysis was computed on the basis of the four traits using species as groups to test the effectiveness of the traits in differentiating individuals of the different species. This was on the basis that traits can simultaneously explain individual plant responses to biotic and abiotic factors, and ecosystem effects.

In order to select the species traits accounting for most of the explained variation in the species, a pairwise comparison was conducted using Tukey's family wise comparison and the



selected traits used for modelling. Success of establishment across the gradient was determined using generalized linear mixed-effects models (GLMMs). Data for the traits was used in the modeling effort with the variables (species traits) as random factors and distance from the lake as the fixed factor. Models were run with root length and number of shoots as the response variable. The difference in variance indicated the amount explained by each factor and thus yielded a good indication of their relative importance.

The use of GLMMs allowed the incorporation of several random effects while handling non-normal data. GLMM was used with the function `lmer` of the `lme4` package in R. The GLMM was considered appropriate given that the dataset involved repeated measures. The model used is generally specified as below:

$$Y_i = X_i\beta + Z_i b_i + \varepsilon_i$$

Where  $X_i = Z_i K_i$  is a matrix of known covariates and where all other components are defined as below.

$$\begin{cases} b_i \sim N(\mathbf{0}, D), \\ \varepsilon_i \sim N(\mathbf{0}, \Sigma_i), \\ b_i \text{ and } \varepsilon_i \text{ are independent.} \end{cases}$$

With the fixed effects  $\beta$  and subject specific effects  $b_i$ . It assumes that the vector of repeated measurements on each subject follows a linear regression model where some of the regression parameters are population-specific whereas other parameters are subject-specific.

$$y_{ij} = (\beta_0 + b_{1i}) + \beta_1 distance_i + \beta_2 species_i + (\beta_3 + \beta_4 distance_i + \beta_5 species_i + b_{2i}) species_{ij} + \varepsilon_{ij} \quad [1]$$

where  $\beta_0$  is the average intercept after correcting for species and distance,  $\beta_3 - \beta_5$  is the average slope effects after correcting for distance and species, and  $\beta_1$  and  $\beta_2$  are the distance and species effects on the intercept and slope, respectively.

Whereas  $\varepsilon_{ij} \sim N(\mathbf{0}, \Sigma = \sigma^2 I_{n_i})$ , and  $b_i \sim N(\mathbf{0}, D)$ , which are both assumed to be independent.

The hypothesis that plant communities easily establish at pits nearer the lake shore than those further away was tested by an interaction of the factors.

### **3.7 Study Limitations**

The study pits were located on an exclusively private owned property which required constant negotiation for property access. Fortunately, the property owners later gained interest in the project and provided full access to the study sites.

The research project had a limited time frame of a 12 month candidature and therefore seasonal replication of data collection was not possible. A comprehensive data collection would require at least two years (minimum of two seasons). The project would also have benefitted from inclusion of additional study sites but this was not possible in the absence of time and finances.

The site also presented major difficulties particularly limited accessibility to research pits in frequently flooded sites calling for the use of boats. Besides, in frequently flooded sites, the unpredictable survival and limited accessibility issues made it difficult to conduct comparisons of the study species.

No accuracy assessment using ground control points was done to ensure the reliability of the classified map obtained from the satellite images and neither was the results compared with any empirical data.

## CHAPTER FOUR

### RESULTS AND DISCUSSION

This section presents results and findings of the various fitted models and implemented approaches.

#### 4.1 Degree of landscape disturbance

##### 4.1.1 Pit characteristics

The summary statistics from the analysis of pit characteristics investigated in the study are presented in Table 4.1 below.

Table 4.1: Summary statistics of the pit characteristics

Parameter	Minimum	Maximum	Mean	Std. Deviation
Pit depth (m)	1.24	3.2	2.07	0.87
Pit width (m)	27.5	93	48.25	24.07
Pit Length (m)	50.3	123.2	82.62	29.69
Pit water depth (m)	1.13	2.61	1.91	0.73
Distance from the lake (m)	480	3600	1861.67	1275.49

Table 4.2: Summary of pit depth verses Distance from the lake

Pit no	Distance from the lake (m)	Pit depth (m)
1	480	1.24
2	680	2.67
3	1390	2.65
4	1900	3.20
5	3120	1.31
6	3600	1.36

From Table 4.1, the pits studied had a minimum depth of 1.24 meters and a maximum of 3.2 meters. The mean pit depth recorded was 2.07 meters with a standard deviation of 0.865 meters. The minimum pit width was 27.5 meters with a maximum of 93 meters and a mean of 48.25 meters. The minimum pit length recorded for all the pits studied was 50.3 meters with a



maximum length of 123.2 meters. There was increasing pit depth with increasing distance from the lake upto a distance of 3.20 meters when the depth starts to drop (Table 4.2). Also, the nearest pit to the lake shore was 480 meters away while the furthest was at a distance of 3600 meters with a mean distance of 1861.67 meters.

a)



b)



**Figure 4.1: Measurement of a) pit length and b) pit depth at the study site**

#### 4.1.2 Land cover changes

The major land-cover classes identified include vegetation, sand fields and open water. The random Forest classification outputs for the four years were further processed in ArcGIS 10.5 and the results are shown in Figure (4.2) and the relative changes further depicted in Figure (4.3)

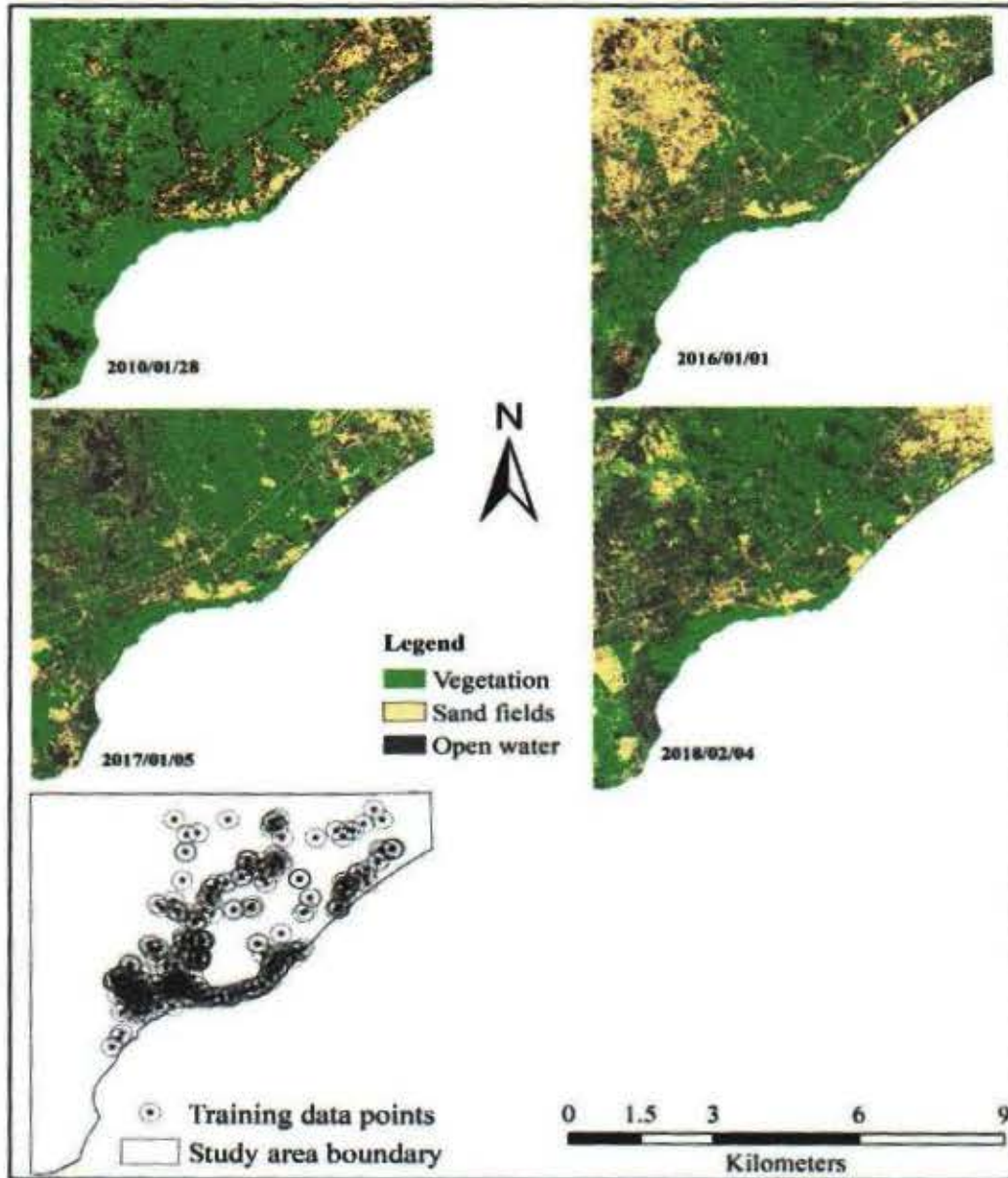
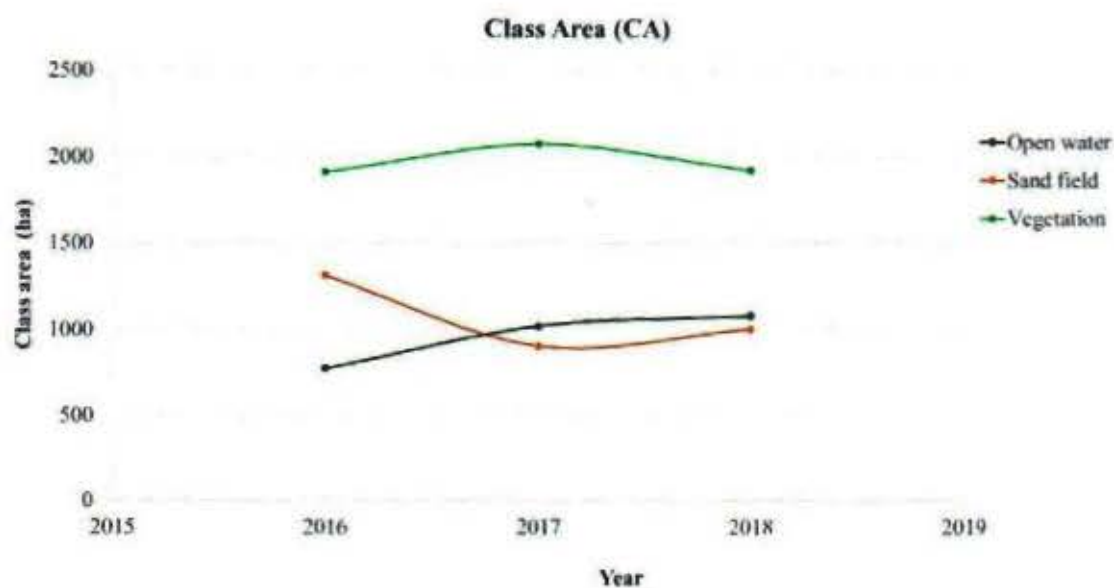


Figure 4.2: Land cover classes for the study area



**Figure 4.3: Computation of class area**

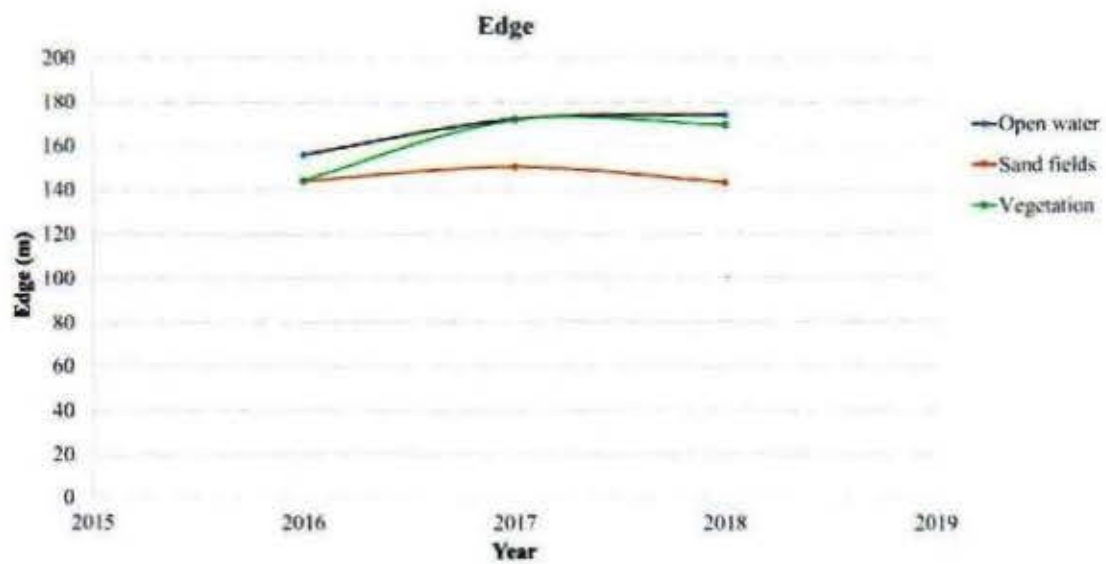
From randomForest land cover classification results (Figure 4.2) and inspection of the confusion matrix, it was noted that there were some inconsistencies with the classification. This could be because the spectral signatures of bare patches and road infrastructure are similar to that of sand fields which confusion could have led to errors. However, the model implemented had an overall OOB error of 36.07%. Validation of the classification results was not possible due to lack of ground truth information which is common for most historical remote sensing data. In reference to the three land-cover classes, randomForest results shown (Figure 4.2) reveal that vegetation cover represented the biggest class followed by sand fields while open water was the least class for all the study years. Vegetation area increased from 1800 ha (2016) to 2070 ha (2017). The area under vegetation however declined to 1900 ha in 2018. The increasing trend in areal extent was also observed for open water (e.g. from 750 ha in 2016 to 1000 ha in 2017 and then 1050 ha in 2018). The area under sand fields declined between 2016 and 2017 (e.g. from about 1300 ha to 900 ha). This however increased to 1000 ha in 2018.

#### **4.1.3 Landscape fragmentation**

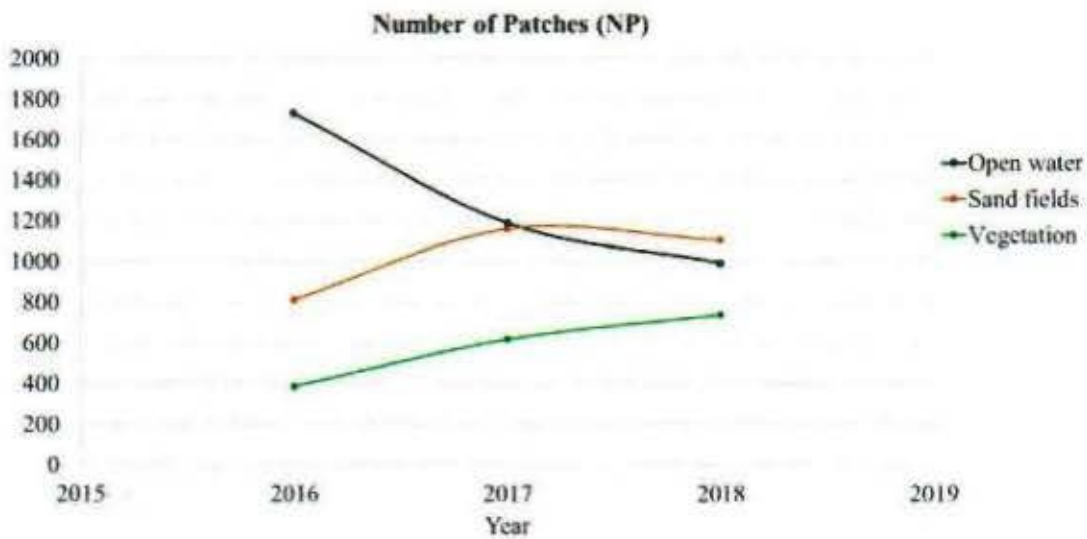
To further explore the landscape disturbances resulting from sand mining, landscape metrics results computed using Fragstats 4.2 was as shown in Figure 4.4;



a)



b)



**Figure 4.4: Computation of (a) Total edge and (b) Number of patches**

There was marked fluctuation between 2010 and the study years showing interplay of disturbance and succession. The number of patches (NP) revealed that greater habitat subdivision was in the open water class. The number of patches for vegetation increased from 400 (2016) through to 610 (2017) and then 750 (2018) (Figure 4.4b). The number of patches

for open water had a declining pattern from about 1750 (2016) to 1200 (2017) and 1000 (2018). The number of patches of sand fields also increased from 800 (2016) to 1195 (2017) and 1100 (2018).

The edge of the different classes also showed increasing trends with vegetation increasing from 144m in 2016 to 172m in 2017 and 170m in 2018 (Figure 4.4a). Sand fields also increased from 144m in 2016 to 150m in 2017 before reducing to 142m in 2018. The edge of the open water class increased from 158m in 2016 to 172m through to 175m in 2018.

The percentage of land area under vegetation increased from 48% (2016) to 52% (2017) before reducing back to 48%. For open water, the percentage of land area increased from 20% (2016) to 26% (2017) and then 27% (2018) while for sand fields; there was a decrease from 32% (2016) to 22% (2017) before increasing to 25%.

## **4.2 Establishment of *Cyperus*, *Typha angustifolia* and *Phragmites***

### **4.2.1 Aboveground and belowground plant traits for benchmarking plant establishment**

Over the study period, the three species showed different aboveground and belowground biomass distribution. Success trends were based upon proportions of the maximum attained lengths in the study period versus the would be length at maturity (Table 3.3). Greater belowground growth was measured for *Papyrus*, followed by *Typha* and then *Phragmites* (Table 4.3).

**Table 4.3: Description of Species by Mean and Standard Deviation**

Species	Variable	Mean	SD	Min	Max	N
<b>Papyrus</b>	Root No.	19.58	9.56	9	44	528
	Root length (cm)	25.12	16.77	1	90	229
	Shoot No.	7.33	2.25	4	11	528
	Shoot Length (cm)	33.43	25.42	3	94	83
<b>Phragmites</b>	Root No.	15	5.12	8	29	528
	Root length (cm)	10.14	6.46	0.4	29	179
	Shoot No.	4.17	1.46	2	7	528
	Shoot Length (cm)	20.88	17.85	1.3	64	50
<b>Typha</b>	Root No.	33.25	18.66	7	84	528
	Root length (cm)	23.39	12.19	3	55	361
	Shoot No.	41.04	22.01	0.5	86	34
	Shoot Length (cm)	2.83	1.07	1	80.14	528

From the table, Papyrus had the longest roots (90cm) and longest shoot length (94 cm). It was followed by *Typha* with a root length of 55 cm and then *Phragmites* (29 cm). *Typha* had the highest number of roots (84) with an average of 34 per plant. The highest root length for *Phragmites* was 29 with an average of 15 roots per plant. All measured traits however, showed significant variation between species ( $p < 0.05$ ).







**Figure 4.5: Above-ground plant establishment of the three study species**

This was further shown by the variance decomposition by pairwise comparison which indicated that the four selected plant traits had a significant species effect (Table 4.4).

**Table 4.4: Difference between Means and Significance of Pairwise Comparison**

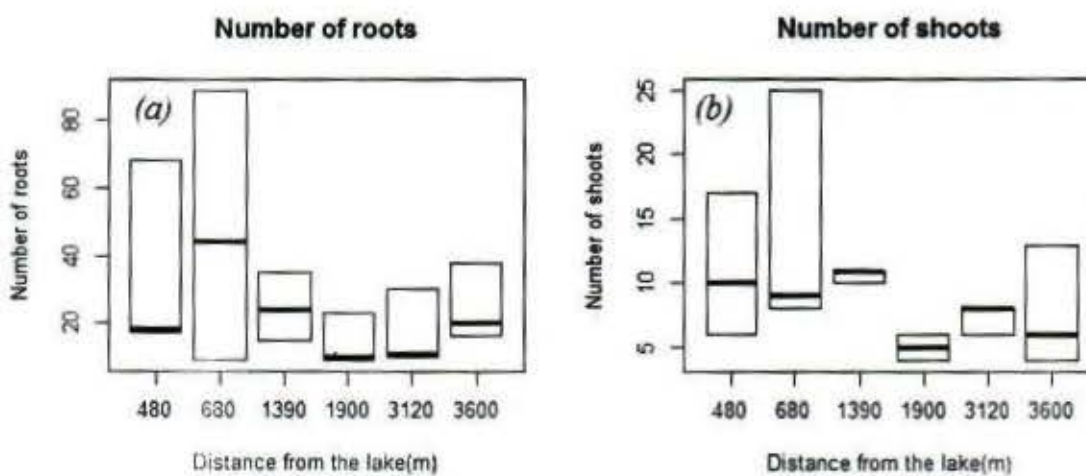
		Mean Diff.	95% C.I	
			Lower	Upper
<b>Root</b>				
<b>Length</b>	<i>Phragmites</i> -Papyrus	-14.8308	-17.11948	-12.542
	<i>Typha</i> -Papyrus	-6.182	-8.226982	-4.137
	<i>Typha</i> - <i>Phragmites</i>	8.6488	6.450137	10.8475
<b>Root</b>				
<b>Number</b>	<i>Phragmites</i> -Papyrus	-6.6667	-8.57265	-4.7607
	<i>Typha</i> -Papyrus	9.6111	7.705119	11.5171
	<i>Typha</i> - <i>Phragmites</i>	16.2778	14.371786	18.1838
<b>Off-Shoot</b>				
<b>length</b>	<i>Phragmites</i> -Papyrus	-23.0306	-31.4077	-14.6535
	<i>Typha</i> -Papyrus	-7.272	-17.12356	2.5795
	<i>Typha</i> - <i>Phragmites</i>	15.7585	5.120735	26.3963
<b>Off-Shoot</b> <b>Number</b>	<i>Phragmites</i> -Papyrus	-3.2778	-3.706004	-2.8496
	<i>Typha</i> -Papyrus	-5.8889	-6.317115	-5.4607
	<i>Typha</i> - <i>Phragmites</i>	-2.6111	-3.039337	-2.1829

Table 4.4 indicates that, the root length significantly differs by plant species. *Phragmites* had shorter root length as compared to Papyrus (Mean diff= -14.831). *Typha* on the other hand,

had shorter root length as compared to Papyrus (Mean diff= -6.182) and longer root length on average when compared to *Phragmites* (Mean diff= -8.646). This implies that the root length of Papyrus is much higher than that of *Typha* and consequently *Phragmites*.

#### 4.2.2 Suitability of Cyperus, Typha and Phragmites in rehabilitation of pits based upon distance from the lake

Regardless of the species, more belowground growth was measured in pits closer to the lake than those further away. The root system of *Typha* was characterized by a very high density of fine roots in contrast to less dense fine roots in *Papyrus* and *Phragmites* across the different distances (Table 4.3). Papyrus, close to the lake was highly distributed followed by *Typha* while *Phragmites* was least distributed (Figure 4.6; 4.7 and 4.8). All the measured traits for Papyrus were higher in pits close to the lake than pits further away (Figure 4.4). The number of roots of *Phragmites* were higher in pits closer to the lake whereas the shoot and root length had higher values further away from the lake shore. For *Typha*, the number of roots reduced with increasing distance while the number of shoots, root and shoot length first increased with increasing distance upto about 2km before assuming a decreasing trend.



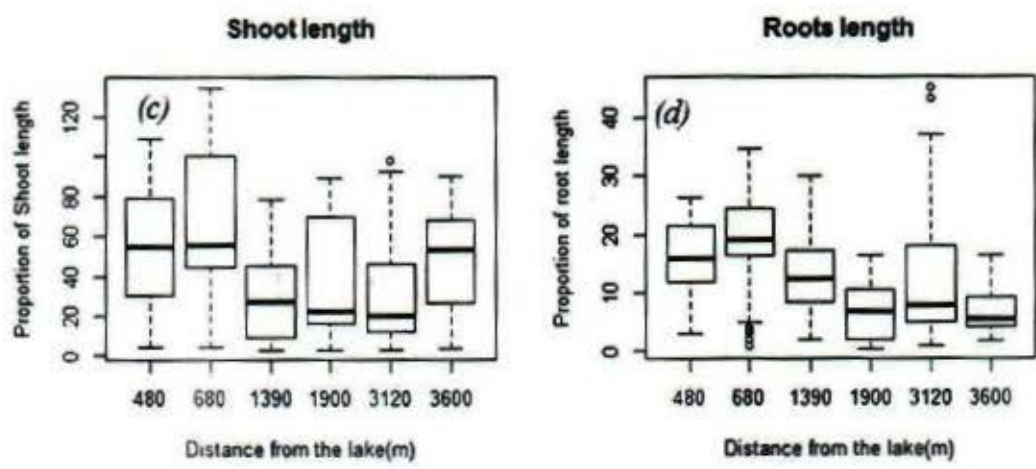


Figure 4.6: a) Number of roots; b) Number of shoots; c) Shoot length and d) Root length of Papyrus at varying distance from the lake

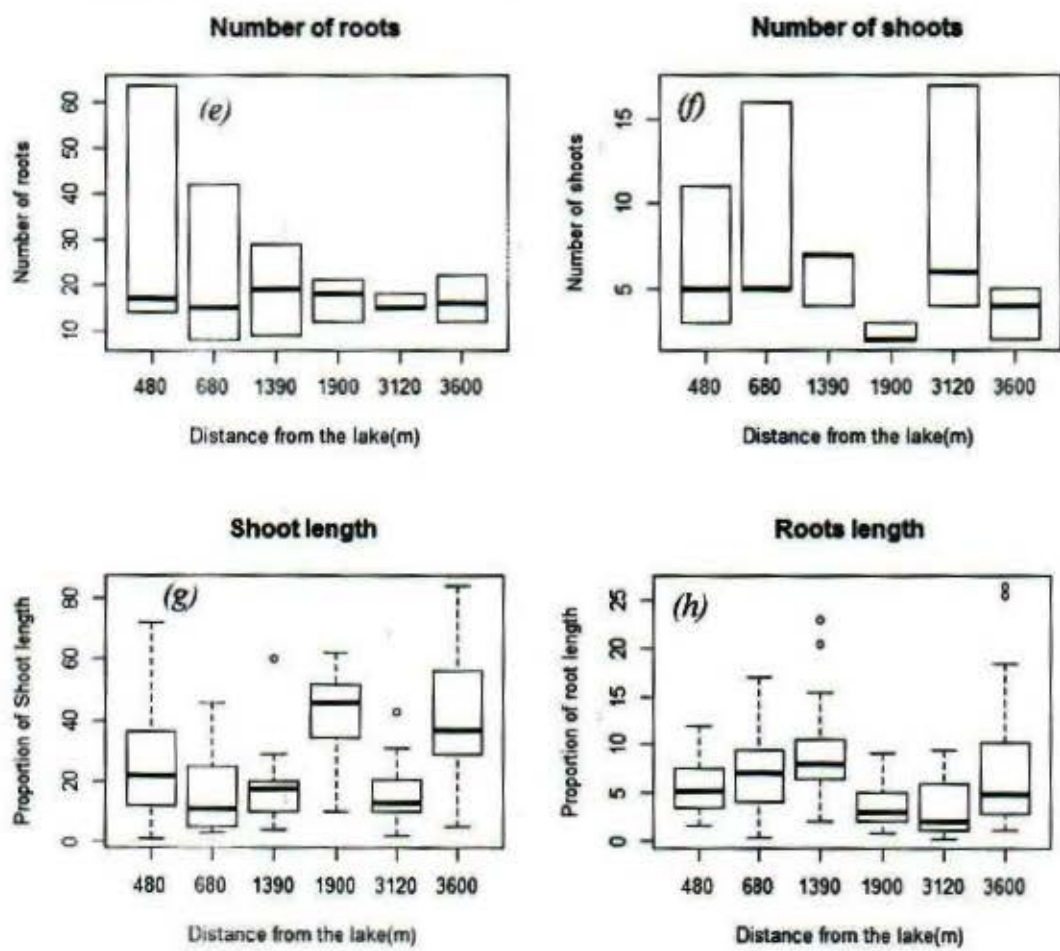
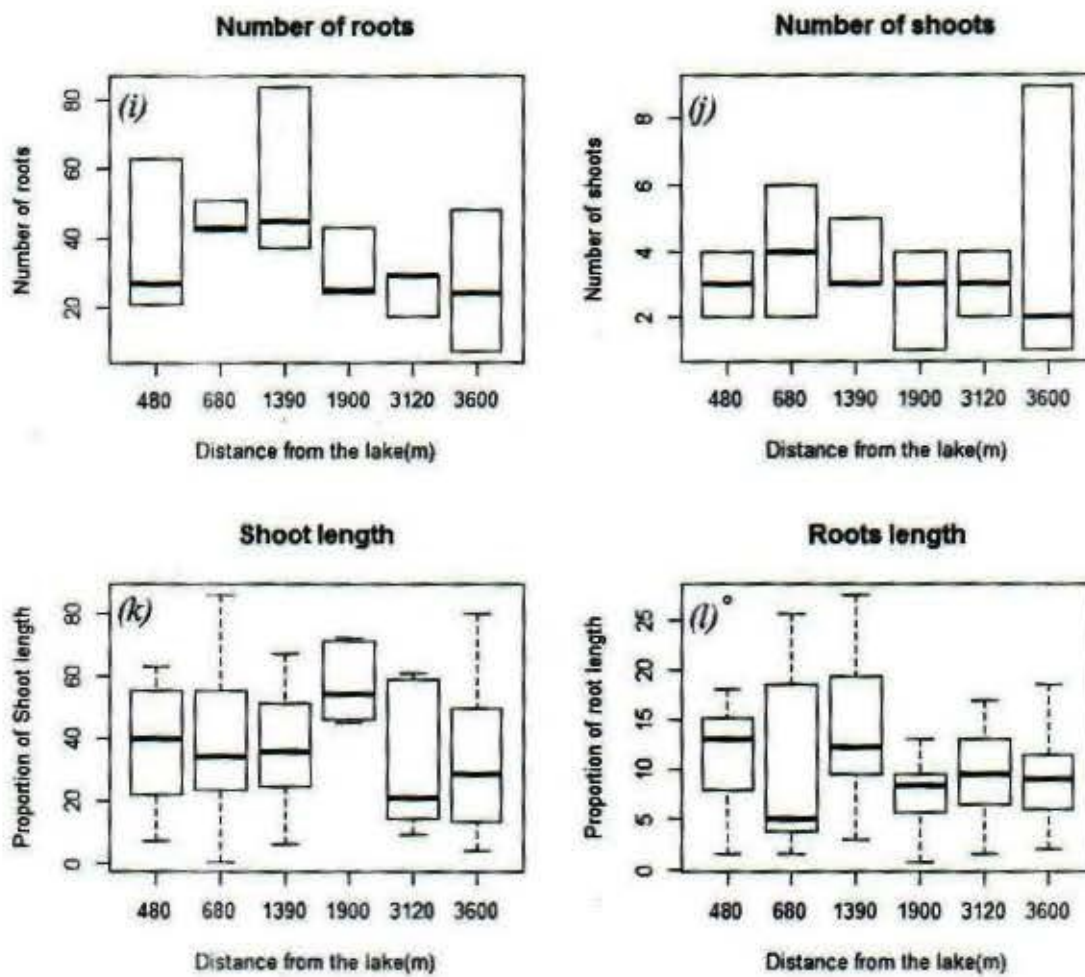


Figure 4.7: e) Number of roots; f) Number of shoots; g) Shoot length and h) Root length of Phragmites at varying distance from the lake





**Figure 4.8: i) Number of roots; j) Number of shoots; k) Shoot length and l) Root length of *Typha* at varying distance from the lake**

Pit depth too had a significant effect on the the establishment of the plant species. For *Papyrus*, shoot length increased with increasing depth and so was root length. The number of shoots and roots increased in depth upto 2.6m before starting to drop. The number of roots of *Phragmites* increased with depth while the number of shoots reduced with depth. Further, the shoot length of *Phragmites* increased while its root length reduced with depth. The root number, shoot number and root length of *Typha* showed decreasing trends with depth before finally increasing. The shoot length of *Typha* however increased with depth.

4.2.3 Establishment of *Papyrus*, *Typha* and *Phragmites* in relation to pit depth

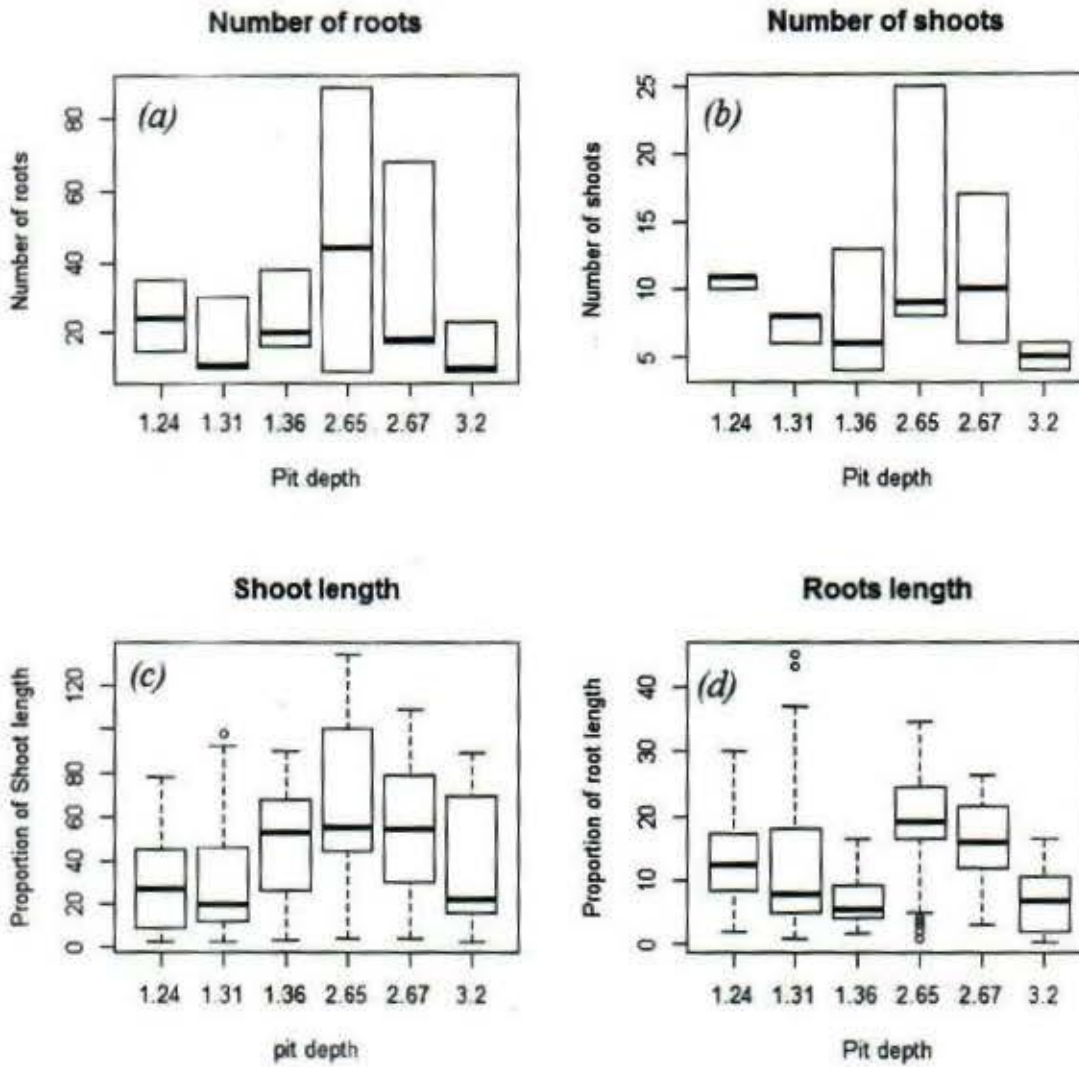


Figure 4.9: a) Number of roots; b) Number of shoots; c) Shoot length and d) Root length of *Papyrus* at varying pit depth

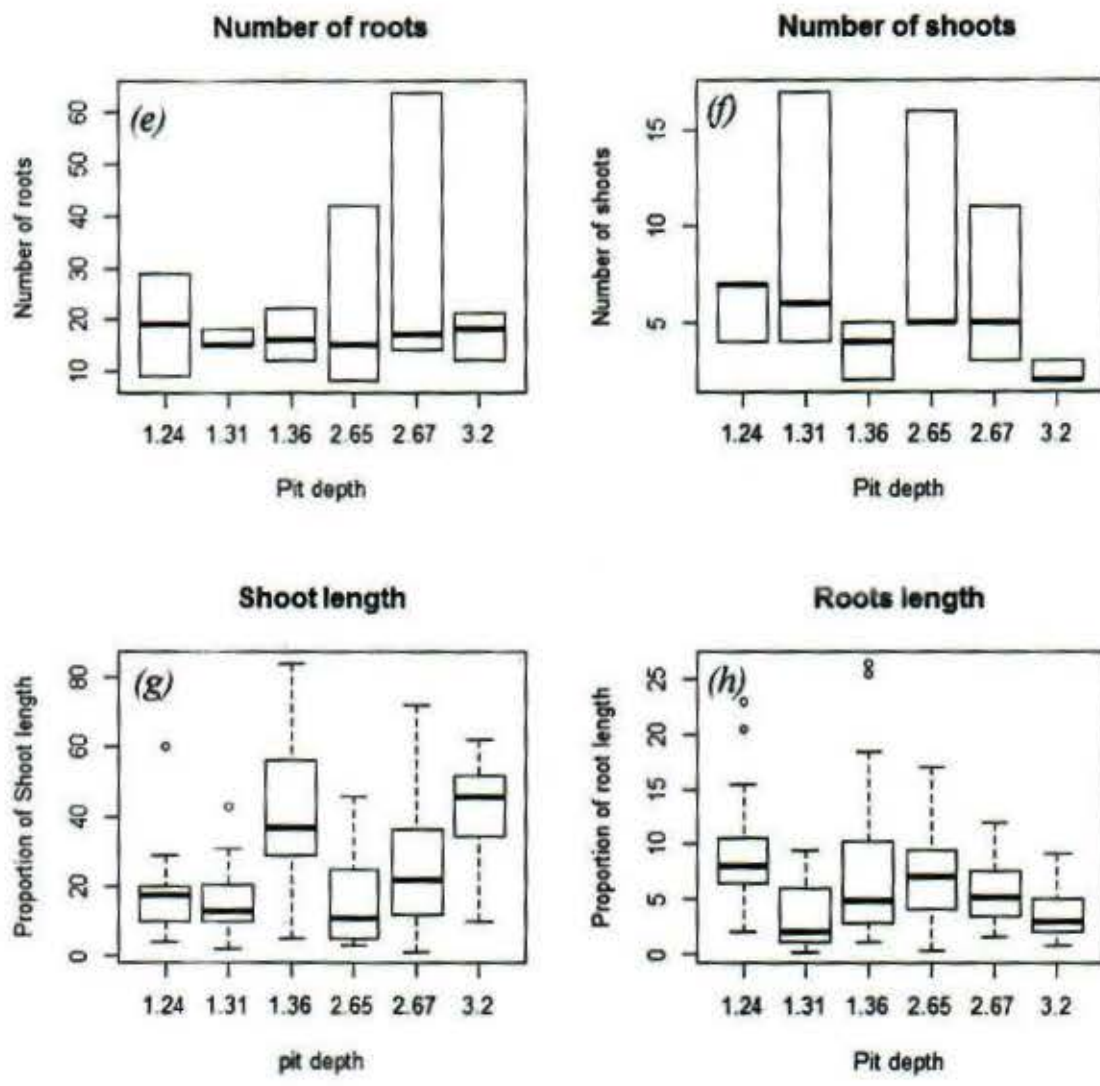
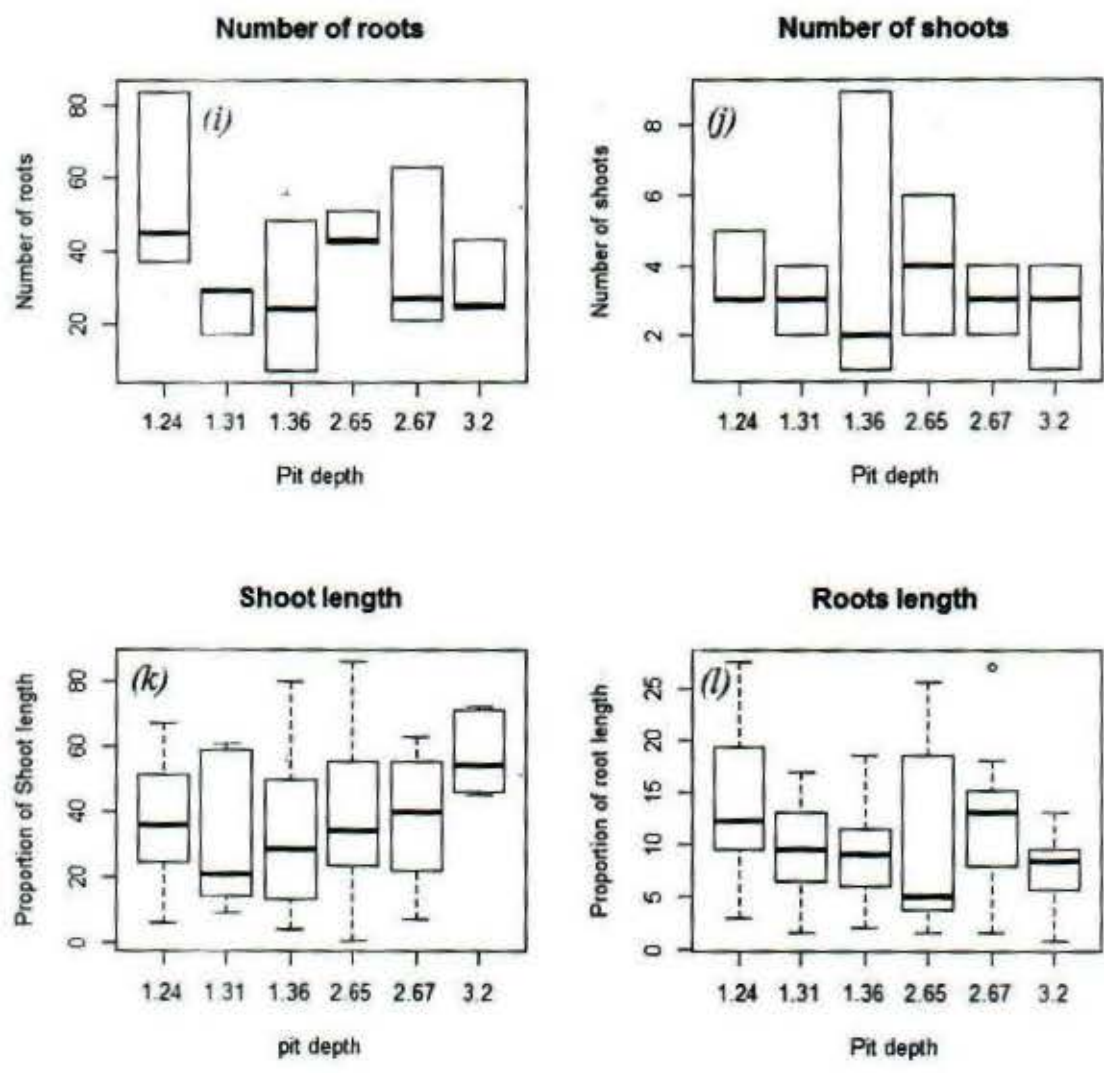


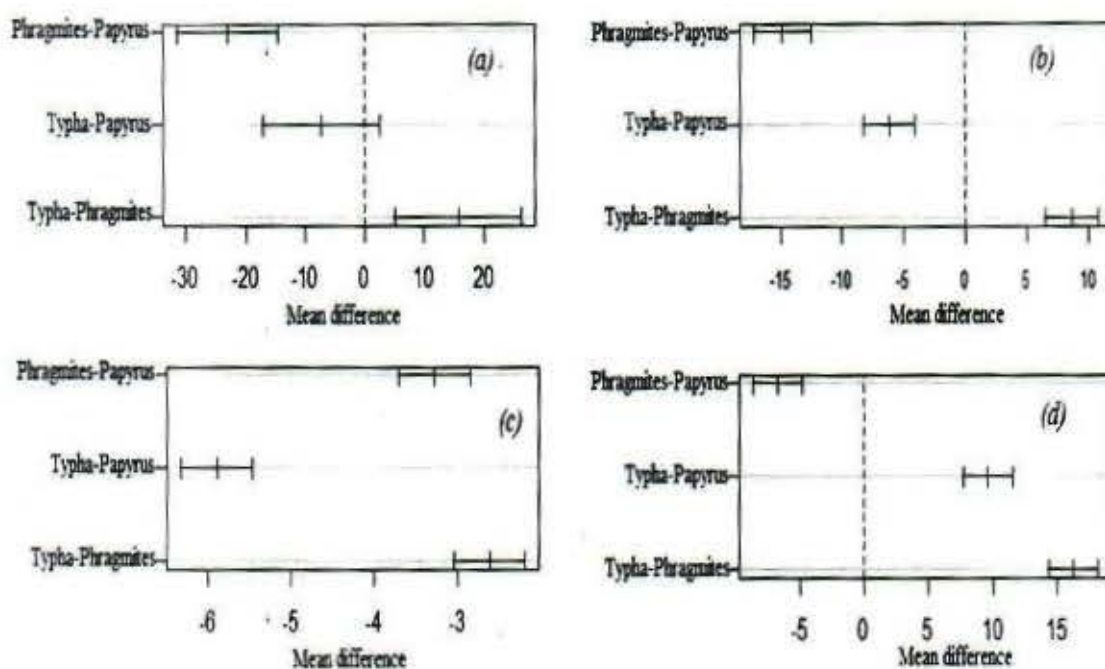
Figure 4.10: e) Number of roots; f) Number of shoots; g) Shoot length and h) Root length of *Phragmites* at varying pit depth





**Figure 4.11: i) Number of roots; j) Number of shoots; k) Shoot length and l) Root length of *Typha* at varying pit depth**

A discriminant analysis was also computed on the basis of the four traits using species as groups to test the effectiveness of the traits in differentiating individuals of the different species. This was on the basis that traits can simultaneously explain individual plant responses to biotic and abiotic factors, and ecosystem effects. The comparison in the measured traits is shown in (Figure 4.12).



**Figure 4.12: Multiple comparisons of differences in means of plants traits (a) Shoot length (b) root length (c) Number of shoots and (d) Number of roots at 95% family-wise confidence level.**

The difference in traits between *Phragmites* and *Papyrus*, *Typha* and *Papyrus* and *Typha* and *Phragmites* are significant except for the shoot length of *Typha* and *Papyrus*. The greatest separation in the species can be seen in the root length (belowground trait) and in the number of shoots (above ground trait) (Figure 4.12).

Controlling for distance from the lake, the GLMM (Table 4.3) predicted that the average root length reduces significantly in *Phragmites* as compared to *papyrus* ( $p < 0.05$ ). However for shoot length, there is still a significant reduction. Also, the average root length reduces

significantly in *Typha* as compared to papyrus. It is however not significant for shoot length ( $p=0.112$ ).

**Table 4.5: Parameter/ Estimates for GLMM for the different responses**

Model 1: Root length				Model 2: Number of shoots		
Parameter	Coeff.	Std. Error	Pr(> t )	Coeff.	Std. Error	Pr(> t )
(Intercept)	37.650	1.056	< 2e-16 ***	12.488	0.232	< 2e-16 ***
Phragmites	-23.990	1.617	< 2e-16 ***	-5.565	0.328	< 2e-16 ***
Typha	-13.790	1.451	< 2e-16 ***	-9.151	0.328	< 2e-16 ***
distance	-0.006	0.001	< 2e-16 ***	-0.002	0.000	< 2e-16 ***
Phragmites*distance	0.005	0.001	8.17e-12 ***	0.001	0.000	3.04e-16 ***
Typha*distance	0.004	0.001	1.53e-09 ***	0.002	0.000	< 2e-16 ***
<b>AIC: 9436.2</b>				<b>AIC: 15420</b>		
Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.1 '.' 1 '***' 0.001 '**' 0.01 '*' 0.1 '.' 1						

From the table, the root length of papyrus increases by 23.990 when compared to *Phragmites* and 13.790 when compared to *Typha*. It can therefore be noted that the root lengths are higher for *papyrus*, followed by *Typha* and then *Phragmites*. Relatedly, the shoot length was highest in *Papyrus*, followed by *Phragmites* and then *Typha*. With regards to distance from the lake, an increase in distance from the lake shore leads to a reduction in root length of *Phragmites* by 0.005 and of *Typha* by 0.004. For the number of shoots, an increase in distance lead to a reduction in *Phragmites* by 0.001 and in *Typha* by 0.002. This means that plants further away from the lake have shorter root lengths as compared to those that are nearer the lake and a reduced number of shoots. This is in line with the hypothesis that plant communities establish easily at pits nearer the lake shore than those far away.



### **4.3 Discussions**

#### **4.3.1 Pit Characteristics**

The summary statistics of the distribution of pit depth by distance (Table.4.2) showed that pits closer to the lake were shallower as compared to those further away. This could be because the difficulties in operation of machinery dictate that the pits are dug deeper where the water table is further and maintained shallower where the water table is close for safety reasons. Pits closer to the lake were also found to be wider and this could be explained by the fact that depth inhibits deep mining and so the pits are made wider to maximize the sand excavated from pits. The low depth in the furthest pits can be attributed to reduced sand deposits that are typical of areas far from the lake. Pits and ditches associated with mined areas are often associated with invasive plant species which reduce vegetation biodiversity (Kercher and Zedler 2004). The pits further constrain movement of land dwelling animals that cannot cross pits in addition to altering the hydrological regimes of the habitats (Trombilak and Frissell, 2000). The ability of wetlands to buffer against floods is thus impacted (Zedler and Kercher, 2004), and this formed the basis for testing establishment of native vegetation in the remnant pits.

#### **4.3.2 Characterization of landscape disturbance**

Mining of sand in the study area resulted in destruction of vegetation and consequently the natural habitats of some animals. By altering the hydrologic regime, sand excavations in wetlands often has significant physical and biological effects on the natural environment and the ecological processes of the affected area. The land use in the study area showed dramatic changes over the study period. There was an overall increase in the number of patches (NP) under vegetation (Figure 4.2b). This can be attributed to increased sand mining activities in the area over the study period with the licensing of commercial sand miners in the wetland (NEMA, 2015) which consequently led to clearing of vegetation to make way for camp sites and infrastructure in the area and thus making the vegetation class patchier. And often time, an increase in the number of patches of vegetation implies fragmentation or dissection of the landscape and consequently a reduction in the area of the habitat (Fahrig, 2003). A reduced habitat area would lead to a decline in species density and composition (Hill & Curran, 2001). This implies that large patches of vegetation are necessary for conservation of species.

Also contributing to the increase in the number of patches under vegetation could be open sand areas that have been abandoned and hence regenerated into isolated vegetation colonies (Kalungu District Local Government, 2016).

The number of patches of open water however showed a declining pattern over the study period (Figure 4.2b). This could be explained by the fact that some of the pits could have been covered by emergent vegetation thus reducing their number and making the landscape appear homogenous and continuous with reduced patches. Relatedly, the low number of patches can also be attributed to increased rehabilitation efforts in the wetland which has become a requirement for the miners currently owning leases in the wetland (NEMA, 2015). Increased patches of open water would lead to an increase in the rate of evaporation resulting from increased open water surfaces, hence lowering the water table, and consequently impacting on plant communities around the wetland (Global Witness, 2010). Revegetation of these pits would therefore go a long way in improving mined landscapes.

An increasing trend in the number of patches of sand fields (Figure 4.2b) can be explained by increasing mining activities in the wetland as more developers get permits to mine in the wetland. The smaller number of patches in the reference year (2010) could be explained by the fact that the wetland had not yet been opened up to commercial mining.

Edge metrics from the analysis also showed increasing trends for all the classes which further explains fragmentation (Figure 4.2a). Edges are transition zones that separate adjacent habitats, and are often created by habitat destruction (Harper et al., 2005). Edge for all the classes increased for the whole period of study (Figure 4.2a). It is reported that edges of vegetation have a tendency to change the biological and physical conditions around patch boundaries and within adjacent patches which impacts on species richness (Ries et al. 2004; Harper et al. 2005). More edge as is reported in the study would therefore lead to an alteration in species populations and facilitate the spread of invasive species as edges tend to be warm, windy and receive more light than habitat interiors (Fahrig, 2003). Increased solar radiation can produce higher temperatures and drier conditions, particularly when coupled with increased airflow from surrounding open which would restructure the ecological community within patches. An increase in edge for the open water and sand fields classes further depicted fragmentation of the landscape.



The class area metrics further confirmed fragmentation of the landscape over time (Figure 4.). The increase in class area of vegetation between 2016 to 2017 could be attributed to increased restoration endeavors in the wetland. The decrease however between 2017 and 2018 can be explained by an increased level of mining that out-paced rehabilitation efforts thus shrinking the vegetation area. A reduction in class area for vegetation would consequently mean a reduction in habitat area. It is widely reported that a reduction in patch or class area exposes the remaining patches to external influences (Saunders et al., 1991) which consequently impacts on survival of certain species. Larger patches are preferable especially for organisms that require interior habitat. MacArthur & Wilson 1967 report that reduction in the area of habitats could result in higher extinction rates in smaller habitats resulting from their reduced populations and vulnerability to environmental effects. Larger wetland area hence supports high species diversity due to within site dispersal opportunities and higher probability of receiving dispersed seeds and propagules in addition to greater habitat heterogeneity (Mathews et al, 2005, Moreno- Mateos et al 2012).

#### **4.3.3 Plant traits suitable for benchmarking establishment of the study species**

This study demonstrated that wetland species along a hydrological gradient showed a parallel continuum of growth patterns in terms of height growth and emergence of roots. The purpose of the experiment was to identify a plant that could mobilise aboveground biomass to support the below ground components so that the roots are extensive enough to mobilise belowground material and in turn form mats that would coalice to rehabilitate the pits over time. A long root structure would provide attachment to the plants and consequently trap suspended material in the system (Boar, 2006).

Since the goal of the study was to compare performance of three species and the factors that could have enhanced their growth, it was shown that higher productivities could be achieved in areas closer to the lake that have a more stable water regime (Callaway, 2001). The plant traits that showed maximum separation of the species were root length and shoot number. It would have been useful to follow the experiment for atleast a year to ascertain what happens to the aboveground and belowground components of the study species but this was not possible in the absence of time and finances. Otherwise, the results as presented are indicative of the potential for using this approach to rehabilitate mined areas only if the pits are not so deep and not so wide as wider pits would require more time for the plants to coalice.



#### 4.3.4 Establishment of the dominant wetland species

Study findings on root length indicated that, papyrus had the longest overall in comparison to *Typha* and consequently *Phragmites*. The plant traits were however shown to be influenced by the distance of the pits from the lake shore which implies variation in water levels. This also confirms earlier work which report strong influence of hydrology on wetland species establishment (Hudon et al., 2005; Jong & Jae, 2017). For *Phragmites*, it was shown that the shoot length of *Phragmites* increased while its root length reduced with depth. The increased proportional allocation to shoots in deeper water is in accordance with results for other emergent species (Boar, 2006). The importance of having longer shoots above the water surface has been attributed to light limitation (Casanova, 2014). It is further documented that Plants growing in deep water face a trade-off between the need for longer stems to grow above the ground and the longer roots for nutrient acquisition. The distribution of root length and shoot length of Papyrus by pit depth indicates that the two traits generally increased with increasing pit depth. The trend was however interrupted by a decline above a pit depth of 2.64m. This same pattern was mirrored in the number of shoots and roots. The response of the species is in line with findings by (Aulio, 2015) that species can have multiple or even opposite responses to one or more environmental gradients and thus different functional traits may respond to different factors. Previous findings have attributed wetland plant establishment to a multiplicity of other factors related to individual sites particularly nutrient availability, light intensity and water quality (Chambers et al., 2002; Hodge 2004). The patterns observed could therefore be attributed to fertility or lack of in some the sites. Although many wetland species are able to survive in a wide range of pit depths (Grace, 2016), the growth of these plants become inhibited at greater depths as sediments become fewer. The shorter root length in *Typha* in this study could have resulted from effects of the more reducing sediment at greater depth. The shorter root length is known to be a result of oxygen stress in highly reducing sediments, (Kludze et al., 1993; Armstrong et al., 1996). Short, thick roots are favoured when plants are under oxygen stress because they have low axial resistances to oxygen diffusion, (Armstrong et al., 1990). Identifying environmental conditions at suitable habitats remain key for successful plant establishment.

## CHAPTER FIVE

### SUMMARY, CONCLUSION AND RECOMMENDATIONS

#### 5.1 Summary and conclusions

The study characterized landscape patterns in Lwera wetland using class level landscape metrics. The metrics indicated higher fragmentation between 2017 and 2018. The results are beneficial in reporting the effects of mining on the wetland and put into perspective the changes that have occurred over time. It further demonstrates the possibility of using remote sensing to quantify spatial changes in the wetland and experimental justification that native vegetation can be revegetated in formerly mined pits by use of platforms. The first goal of the study was to evaluate the effects of mining on the extent of fragmentation of Lwera wetland. Analysis done involved size, edge, shape and number of the patches. The results revealed three important aspects;

- i. The three classes were heterogeneously distributed across the landscape with fluctuations in both configuration and extent over the study period.
- ii. All scenarios indicated more patches than existed during the reference period.
- iii. Many of the metrics applied showed habitat loss and fragmentation.

The increase in patch number with a corresponding reduction in the average area is characteristic of disturbed areas which are an indication of fragmentation in the post mining landscape. An increase in the length of the patch boundaries (TE) indicates trenching of the landscape which also leads to the fragmentation (disintegration) of large and dense patches that often dominate the structure of the pre-mining area.

The study also validated, for the species tested, that vegetation can be re-established in mined areas. The establishment of wetland tree species on previously degraded pits offers insights into reduction of fragmentation which may prove useful in rehabilitation projects. Generally, it was found that the strength of the species signal is strong enough for all the traits to allow them be used in monitoring plant establishment in rehabilitated lands. The results further show the potential for *Papyrus* to out-perform *Typha* and *Phragmites* in establishment although more work is still needed in longer term monitoring of the trends.



Further, there was a high survival rate of the planted species, and the plants spread rapidly during the two months of study; an indication of a promising performance in the system. More growth and expansion is expected judging from the growth trends. The plant species introduced in the mined areas rapidly established, but *Papyrus* was particularly more successful growing upto a height of 94cm. The findings herein provide experimental information on establishment of vegetation on formerly mined lands and can thus be used to improve our ability to predict the dynamics of wetland vegetation and so facilitate the formulation of wetland restoration strategies.

The analyses also showed that water depth is not the only explanation for differences in plant root and shoot length. The three species each showed roughly the same pattern with peak growth recorded after six weeks from planting. Data from the earliest visits suggests that papyrus emerged faster than *Typha* and *Phragmites*. The observed interactions among sites, species, and experimental treatments highlight the need to accurately match species and sites to achieve optimum growth and survival rates. The response trend of the study species requires further study based on more field observations and analyses.

The results obtained from the analysis therefore should constitute the basis for indicating the areas that require rehabilitation, along with the determination of the kinds of habitat necessary to strengthen the natural structure of the degraded areas. At the same time, they can be used to determine the directions of reclamation and management of the areas, which in effect will allow the restoration or creation of the appropriate structure of post-mining landscape. This would facilitate both a maximization of benefits for people and the achievement of a new equilibrium in the natural system. Planting vegetation in the mined lands would contribute to large vegetation patches providing an improved patch size distribution by offsetting the numerous small patches caused by disturbance (Dale & Pearson, 1997).

## **5.2 Conclusions**

A number of conclusions have been drawn on the basis of findings from the study;

The findings revealed that pits closer to the lake were shallower as compared to those further away and that mining of sand in Lwera wetland had resulted in destruction of vegetation and consequently the natural habitats of some animals as indicated by an increase in the number



of patches and an overall reduction in the area of vegetation. Further, it was also shown that fragmentation in the wetland could be described using Number of patches and class area metrics.

It can also be concluded that the root length and number of shoots are the traits suitable for benchmarking establishment of the tested species as the two traits explained more variation among the species. Results also showed that papyrus established faster than *Typha* and *Phragmites* following a hydrological gradient from the lake shore.

### **5.3 Recommendations**

Most of the rehabilitation efforts have hitherto been based on gut feeling rather than scientific procedures making them largely unpredictable and as such, these methods are poorly captured in literature limiting their application. It is therefore recommended that;

The newly revegetated areas are regularly monitored to identify long term performance of the planted species and to map out and control invasives as these compete for vital resources like nutrients, light and water.

It was also clear that expansion dynamics of the planted species cannot be studied in a short period of time which calls for a doctoral project. The work so far done is a critical step that would facilitate operational costing in terms of time and finances.

The study is a contribution to the science on hydrological manipulation of mined wetlands which should further investigations into other approaches that would increase vegetation resources in mined areas.

With regulators becoming increasingly interested in tracking restoration progress, there is need for bolder approaches which are dependent on field experimentation at numerous temporal and spatial scales so as to ably predict restoration projectory. Research therefore needs to bridge the gap between structural attributes that can be easily measured and ecosystem functions.

There is need to increase public funding to facilitate wetland rehabilitation in sites that provide the greatest environmental benefits at a landscape scale. It is also important to recognize the desire of many private landowners to restore wetlands for the site-scale benefits

they provide. It is also important for governments to prioritize rehabilitation of sites without sacrificing standards for design and implementation.

Besides, our limited experience in rehabilitating degraded lands calls for development of rehabilitation plans that are site specific to increase success rates. Possible constraints ought to be documented to facilitate rehabilitation in similar environs. The objectives of restoration should also be more open to allow for authenticity and spontaneous recovery as opposed to end points of natural succession.

Increased international dialogue is needed to develop the science of restoration, and design implementation practices for both habitat oriented and multi-objective projects. Cooperation is needed to provide the guidance materials and necessary training

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**APPENDICES**

**Appendix 1: Data collection sheets**

**Sheet 1. (A)**

**Pit Data**

**Pit location:**

Village. \_\_\_\_\_ Parish. \_\_\_\_\_ Sub-County. \_\_\_\_\_ District. \_\_\_\_\_

Latitude. \_\_\_\_\_ Longitude. \_\_\_\_\_ Pit No. \_\_\_\_\_ Band. \_\_\_\_\_ (m)

Date of excavation. \_\_\_\_ / \_\_\_\_ / \_\_\_\_

**Pit Dimension:** Length. \_\_\_\_\_ (m) Width. \_\_\_\_\_ (m)

Depth. \_\_\_\_\_ (m) Size. \_\_\_\_\_ (m)

**Water quality:** Turbidity. \_\_\_\_\_ PH. \_\_\_\_\_

B.O.D. \_\_\_\_\_ Water Level. \_\_\_\_\_

**Sheet 1. (B)**

**Plant Data**

*Typha*: below and above ground characteristics

Date	Substrate Treatment	Root Length (cm)	Root No.	Node length (cm)	Node No.	Leaf length. (cm)	Leaf No.	Rhizome length (cm)	Off-shoot No.	Culm height (cm)
	Perforated Sisal bags									
	Perforated Mats									

**Notes**

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**Sheet 3. (A)**

**Pit Data**

**Pit location:**

Village. \_\_\_\_\_ Parish. \_\_\_\_\_ Sub-County. \_\_\_\_\_ District. \_\_\_\_\_

Latitude. \_\_\_\_\_ Longitude. \_\_\_\_\_ Pit No. \_\_\_\_\_ Band. \_\_\_\_\_ (m)

Date of excavation. \_\_\_\_/\_\_\_\_/\_\_\_\_

**Pit Dimension:**

Length. \_\_\_\_\_ (m) Width. \_\_\_\_\_ (m)

Depth. \_\_\_\_\_ (m) Size. \_\_\_\_\_ (m)

**Water quality:**

Turbidity. \_\_\_\_\_ PH. \_\_\_\_\_

B.O.D. \_\_\_\_\_ Water Level. \_\_\_\_\_

**Sheet 3. (B)**

**Plant Data**

*Phragmites*: below and above ground characteristics

Date	Substrate Treatment	Root Length (cm)	Root No.	Node length (cm)	Node No.	Leaf length. (cm)	Leaf No.	Rhizome length (cm)	Off-shoot No.	Culm height (cm)
	Perforated Sisal bags									
	Perforated Mats									

**Notes**

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**Appendix 2: Metrics for landscape fragmentation**

YE AR	TYP E	CA	PLAN D	LPI	TE	ED	AREA_ MN	AREA_AM
2010	Cls_ 1	522.176	13.062 2	0.792	398607	99.711	0.5738	6.8114
2010	Cls_ 2	633.907	15.857 1	3.740	377256	94.370	0.6715	51.670
2010	Cls_ 3	2841.52 8	71.080 7	63.126	428835	107.27 3	18.2149	2259.70
2016	Cls_ 1	771.992	19.319 2	1.2182	623964	156.14 8	0.4452	5.5613
2016	Cls_ 2	1312.13 6	32.836 4	19.313	575091	143.91 7	1.6139	461.824
2016	Cls_ 3	1911.84 8	47.844 3	42.385	577071	144.41 3	4.9274	1501.63
2017	Cls_ 1	1019.08 6	25.502 8	7.036	688809	172.37 6	0.8564	88.105
2017	Cls_ 2	901.583	22.562 3	3.954	601227	150.45 8	0.7772	35.092
2017	Cls_ 3	2075.30 7	51.934 9	44.162	687456	172.03 7	3.3527	1501.24
2018	Cls_ 1	1076.69 4	26.944 5	8.827	696267	174.24 2	1.0854	125.523
2018	Cls_ 2	998.613	24.990 5	5.161	572715	143.32 3	0.9054	60.159
2018	Cls_ 3	1920.66 9	48.065 1	34.676	678414	169.77 4	2.6347	1010.09