Weed species composition and diversity in flood recession farming in the Okavango Delta, Botswana.

by

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Disclaimer

The work contained in this thesis was completed by the author at the University of Botswana from June 2014 to June 2018. It is an original work except where due references are made. It neither has been nor will be submitted for the award of any other university.

Signature: __________________________

Dedication

This work is devoted to my family, especially my children (Wame-Lola and Sean-Wedu) and my late mother Agnes Mmereki.

Thesis outline

In Chapter 1 the general introduction of the study is provided. This also includes the statement of the problem and the study objectives. In Chapter 2 the weeds species composition and diversity in flood recession farming areas of the Okavango Delta were investigated. The influence of cultivation frequencies on weed species composition and diversity in flood recession farming in the Okavango Delta was determined in Chapter 3. The drivers influencing weed species composition and diversity in flood recession farming were investigated in Chapter 4. Chapter 5 dealt with assessing the association of weed species biomass and maize biomass in flood recession farming. A synthesis of the study findings are provided in Chapter 6.

Abstract

Globally, flood recession farming is practiced in wetlands such as lakes, floodplains, swamps and rivers. Major wetlands where flood recession is practiced include the Dianchi and Kunming lakes in China, the Yunnan River in Malaysia, the Pantanal in Brazil, the Sudd Swamps of the Sudan, the Omo Valley in Ethiopia, Tana River in Kenya and Rufiji River in Tanzania. In Botswana it is practiced along the Chobe River and the Okavango Delta. It is locally known as *molapo* farming. It is generally perceived as giving higher yields than dryland because it is practised in an environment with high soil moisture and fertile soils. Agroecosystems in floodplains can modify plant communities by creating micro-climatic conditions that favour some and disfavour other plant species. Previous studies on flood recession farming focused more on yields and less on weeds. Most phytosociological work on floodplains in the Okavango Delta has been focussed on natural vegetation communities and their response to hydrology, while little attention has been given to the use of seasonal floodplains for agricultural production. Therefore this study seeks to determine the weed species composition and diversity in flood recession farming in the Okavango Delta.

The study was conducted in Shorobe, Makalamabedi and Lake Ngami in north western Botswana. Vegetation sampling was conducted in 36 *molapo* fields from March to April 2016. The fields were categorised according to the number of years they were cultivated continuously. The categories were: cultivated for 5 years; 10 years; 15 years and uncropped sites**.** Full species counts were done in $1m^2$ quadrats placed at 10m intervals along a line transect. Soil samples and GPS coordinates were taken from each field. Hierarchical cluster analysis was used to determine weed species communities using indicator values derived from Indicator Species Analysis. A multi-response permutation procedure was used to test the hypothesis of no difference between the groups of species communities. Kruskal-Wallis was used to test for statistically significant difference in species diversity between species communities. Diversity indices (Shannon's index and Evenness) were used to determine

species diversity for each cultivation frequency within and across the study sites. Kruskal-Wallis was used to test for significant difference in species diversity between the cultivation frequencies. Rank of abundance was used to determine the association of weeds with the cultivation frequencies. To evaluate whether the mean biomass of crops and field status (weed free and weedy) were statistically different from one another, Independent-t test was used.

Results showed no statistically significant difference ($p > 0.05$) in species diversity (Shannon's index) between weed species communities in flood recession farming but species evenness (Equitability index) was significant at $p < 0.001$. There was a significant difference ($p = 0.042$) in diversity indexes across the 4 cultivation frequencies. The 5 year frequency recorded the highest median score (Md = 1.352) while the 15 year frequency recorded the lowest median score (Md = 1.035). *Corchorus tridens* L. was the most abundant weed species at the 5 and 15 year frequencies. *Cynodon dactylon* (L) Pers. was most abundant in the 10 year frequency while *Cyperus esculentus* L. was most abundant in uncropped fields. The canonical correspondence analysis results indicated that variations in weed species composition in flood recession farming were explained more by available phosphorus and flood frequency. There was a statistically significant difference $t(14) = 7.553$, $p \leq 0.001$ in the mean maize biomass scores between weed free and weedy fields.

Cultivation frequency influenced weed species composition and diversity in flood recession farming areas of the Okavango Delta. Uncropped sites were composed of wetland species that tolerate some dry periods or seasonal flood plains. Flood recession farming fields were dominated by common weed species which are also troublesome in dryland arable farming.

Flooding frequency and available phosphorus were the main drivers of composition and diversity of weed species in *molapo* farming. For instance, species like *Cyperus longus*,

Zornia glochidiata and *Alternathera sessilis* were found mainly in *molapo* fields with high flooding frequency.

This study has provided an inventory of the most abundant and trouble-some weed species in flood recession farming in the Okavango Delta. The study has also revealed that high cultivation frequency tends to suppress weeds hence reduction in their diversity. And at a moderate cultivation frequency weeds species were activated and newly created micro-climate favoured their germination and growth. The study have assisted in understanding the status of weeds in *molapo* farming as such provided valuable information which might be useful when designing a sound and successful weed management program in flood recession farming areas in the Okavango Delta.

Keywords: Flood recession farming; Cultivation frequency; Weed species; Diversity.

Chapter 1

1.0 General introduction

1.1 Introduction

Farming practices around the world include shifting agriculture, wet rice cultivation in Asia, pastoral nomadism and Mediterranean agriculture (Grigg, 1974). Farming systems can be categorised depending on the environmental conditions of the area under which they are being practised and the level of production employed. For instance, Dixon et al. (2001) categorised farming systems as rainfed highlands, rainfed dry/cold and small holder irrigation schemes. Small holder rainfed highland farming system is practised in steep and highlands areas, and includes diversified crop-livestock systems which are traditionally oriented to subsistence production (Dixon et al. 2001). According to Harrington and Tow (2011), rainfed farming systems are found in areas as diverse as the Sahelian zone of West and Central Africa, East and Southern Africa, West and Central Asia, Western China and Semi-arid Australia. The intensity and productivity of this farming system is influenced by factors such as water availability, drought risk, and ratio of precipitation to potential evapotranspiration as well as soil quality (Harrington and Tow, 2011). These factors influence immensely, the contribution of the agriculture sector to the overall country's economy. For example, in Uganda the agricultural sector employed 69% of the population and contributed 26% to the gross domestic product (GDP) in 2015 (Deloitte & Touche 2016). In South Africa it contributed 1.9% in 2015 (DAFF 2016) and the Zambian agricultural GDP has consistently been above 8% though the rate of growth has remained below the Comprehensive Africa Agricultural Development Programme (CAADP) target of 6% in 2015 (Chapoto and Chisanga 2016).

Batswana practice pastoral farming and arable farming. The agriculture sector's contribution to GDP decreased from 40% at independence in 1966 to 2.5% in 2003 (FAO 2005) and recently dropped to 2.3% in 2013 (Statistics Botswana 2014). This apparent decline was largely due to an exponential increase in the contribution of minerals to the country's GDP (Seleka 1999). Challenges such as recurring droughts and inadequate use of appropriate technologies have negatively affected the agricultural productivity. ICRISAT-ILRI (2005) has shown that arable farming is the most affected due to its heavy dependence on rainfall compared to livestock farming. Arable farming in Botswana is mostly constrained by water (Moroke et al. 2010). There are limited opportunities for irrigated agriculture because of lack of enough surface water (Batisani 2010). Lack of adequate water is closely associated with low annual rainfall that is also erratic with significant between and within season variability. In addition, droughts which occasionally occur are largely responsible for crop failures in dryland farming. That notwithstanding, agriculture still plays a significant role in food security, income and employment creation for a significant number of households residing in rural areas (Seleka 1999). Arable practices have not significantly changed in the traditional farming sector. Farmers still practice broadcasting method of sowing and very limited weeding (ICRISAT-ILRI 2005). To date, agriculture still remains the basis of livelihood mainly as a source of food and income for many Batswana.

In Ngamiland district, arable agriculture is twofold; dryland and flood recession farming. The former is common and relies on local rainfall occurring in summer from October to April, and the latter relies on both local rainfall and floods from the Angolan highlands and is a key livelihood for riparian communities that reside along the fringes of the Okavango Delta (Magole and Thapelo 2005; Motsumi et al. 2012). Flood recession farming is a farming practice based on natural irrigation and fertilisation of the floodplains. It is commonly known as *molapo* farming in Botswana. It is intensively practiced by Botswana farmers who reside on the fringes of the Okavango Delta in the North West District. Favourable conditions under *molapo* farming such as high soil fertility and available soil moisture make *molapo* farming prone to weeds. Weeds are plants that interfere with human activity in crop and non-crop areas (FAO 1994). They are herbaceous plants not valued for use or beauty but regarded as hindering growth of superior vegetation. They are highly competitive and successful organisms since they can scavenge and compete for resources and respond rapidly to favourable growing conditions (Finney 2004). Weeds are problematic to agriculture. They impact negatively on crop yields and quality of produce. Weeds produce the highest potential yield loss of about 34% compared to animal pests and pathogens which cause 18% and 16% losses respectively, worldwide (Oerke 2005).

1.2 Socio-economic cost of weeds

Weeds are responsible for significant crop yield and financial losses in agriculture production. The losses are estimated to be in the order of 10% to 34% per year worldwide (Oerke 2005; Baucom 2009). Weeds cost Australian farmers around $1.5 billion a year in weed control activities and a further $2.5 billion a year in lost agricultural production since weeds reduce quantity and quality of agricultural, horticultural and forestry products, and subsequently the economic viability of the industries and the health of the consumers (Sinden 2004; Oerke 2005). Weeds still cause considerable yield losses (possibly as much as diseases and pests combined) despite the disproportionate effort expended in mechanical and hoe-weeding by smallholder farmers in Africa (Labrada 1994).

In Cameroon, Democratic Republic of Congo, Togo and Uganda, a single weeding required an average of 173 hours per hectare, while the second weeding event required an average of 130 hours per hectare per weeding and the third weeding event required an average of 125 hours per hectare per weeding (Ogwuike 2014). Smallholder farmers require an average of 460 hours to effectively hoe-weed a hectare of maize in South Africa (Auerbach 1993). There is very little documented work on the effects of weeds on crop yields in Botswana for either dryland or flood recession farming.

1.3 Ecology of plant succession

Weed species may be a symptom of an underlying process of ecosystem degradation such as pollution or excessive water extraction (Stokes 2009). Certain classes of weeds share adaptations to disturbed environments where soil or natural vegetative cover has been damaged or frequently gets damaged. Such disturbances give the weeds advantages over desirable crops, pastures, or ornamental plants. Disturbance mechanisms include veld fires, floods, volcano eruptions, deforestation, construction of roads, mining and agricultural practices such as overgrazing and total tillage.

In plant succession ecology, the first plant community to invade a disturbed area is known as the pioneer community and it consists mainly of annual grasses and herbs (van Oudtshoorn 1992; Odum and Barrett 2005), which are adapted to unfavourable conditions. In arable farming where tillage is a common form of disturbance, annual grass weeds such as *Urochloa mosambiscensis* (Hack) Dandy and broad-leaved forb such as *Sida cordifolia* L. are usually the first to emerge after tillage. One of the primary ecological functions of annuals in early stage succession on “brown fields” (recently fallow or abandoned fields) is to grow rapidly and produce organic matter which helps to rebuild soil, communities and fertility. In brown fields, plant succession can be controlled by availability of seed banks and propagules as well as availability of favourable microclimatic conditions that promote plant establishment. Forbs such as *Eupatorium cerasifolium* Sch.Bip. and *Phyllanthus* species, and grasses such as *Andropogon bicornis* L., *Panicum pilosum* Sw. and *Paspalum decumbens* Sw. usually predominate during the first year following abandonment in areas subjected to slash and burn agriculture (Uhl 1987) .

Soil tillage leads to breakdown of soil aggregates resulting in improved aeration. This then facilitates the rapid breaking down of soil organic matter which may leads to distortion of the soil structure. This activity relates to disturbance since it affects the resource levels in the soil which in turn alters survival and fecundity of communities. On the other hand, soil tillage creates conducive environment for weed species to establish. According to Froud-William (1984), cultivation influences abundance and scarcity of weed species. Similarly, Hobbs and Huenneke (1992) mentioned that where a disturbance has been a component of the ecosystem, there is likely to be a substantial fraction of the flora that is specialised or adapted to that establishment. For instance, tillage operates as a constraint on community assembly by filtering species with perennial life cycle which results in a predictable shift from perennial to annual dominated weed communities (Booth and Swanton, 2002). Likewise, disturbance regimes like cultivation and timing can influence weed species composition and diversity. For example, disturbance associated with spring tillage lead to weed communities dominated by early emerging forbs while later emerging forbs can be expected to dominate communities under fall tillage (Froud-William, 1984; Smith, 2006). Similarly, Cardina (2002) mentioned that crop rotation and tillage are also important environmental filters, and they often interact to determine the abundance and composition of seeds in the soil seedbank. In summary, these will reflect the existing weed species composition and diversity as well as giving a prediction of future weeds occurrence.

Frequency of disturbance is critical in species composition and diversity. For instance, the time interval between successive disturbances can have significant effect on community response because species composition changes within time since disturbance and many species require some time after disturbance to reach reproductive maturity (Hobbs and Huenneke, 1992). In view of the above, this study is informed by the Intermediate Disturbance Hypothesis (IDH). This theory was proposed by Grimme, (1973); Connell, (1978) and based on the argument that ecological communities seldom reach an equilibrium state in which competitively superior species exclude others. Huston (1979), explained that low or reduced levels of disturbance will lead to low diversity through competitive exclusion and dominance of long-lived species incapable of rapid recolonization and growth. Therefore, at intermediate levels of disturbance, diversity is maximised giving a hump-backed curve. This is mainly attributed to the interplay between disturbance and exchanges in species traits along successional gradients (Connell, 1978; Shea et al. 2004). The IDH will offer insight on how tillage activities in flood recession farming influences weed species composition and diversity.

1.4 Agriculture in Botswana

In Botswana about 70% of rural households derive a large part of their livelihoods from agriculture, through subsistence livestock farming and rain-fed crop production (UNDP-UNEP 2012). Botswana has a population of 2.2 million people of whom 70% live in rural areas (CSO 2011). Small-holder farming in Botswana is a major source of employment, food and income. Arable agriculture is the more dominant sector compared to the livestock sector in Botswana (Statistics Botswana 2012). There are about 63000 arable farms in Botswana, with an average area of 5ha and 112 farms that are larger than 150ha. Crops that are grown are mostly maize, sorghum, millet, legumes, watermelons and sweet reed. Generally, yields are low, with a typical yield of cereal crops in Botswana of 200 kg ha^{-1} on traditional farms compared to 500 kg ha^{-1} on commercial farms (FAO 2005). In the traditional farming sector, in the 2011/2012 cropping season in comparison with the 2010/2011 cropping season sorghum yield increased from 93 kg ha^{-1} to 144 kg ha^{-1}, maize yield decreased from 192 kg ha^{-1} to 53 kg ha^{-1} and millet stagnated at 189 kg ha^{-1} (Statistics-Botswana 2012). These still was below the domestic grain production since it satisfies only 10% of the national staple grain requirement (UNDP-UNEP 2013). The shortfall saw Botswana importing 250 000 to 300 000 tonnes of grain from South Africa (FAO 2005).

The agricultural sector in Botswana has become less sustainable, and with increasing exposure to drought conditions the risk of engaging in this sector has increased. This has led to reduced productivity in the last 10 years (BIDPA 2013). Similarly, the traditional arable agricultural sector has also consistently underperformed due to harsh climatic and environmental conditions, for example poor soil quality, fertility, persistent droughts and unpredictable weather patterns, global warming and issues with weeds. However, weed interactions with crops are problematic to farmers because they compete with crops for available moisture, nutrients and sunlight. They also harbour pests while others produce allelo-chemicals that interfere with growth and development of crops. Such kinds of weeds are referred to as noxious weeds because they are difficult to eliminate and also have a strong tendency to depress the growth and reproductive ability of host crops. Two major types of parasitic weeds in arable agriculture are yellow witchweed (*Alectra vogellii* Benth.) and Asiatic witchweed *(Striga asiatica* L. Kuntze.) (Agrinews 2013). A survey on arable weeds in Botswana by Phillips (1992) indicated that forbs such as *Ipomoea obscura* (L.)Ker Gawl, *Ipomoea sinensis* (Desr.), *Blepharosepala* species and *Xenostegia tridentata* (L) D.F.Austin & Staples. were the most common weeds across the country. *Striga asiatica* (L.) Kuntze. affected fields of sorghum and millet, but less or none of maize. According to Labovitch (1978) *Cynodon dactylon* L. is the most troublesome grass weed in Botswana. It spreads by rhizomes and is very difficult to eradicate by any method of tillage. Among the broad leaved plants, *Xanthium strumarium* L. is difficult to eradicate because of its abundant seeds and effective dispersal mechanism (Labovitch 1978). Other broad leafed weeds that are common in arable areas are *Datura ferox* L., *Hibiscus meeusei* Exell., *Borreria scabra* (Schum. Et Thonn) and *Argemone subfusiformis* GB Ownbey. Grasses which are considered weeds include *Chloris virgata* Sw., *Tragus beteronianus* Schult. *and Urochloa mosambicensis* (Hack.) Dandy. In most brown fields, *Pechuel-loeschea leubnitziae* (Kuntze) O.Hoffm seem to be the most dominant weed species.

1.5 Statement of the Problem

Dryland farming in Botswana is hampered by low and erratic rainfall, high evapotranspiration rate and incidence of pests and weeds. In 2016, 70.34 ha of maize fields were damaged by *Spodoptera frugiperda* (J.E. Smith) in the north eastern part of the country (SADC Transboundary meeting, 03/2017). *Molapo* farming is practiced mostly by smallholder subsistence farmers with small areas of land and relies mostly on residual moisture and natural fertilisation of the flood plains. However, favourable conditions under *molapo* farming not only enhance crop yield, but also provide a conducive environment for weeds to proliferate. Weeds grow rapidly in response to abundant moisture and improved aeration through soil cultivation. Cultivation is known to promote weed growth and influences abundance or scarcity of individual weed species (Froud-Williams 1983). Similarly, flooding frequency plays a major role in vegetation zonation (Bonyongo 1999) while occasional flooding causes soil erosion and degrade vegetation (Donaldson 1997). Weed species that are tolerant to such a disturbance will invade such niches especially in areas being exposed to tillage. In addition, flood water can carry with it seeds and other propagules and deposit them on floodplains where they germinate once flood water recedes. Studies have been extensively done on this smallholder farming activity by Bendsen (2002); VanderPost (2009); Motsholapheko (2011); Motsumi (2012) and Molefe (2014) to assess the impact of *molapo* farming on the livelihoods of people residing on the confines of the Okavango Delta. Studies have also been done on floodplain vegetation classification by Bonyongo (1999); Tsheboeng, et al. (2014) in Nxaraga lagoon and Murray-Hudson et al. (2011) and studies by these authors were on areas undisturbed by humans in the Okavango Delta. A good understanding of the weed species composition and diversity in *molapo* farming is a pre-requisite for development of effective weed management strategies.

1.6 Research Questions

Below are the questions that the study intends to answer:

1. What is the composition and diversity of weed species in flood recession farming areas in the Okavango Delta?

2. What is the influence of the frequency of cultivation on composition and diversity of weed species in flood recession farming in the Okavango Delta?

3. What are the main variables influencing composition and diversity of weed species in flood recession farming?

4. Is there a relationship between weeds biomass and crop biomass in flood recession farming?

1.7 Hypotheses

1. There is high weed species composition and diversity in flood recession farming areas of the Okavango Delta.

2. High frequency of cultivation increases weed species composition and diversity in flood recession farming in the Okavango Delta.

3. Flooding frequency is the main driver of weed species composition and diversity in flood recession farming..

4. There is a negative relationship between weed biomass and crop biomass in flood recession farming areas.

1.8 Objectives

1.8.1 General Objective

To determine the composition and diversity weed species in flood recession farming.

1.8.2 Specific Objectives

1. To determine the weed species composition and diversity in flood recession farming areas in the Okavango Delta.

2. To determine the influence of cultivation frequency on species composition and diversity in flood recession farming area.

3. To establish the main drivers of weed species composition and diversity in flood recession farming areas.

4. To determine the relationship between weed biomass and crop biomass in flood recession farming area.

1.9 Study Area

This study was done in the Okavango Delta (Figure 1) in the Ngamiland District of Botswana. The Okavango Delta is a large inland wetland found in the Northern Botswana in the Ngamiland District. The Ngamiland District has a human population of 137,593 (CSO, 2011).The Okavango Delta is the largest freshwater wetland in Southern Africa, and one of the largest inland wetlands in the world, still in a relatively pristine state and home to a large number of plant and animal species (Magole 2009). It covers an area of almost 40 000 km^2 (McCarthy 2005) and draws its water from the Okavango River which originates from Angola. The pattern of flooding is roughly inverse to the pattern of rainfall. Floodwaters from the catchment area in the Angolan highlands reach the panhandle in April, and meander through a mosaic of islands to eventually reach Maun around August to October (Turpie 2006).

The vegetation of the Okavango Delta is composed of a mosaic of perennial swamps, seasonally flooded open grasslands, woodlands and palm-fringed islands with forests as described in the Okavango Delta Management Plan (ODMP) of 2008. According to Gumbricht et al. (2004), the Okavango Delta has three main hydrological regions, namely permanent swamps, seasonally flooded floodplains and occasionally flooded floodplains. The panhandle and upper part of the Delta form permanent swamps since they are inundated almost the whole year around while the occasionally flooding floodplains are areas that are on the periphery and further downstream and get inundated only during years with high rainfall and flooding conditions. Biggs (1976) described the seasonally flooded floodplains (low-lying primary floodplains) as those which are flooded yearly for 4 to 8 months under average flooding conditions. According to McCarthy (2005), about 10 km^3 of water is discharged into the Delta by the Okavango River and this amount of water is augmented by 6 km^3 of rainfall which sustains about 2500 km^2 of permanent wetlands and up to 8000 km^2 of seasonal wetlands. The seasonal wetlands are mainly used by people residing on the confines of the Delta for different livelihood activities. These include intensive cultivation of the floodplains known as *molapo* farming. *Molapo* farming is mostly practiced on seasonal flood plains of the Okavango Delta (Oosterbaan et al. 1987; Petermann, 1989; Bendsen 2002 & Mmopelwa 2011). Cultivation of *molapo* fields is mainly conventional tillage through the use of mouldboard plough with donkeys as the major source of draught power. Of the 16 km^3 of water which enters the delta each year, 96% is lost in the atmosphere by evapotranspiration, 2% to groundwater and 2% is left as surface flow (Ellery and McCarthy 1998). The soils consist of superficial deposits of considerable thickness of windblown sands and alluvial sediments (Kunze and Loos, 1990). They are predominantly arenosols in the Delta and Kalahari sands in the dryland areas. According to Staring (1978) the taxonomic units present in the Delta are soils developed on aeolien deposits and those developed in alluvial deposits. The vegetation of the Delta is a mosaic of perennial swamps seasonally flooded open grasslands, woodlands and palm-fringed islands with forests.

1.10 Study sites

To manage the study effectively, three study sites were selected as a way of narrowing the scope of the research. These sites were Lake Ngami and Shorobe located in the south eastern and north eastern parts of the Okavango Delta respectively and Makalamabedi which is located in the south eastern part of Maun in the Ngamiland District and Central District of Botswana (Figure 1).

The study was conducted in the villages of Shorobe, Makalamabedi and Lake Ngami from March to April 2016. The sites were chosen based on their differences in flooding patterns and the location of molapo fields. Shorobe is located in the eastern end of the Okavango Delta and lies 30 km east of Maun in Ngamiland District. It has a human population of 1,031 (Statistics Botswana 2011). *Molapo* fields are located to the northwest of the village and are inundated by the Santantadibe and Gomoti Rivers and by backflow from the Thamalakane River. The *molapo* fields in Shorobe are mainly found in islands with dense riparian woodlands, have a saucer-shaped cross-section and obtain moisture from spill over or back flow water from the main river channels (Bendsen, 2002). Normally this area experiences maximum flood extent between August and September and by the end of October the flood begins to recede. Lake Ngami occupies the northeast part of a shallow sedimentary basin bounded to the southeast by a low escarpment of Karoo and Ghanzi Formation rocks along an extension of the Kunyere Fault (Reeves 1978). Lake Ngami did not receive enough flood water between 1989 and 2004. And farmers did not cultivate their *molapo* fields during these dry periods (Mmopelwa 2011). As a result most molapo fields are relatively new and not permanently placed like those at Shorobe and Makalamabedi. The maximum flood extent is usually experienced in October. The lake is surrounded by Toteng, Sehithwa, Bodibeng and Bothatogo villages. At the last census, the human population for these villages was 902; 2 748; 778 and 555 respectively (Statistics Botswana 2011). Lastly, Makalamabedi lies 83 km south east of Maun along the Boteti River. The veterinary cordon fence that cuts through the village divides the village into two districts. Makalamabedi on the western side of the cordon fence lies on the Ngamiland District with a population of 1,010 while the Eastern side of the fence lies on the Central district with 1,674 people (Statistics Botswana 2011). Arable farming is done in fields allocated along the Boteti River. *Molapo* fields located on steep banks along the Boteti River are characterised as channel type (Bendsen 2002). This river is an ephemeral water channel which derives flood waters from the Okavango Delta through Thamalakane River. It flows in a south-easterly direction, and finally discharges into Lake Xau. The peak floods are between August and September.

In addition, the study sites also have different soil and vegetation types. For instance, Shorobe is mostly characterised by riparian woodland and floodplain grass while Lake Ngami and Makalamabedi have mostly acacia woodland while soils are predominantly arenosols in the Delta and Kalahari sands in the dryland areas and the vegetation of the Delta is a mosaic of perennial swamps seasonally flooded open grasslands, woodlands and palm-fringed islands with forests.

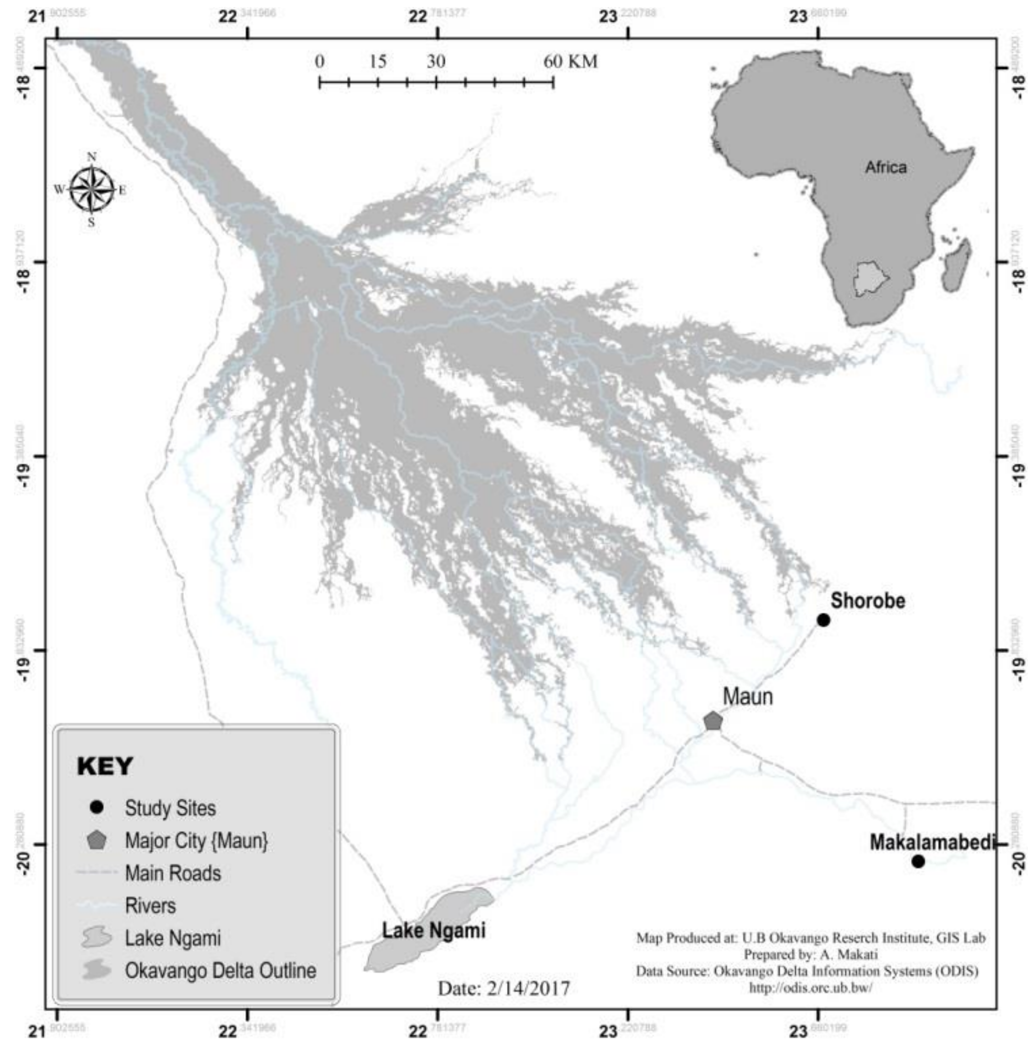

Figure 1: Map of the Okavango Delta showing the study sites of Shorobe, Makalamabedi and Lake Ngami

1.11 Conclusion

Molapo farming is a key livelihood activity for people residing on the fringes of the Okavango Delta. Due to its favourable growing conditions, it has an advantage of good crop yields compared to dryland farming. However, this good growing environment also makes *molapo* farming prone to weeds infestation. These weeds produce highest potential yield losses. The agro-ecosystems in the seasonal floodplains influence weed species composition and diversity due to disturbances in form of cutting down of trees and soil tillage. For instance, tillage operates as a constraint on weeds community assemblages leading to shifts from perennial to annual dominated weed communities. This is evident since the common types of arable weeds in Botswana are broad leaved plants like *Ipomoea sinensis* and *Hibiscus meeusii* as well as grasses such as *Chloris virgata* and *Urochloa mosambicensis*.

Chapter 2

Weed species composition and diversity in flood recession farming areas in the Okavango Delta

2.0 Introduction

Flood recession farming is practiced around the world where there are lakes, flood plains or swamps. Some of the countries where flood recession farming is practiced include China and Malaysia (Juraimi 2011), the Philippines (De Datta 1979), Cambodia (Fox 1999) and Brazil (Shorr, 2000). In this farming system, crops are planted in seasonally flooded floodplains or along river banks/beds following receding water. According to Scudder (1991) and Richter (2010), flood-recession agriculture is an old age practice in Africa, extending back at least 5000 years in the case of Egypt’s Nile valley. Furthermore, the presence of early-maturing and drought-resistant varieties of millet and sorghum suggests that flood-recession cultivation was historically widespread on the continent (Scudder 1991; Richter 2010). For instance, there is a rich knowledge of floodplain farming along the rivers of Niger, Sokoto, Rima, Senegal in West Africa., Tana and Rufiji Rivers in East Africa, the Zambezi and Lufira rivers in Central Africa and Southern Africa, the Sudd swamps and Omo Valley in north eastern Africa (Barrow, 1999).

According to Bendsen (2002), in Botswana flood recession farming, called *molapo* farming is mostly practiced along the fringes of the Okavango Delta (Figure 2). It is an important land use and livelihood activity for the rural poor and vulnerable riparian communities that reside around the Okavango Delta (Motsumi 2012). Flooding in the Delta enhances ecosystem services by supplying water and nutrients to support the rich biodiversity (McCarthy et al. 2003) and household livelihoods in the Delta (Motsholapheko et al. 2011). More importantly, annual flooding naturally provides moisture and fertilises *molapo* farms, and as water starts to retreat in October farmers start to plough and plant crops (Oosterbaan et al. 1987). Higher yields are normally realised under *molapo* farming in the Okavango Delta compared to dryland farming. For instance, sorghum grain yield normally ranges from 1,800 to 2,900 kg ha^{-1} whereas; under dryland it can be as low as 121 kg ha^{-1} (Bendsen 2002; Arntzen 2005). Despite having more advantages than dryland farming in terms of crop growth and yield, *molapo* farming has challenges. This might be due to the fact that *molapo* farming is largely influenced by flood duration and areal extent. High floods can inundate *molapo* fields for a long time preventing farmers from cultivating their crops, or floods can be too low to inundate *molapo* fields resulting in them being unsuitable for cultivation. For instance, high and prolonged floods made *molapo* farming impossible in the period from 1974 to 1978 in Shorobe (Oosterbaan et al. 1987) and similarly in 2010 the Gomoti floods were so high that most *molapo* farms remained inundated throughout the planting season of 2010/2011 and crop cultivation was impossible (Mmopelwa 2011). As a result, there was a dramatic decrease in the area farmed because much of the potential farming areas remained inundated for the entire farming period (Molefe et al. 2014). Low flooding can also have an impact on the total area farmed in *molapo* farming. An example of insufficient flooding causing problems could be seen in Xhobe along the Boteti River, where a decline in flood volume led to a decrease in the area farmed while in Shorobe the area farmed increase during a low flood phase (Molefe at al. 2013). This difference is due to the fact that floodplains in Shorobe are typically wide and shallow, as opposed to the narrow channel type *molapo* farms in Xhobe along the Boteti River.

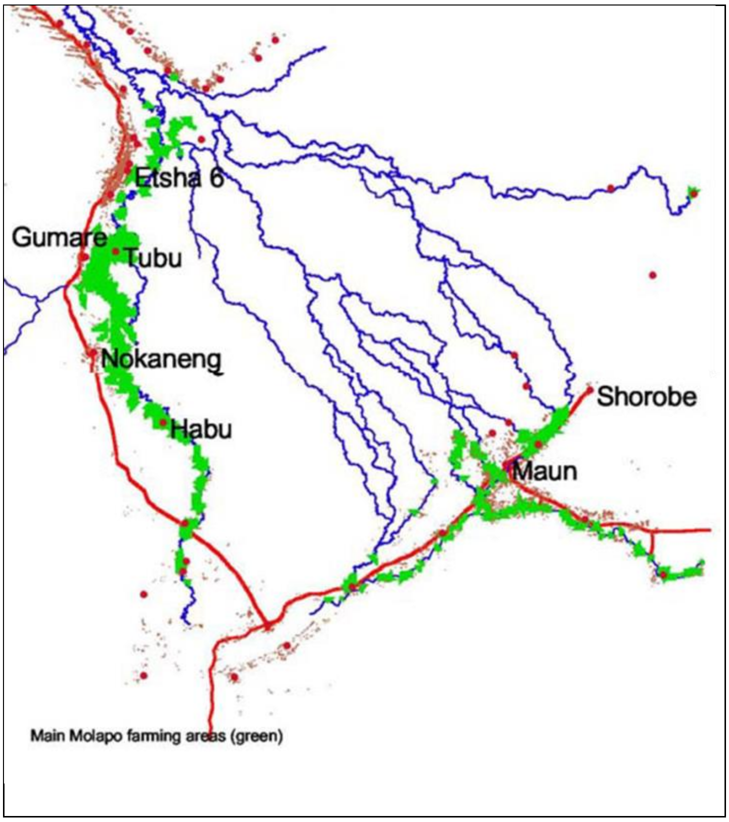

Figure 2: Molapo farming areas (green) in the Okavango Delta. Adopted from VanderPost (2009).

Seasonal flooding of the floodplains or river beds (locally called *molapo*) not only promotes crop growth but other plants also proliferate under this conducive environment. Weedy species in particular, grow vigorously in the nutrient rich floodplain soils and sometimes pose management challenges to the farmers. As a result, *molapo* farming can have a positive effect on species diversity of weedy communities. This effect may be due to micro-climatic conditions enhanced by the cultivation regime or anthropogenic disturbances occurring during farming. Cultivation can affect soil heterogeneity, through redistribution of ecosystem components like soil microbial biomass or through enhancement of physical properties such as soil structure. Other factors that can affect weed species composition are historical disturbances and landscape patterns (Urban et al 2000 and Woldermariam 2008) as well as habitat disturbance by intense wildlife grazing and impact of human activities (Ruto 2012). These factors can influence the distribution of plant communities including weed species because certain classes of weeds thrive well in disturbed environments. Weeds colonise disturbed sites and maintain their abundance under conditions of repeated disturbance (Liebman et al. 2001). For instance, according to Barker (1965) agrestal weeds colonise and increase under disturbances created by farming while ruderal weeds colonise and increase in non-agricultural disturbances. In a study on arable weed vegetation in the Czech Republic, Cimalova (2009) found that most variation in species composition was explained by crop type, followed by other variables such as climatic variables and altitude, soil pH, season and soil type. The study did not however rule out the other confounding factors that might contribute to species composition such as use of fertilisers and herbicides.

Studies by Capon (2005), Robertson (2001) and Tsheboeng et al. (2014) found that flooding is the major factor affecting species composition diversity in the seasonal flood plains. It is important to note that flooding as an agent of disturbance can create conditions that is favourable to certain plant species. This phenomenon can lead to situations where some species are replaced by ones which are more tolerant of disturbance. In the Okavango Delta, *Paspalidium obtusifolium* was replaced by *Eleocharis dulcis* and *Leersia hexandra* during prolonged flooding in the Nxaraga lagoon (Tsheboeng et al. 2014) while *Setaria sphacelata* was found to be tolerant to shallow flooding depth and short flooding duration (Bonyongo 1999). The main indicator species in seasonally flooded grassland were found to be *Nicolasia costata*, *Eragrostis lappula, Cyperus sphaerospermus, Setaria sphacelata, Leersia hexandra and Cyperus articulatus* (Murray-Hudson 2011). The findings of these studies cannot be extrapolated to flood recession farming areas because they were done in non-cultivated sites. However, in flood recession farming, cultivation may have additional effects and its interaction with flooding may produce contrasting results. *Molapo* fields are subjected to anthropogenic disturbance such as soil tillage and removal of natural vegetation (cutting trees, removing stumps, slash and burn practice) to facilitate tillage. These forms of disturbance can alter the soil chemical properties and soil structure giving rise to introduction of new weed species and disappearance of some ‘native’ species of the seasonal floodplain. There is very little documented information at all on weeds in flood recession agriculture – not only which species they are, but also how to control them, what intensity of problem they cause, and how they affect the crop species and the cultivation process. One important part of remedying this gap is to record and analyse the non-crop species. It is against the backdrop of this limitation that this study sought to investigate the weeds species composition and diversity in flood recession farming areas (*Molapo* fields). This might assist in providing valuable information to design a sound successful weed management program in *molapo* farming. Furthermore, it could help us understand the ecology and potential threats of status of weeds in seasonal floodplains used as *molapo* farming.

2.1 Objectives

1. To determine weed species composition in flood recession farms in the Okavango Delta.

2. To determine weed species diversity in flood recession farms in the Okavango Delta.

2.2 Materials and Methods

2.2.1 Study sites

The study was conducted in three different *molapo* farm sites along the the Okavango Delta. The *molapo* farming sites were in Shorobe, Makalamabedi and Lake Ngami from March to April 2016 (Refer to chapter 1 for a full description of the study sites).

2.2.2 Selection of molapo fields

Field visits were conducted to identify *molapo* fields at the different study sites. Once suitable fields had been identified, consent was sought from farmers and information gathered on tillage history in terms the number of years the field have been cultivated. The fields were categorised according to the historic frequency of continuous cultivation in years.

The categories were defined as: continuous cultivation for the previous five years; 10 years and 15 years, while equivalent sites with no history of cultivation were used as a control. Simple random sampling (SRS) was then carried out using a random number generator in MS Excel to draw three fields from each stratum or cultivation frequency. A total of 12 fields per study site were selected with an overall total of 36 *molapo* fields (Figure 3).

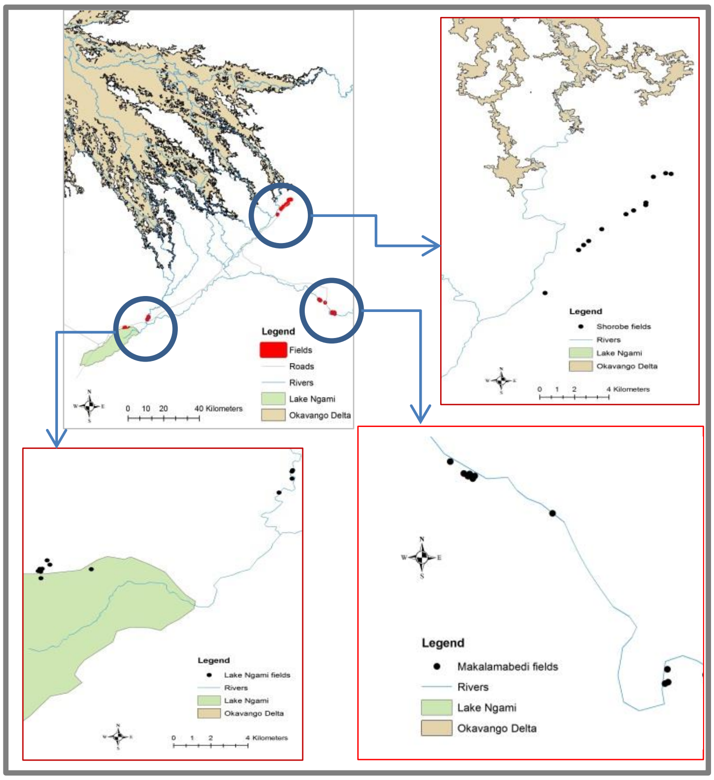

Figure 3: Distribution of *molapo* fields across the study sites (Lake Ngami, Makalamabedi and Shorobe)

2.2.3 Vegetation Sampling

Vegetation was surveyed at the three sites from March to the end of April 2016, when most plants were flowering for easy identification. Due to the smaller sizes of *molapo* fields, a 50 m tape measure was used as a line transect in each field. The line transects were laid parallel to each other and spaced 20 m apart (Morgan 1998) from the lower to upper gradient in each molapo field. Weed species composition and abundance were then recorded in 1m^2 quadrats placed along each transect at 10 m interval (Morgan 1998). Placement of transect and quadrats was through the modified stratified sampling adopted from Gillison and Brewer (1985) using gradient oriented transects. Since *molapo* fields have small area and irregularly shape, the number of quadrats surveyed differed from one site to the other. A total of 93 quadrats were surveyed at Shorobe, 86 at Makalamabedi and 74 at Lake Ngami. In each quadrat, all species were identified and the number of individuals was counted (without accounting for vegetative reproduction). In total, 253 quadrats were surveyed across the three sites. Unidentified plants were pressed and taken to Peter Smith University of Botswana (PSUB) herbarium for identification. The plant species were identified to species level using the nomenclature followed by Germishuizen and Meyer (2007). Plant species eveness and Shannon diversity indices were determined both within sites and between the sites.

2.2.4 Data Analysis

Agglomerative hierarchical cluster analysis was used to group species. It was performed using Sorensen distance measure with flexible beta linkage; β = -0.25 in PC-ORD 6 software (McCune and Mefford, 2011). This was done by Clustering groups of species based on the number of times they occur with each other in the field quadrat data. Indicator Species Analysis (Dufrene & Legendre, 1997) was used to calculate indicator values for species in groups determined from cluster analysis. Each group was named using the weed species with the highest indicator value and a significant p-value ($p \leq 0.05$). A multi response permutation procedure (MRPP) was used in testing the hypothesis of no difference between the groups of species communities in *molapo* farming using the Sorensen distance measure. The test statistic T was calculated as: T= *(δobserved - δexpected) / s.devδexpected)*. This determines the separation between communities, with more negative values indicating stronger separation. Within group homogeneity was determined by the effect size or chance-corrected within group agreement A=1-(*δobserved/δexpected)*. A =1 when all items are identical within groups (δ=0), A=0 when heterogeneity within groups equals expectation by chance, A<0 with more heterogeneity within groups than expected by chance.

Since the data did not meet the assumptions of Analysis of Variance (ANOVA), Kruskal-Wallis was used to test for statistically significant differences in species diversity between the species communities and test the hypothesis that the distribution of species evenness is the same across the species communities. This was performed in SPSS version 24.

2.3 Results

A total of 101 weeds species were enumerated in the entire flood recession area (Table 1). These species belonged to 24 different families. The family with the most species was Poaceae (Table 1). It was represented by 25 different species with a mean density of 8064.82 individuals per hectare. This was followed by the family Fabaceae comprising 17 species with mean species density of 1576.38 species per hectare.

Table 1: Families of species showing the number of species in each family and density of individual species.

Family	Number of species	Average Density (Individuals ha^{-1})
Poaceae	25	8064.8
Fabaceae	17	1576.4
Malvaceae	9	15999.1
Cyperaceae	8	16279.6
Convolvulaceae	6	9005.3
Amaranthaceae	6	810.3
Asteraceae	5	7438.7
Tiliaceae	3	22147.6
Rubiaceae	3	3188.4
Sterculiaceae	2	79.1
Solanaceae	2	118.6
Polygonaceae	2	237.2
Molluginaceae	2	4743.1
Verbenaceae	1	8063.2
Portulacaceae	1	1146.2
Nyctaginaceae	1	197.6
Onagraceae	1	118.6
Gisekiaceae	1	6561.3
Lamiaceae	1	553.3
Euphorbiaceae	1	39.5
Cucurbitaceae	1	355.7
Boraginaceae	1	14782.6
Campanulaceae	1	39.5
Aizoaceae	1	158.1
Total	101	121703.9

2.3.1 Indicator Species Analysis

The number of weedy species was determined at 4 divisions where the p-value ($p < .05$) was minimised (Figure 4). The main weedy species communities identified were *Cynodon dactylon- Bulbostylis hispidula Sida cordifolia – Corchorus tridens*, *Glinus oppositifolius – Heliotropium ovalifolium and Sida alba – Abitulon angulatum* (Figure 5). The full list of species in each community are in appendix 1 to 4.

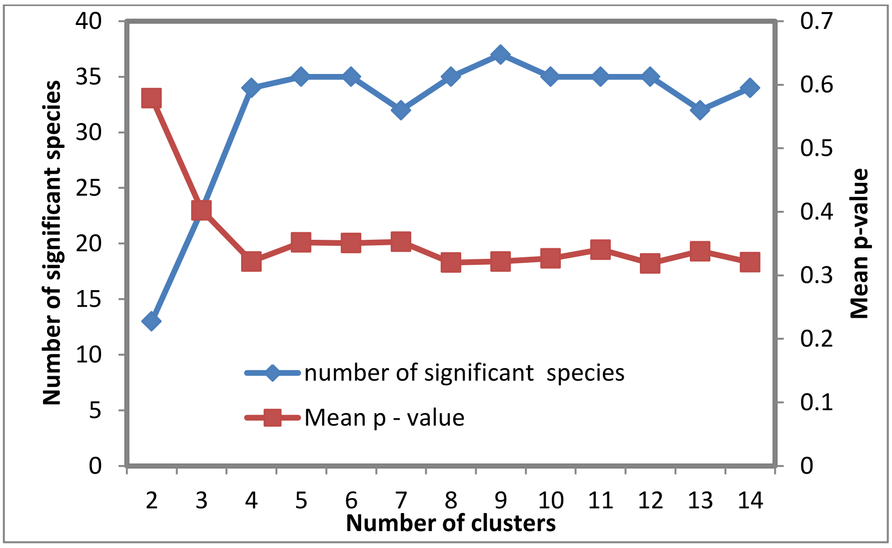

Figure 4: Determination of number of ecologically meaningful clusters for weedy species classification

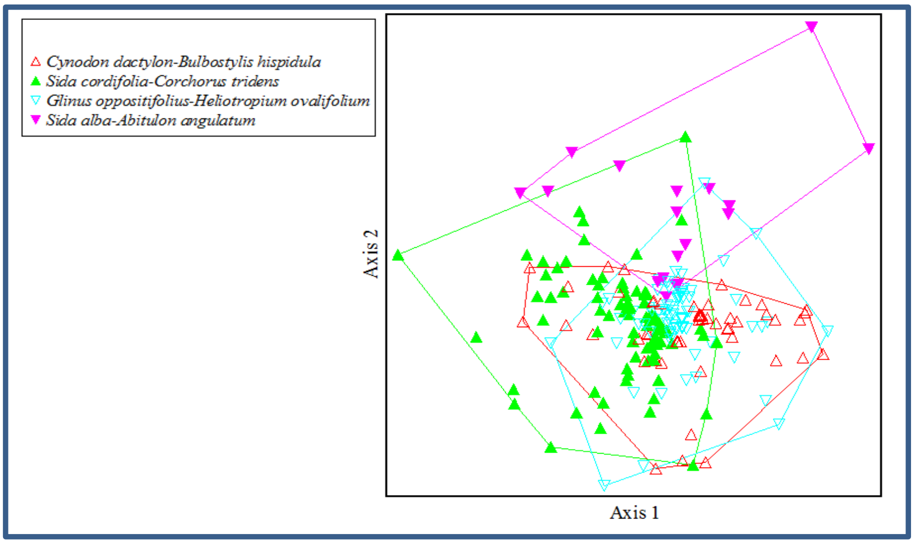

Figure 5: Non-Metric Multidimensional Scaling (NMS) depiction of the 4 weed species communities of the flood recession farming areas in the Okavango Delta.

2.3.2 Description of the different weed species communities

(i) Cynodon dactylon- Bulbostylis hispidula community

This community was composed of 30 species and was dominated by *Cynodon. dactylon* (L) Pers and *Bulbostylis hispidula* (Vahl.) (Table 2). Other species in this community included *Acanthospermum hispidum* DC., *Triumfetta pentandra* A.Rich, *Nidorella resedifolia* DC. and *Phylla nodiflora* (L.). This community was mostly characterised by herbaceous plants and a few species from the Poaceae family. It was observed that it occurs mainly in fields that have an average of 10 year cultivation frequency. It had an average species density of 9293.8 per hectare. The number of different species in the *C. dactylon* and *B. hispidula* community was 30 and evenness was 0.53. The Shannon's Diversity index was 1.15 (Table 3).

Table 2: *Cynodon dactylon- Bulbostylis hispidula* community composition in flood recession farming in the Okavango Delta. A full list of weed species belonging to this community is in Appendix 1.

Species	**Indicator Value**	**p-value**	**Total number of individuals**	**Density (ha $^{-1}$)**	**Family**
Cynodon dactylon (L) Pers	50.0±2.68	0.0002	3319	131186	Poaceae
Bulbostylis hispidula (Vahl)	28.9± 2.74	0.0004	645	25494.1	Cyperaceae
Acanthospermum hispidum DC.	21.3±2.70	0.0024	515	20355.7	Asteraceae
Triumfetta pentandra A.Rich	20.0 ±2.83	0.0054	486	19209.5	Malvaceae
Nidorella resedifolia DC.	12.5±1.82	0.0024	155	6126.48	Asteraceae
Phylla nodiflora (L.)	12.4 ±1.98	0.0046	204	8062.24	Verbenaceae
Kyllinga erecta Schumach.	7.1±1.41	0.0242	274	10830	Cyperaceae
Kohautia subverticillata (K.Schum.)	6.2 ± 1.74	0.0516	18	711.46	Rubiaceae
Cyperus longus L.	5.6± 1.99	0.1328	765	30237.2	Cyperaceae
Spermacoce senensis (Klotzsch)	3.6 ± 1.24	0.1372	7	276.68	Rubiaceae
Vernonia glabra (Steetz) Vatke	3.6 ±1.24	0.1372	2	79.05	Asteraceae
Eragrostis sarmentosa (Thunb.)	3.6 ±1.28	0.1648	167	6600.79	Poaceae
Gomphrena celesiodes Mart.	3.5 ± 1.36	0.193	20	790.51	Amaranthaceae

Table 3: Number of individual species found in each community, the average species density for each community and their diversity indices.

Communities	**Number of individuals**	**Species Density (ha ⁻¹)**	**Evenness**	**Shannon's Diversity (H')**
Cynodon dactylon – Bulbostylis hispidula	30	9293.775	0.533±0.025	1.1461±0.038
Sida cordifolia – Corchorus tridens	28	8465.557	0.645±0.017	1.179±0.047
Glinus oppositifolius – Heliotropium ovalifolium	29	3365.126	0.632±0.021	1.180±0.042
Sida alba – Abitulon angulatum	15	4579.709	0.720±0.041	1.161±0.126

(ii) Sida cordifolia – Corchorus tridens weed species community

This community was comprised of a total of 28 species, dominated by *Sida cordifolia* L. and *Corchorus tridens* L. This community also had *Ipomea sinensis* (Desr.), *Digitaria debilis* (Desf.), *and Ipomoea coptica* (L.)Roem. & Schult. and *Hibiscus cannabinus* L. Some species in this community were observed to be mostly dominant in fields with 15 year cultivation frequency like *Corchorus tridens* L., *Ipomea sinensis* (Desr.) *and Panicum coloratum* L. The mean species evenness for this community was 0.65 with a mean Shannon Diversity index of 1.18 (Table 4).

Table 4: *Sida cordifolia – Corchorus tridens* community composition in flood recession farming in the Okavango Delta. Sp1 is an unidentified species.

Species	**Indicator Value**	**p-value**	**Total number of individuals**	**Density (ha ⁻¹)**	**Family**
Sida cordifolia L.	37.2 ±3.45	0.0004	1573	62173.9	Malvaceae
Corchorus tridens L.	35.4 ±3.43	0.0026	1648	65138.3	Tiliaceae
Ipomoea sinensis (Desr.)	27.2 ±3.15	0.003	832	32885.4	Convolvulaceae
Digitaria debilis (Desf.)	23.6 ±2.77	0.002	438	17312.3	Poaceae
Ipomea coptica (L.)Roem. & Schult.	15.2 ±3.04	0.064	519	20513.8	Convolvulaceae
Hibiscus cannabinus L.	14.4 ±3.26	0.1236	325	12845.9	Malvaceae
Sp1	11.8 ±2.29	0.0154	61	2411.07	
Indigofera flavicans Baker.	9.5 ±2.52	0.0642	143	5652.17	Fabaceae
Panicum coloratum L.	7.7 ±2.06	0.0652	223	8814.23	Poaceae
Chloris virgata Sw.	3.1 ±1.36	0.2068	10	395.26	Poaceae

(iii) Glinus oppositifolius – Heliotropium ovalifolium weed species community

A total of 29 species were identified in this community. It was dominated by *Glinus oppositifolius* (L.) Aug.DC. and *Heliotropium ovalifolium* Forssk. This community also had *Cyperus esculentus* L., *Fimbristylis dichotoma* (L.) Vahl, *Cyperus latifolius* Poir., *Pavonia senegalensis* Cav. and *Alternanthera sessilis* (L.) DC. These species are tolerant of high moisture content. It was observed that this community occurs mainly in uncropped fields which normally get inundated during flooding. The mean evenness and Shannon Diversity index were 0.63 and 1.18 respectively (Table 5).

Table 5: *Glinus oppositifolius – Heliotropium ovalifolium* community composition in flood recession farming areas in the Okavango Delta.

Species	Indicator Value	p-value	Total number of individuals	Density (ha ⁻¹)	Family
Glinus oppositifolius(L.) Aug.DC.	26.2 ±2.15	0.0002	114	4505.93	Molluginaceae
Heliotropium ovalifolium Forssk.	18.0± 30.5	0.0218	374	14782.6	Boraginaceae
Fimbristylis dichotoma (L.) Vahl	13.8 ±2.02	0.004	101	3992.09	Cyperaceae
Cyperus esculentus L.	15.0 ±2.17	0.0044	1039	3675.89	Cyperaceae
Cyperus latifolius Poir.	13.6 ±2.08	0.0058	82	3241.11	Cyperaceae
Pavonia senegalensis Cav.	12.2±2.14	0.0074	174	6877.47	Malvaceae
Alternanthera sessilis (L.) DC.	11.2 ±1.96	0.0072	40	1581.03	Amaranthaceae
Cyperus articulatus L.	7.8 ±1.94	0.0406	346	13675.9	Cyperaceae
Portulaca oleracea L.	3.8 ±1.36	0.1266	29	1146.25	Portulacaceae
Echinochloa jubata Stapf.	3.8 ±1.36	0.1284	30	1185.77	Poaceae
Kohautia virgata(Willd.) Bremek.	3.7 ±1.79	0.2278	217	8577.08	Rubiaceae
Echinochloa colona (L.) Link	3.2 ±1.70	0.3037	61	2411.07	Poaceae

(iv) Sida alba – Abitulon angulatum weed species community

This community was constituted by 15 species dominated by *Sida alba* L. and *Abitulon angulatum* (Guill&Perr) Mast. Other species in this community were *Xanthium strumarium* L., *Chenopodia carinatum* R.Br., *Eclipta prostrata* (L.) and *Chamaecrista biensis* (Steyaert) Lock. This community had the evenness of 0.72 and the Shannon Diversity index of 1.16 (Table 6).

Table 6: *Sida alba – Abitulon angulatum* community composition in flood recession farming areas in the Okavango Delta.

Species	Indicator Value	p-value	Total number of individuals	Density (ha ⁻¹)	Family
Sida alba L.	80.8 ± 3.15	0.0002	515	20355.7	Malvaceae
Abitulon angulatum(Guill&Perr) Mast	47.7 ±2.60	0.0002	510	20158.1	Malvaceae
Xanthium strumarium L.	28.3 ± 3.88	0.0038	202	7984.19	Asteraceae
Chenopodia carinatum R.Br.	19.0 ± 1.42	0.0002	13	513.83	Amaranthaceae
Eclipta prostrata (L.)	17.3 ±3.13	0.0136	67	2648.22	Asteraceae
Chamaecrista biensis (Steyaert) Lock.	13.5 ±2.06	0.003	55	2173.91	Fabaceae
Hibiscus trionum L.	9.1 ± 1.65	0.014	12	474.31	Malvaceae
Amaranthus hybridus L.	8.6±2.15	0.035	38	1501.98	Amaranthaceae
Digitaria eriantha Steud.	7.9 ± 1.77	0.0212	11	434.78	Poaceae
Indigofera tinctoria L.	7.5 ± 2.40	0.1156	46	1818.18	Fabaceae

2.3.3 Multi Response Permutation Procedure for weed species communities

A pairwise comparison between the species communities was performed using MRPP. The effect size or chance- corrected within group agreement A: was 0.09061782 based on observed delta: 1.4068533and expected delta: 1.5470429. The significance of delta: < 0.001. The group comparisons show the negative T –statistic and the effect size of A< 1 (Table 7). There was a statistically significant difference ($p < 0.05$) between the four communities. The T-statistic also indicated that there was a stronger separation between *Cynodon dactylon-Bulbostylis hispidula* and *Sida cordifolia – Corchorus tridens* communities. *Sida cordifolia – Corchorus tridens* and *Sida alba - Abitulon angulatum* communities were closer together than other communities.

Table 7: A Multi Response Permutation Procedure (MRPP) pairwise comparison for the species communities. Cyndac - Bulhis = *Cynodon dactylon- Bulbostylis hispidula,* Sidcor-Cortri = *Sida cordifolia-Corchorus tridens,* Sidalb-Abiang = *Sida alba-Abitulon angulatum* and Gliopp-Helova = *Glinus oppositifolius - Heliotropium ovalifolium. T-statistic determines the differences between the groups and A is the effect size.*

Groups Compared	**T-statistic**	**A(agreement)**	**p-value**
Cyndac-Bulhis vs. Sidcor-Cortri	-38.6297913	0.071374	0.001
Cyndac- Bulhis vs. Gliopp - Helova	-34.7072352	0.0659926	0.001
Cyndac - Bulhis vs. Sidalb-Abiang	-20.8766535	0.0887329	0.001
Sidcor-Cortri vs. Gliopp - Helova	-35.3593382	0.0470391	0.001
Sidcor-Cortri vs. Sidalb-Abiang	-19.6246419	0.0481293	0.001
Gliopp - Helova vs. Sidalb-Abiang	-20.4255302	0.0505249	0.001

2.3.4 Evenness and Shannon Diversity index

Since the data did not meet the assumptions of One-Way ANOVA, Kruskal-Wallis was used to test for statistically significant difference in species diversity between the species communities. There was no statistically significant difference in Shannon's diversity between communities, X^2 (3, N = 253) = 0.794, $p > 0.05$ (Figure 6).

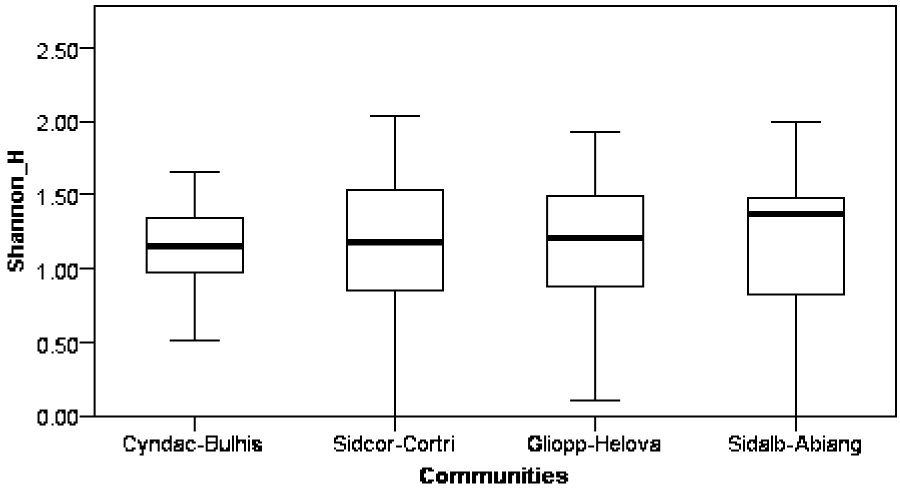

Figure 6: Graphical representation of the Independent samples test showing Shannon's Diversity indices across the 4 communities. Cyndac - Bulhis = *Cynodon dactylon-Bulbostylis hispidula,* Sidcor-Cortri = *Sida cordifolia-Corchorus tridens,* Sidalb-Abiang = *Sida alba-Abitulon angulatum* and Gliopp-Helova = *Glinus oppositifolius - Heliotropium ovalifolium.*

The test revealed that there was a statistically significant difference in species evenness across the 4 different communities (*Cynodon dactylon-Bulbostylis hispidula*: n = 56, *Sida cordifolia –Corchorus tridens:* n= 96, *Glinus oppositifolius-Heliotropium ovalifolium*: n =80, *Sida alba-Abitulon angulatum*: n = 21), X^2 (3, N = 253) = 21.341, p = 0.001. The hypothesis that species evenness is the same across the species communities was thus rejected. *Sida alba-Abitulon angulatum* community recorded the highest median value (Md = 0.767) while *Cynodon dactylon-Bulbostylis hispidula* recorded the least median value (Md = 0.507) of all the communities. *Sida cordifolia-Corchorus tridens* and *Glinus oppositifolius-Heliotropium ovalifolium* recorded median values of 0.637 and 0.644 respectively. A pairwise comparison was done to determine the groups that differ using the Independent samples median test. *Cynodon dactylon-Bulbostylis hispidula* community differed significantly to the other communities in species evenness (Figure 7).

Figure 7: Graphical representation of the Independent-Sample Median Test showing the Evenness of species across the 4 communities. Cyndac - Bulhis = *Cynodon dactylon-Bulbostylis hispidula,* Sidcor-Cortri = *Sida cordifolia-Corchorus tridens,* Sidalb-Abiang = *Sida alba-Abitulon angulatum* and Gliopp-Helova = *Glinus oppositifolius - Heliotropium ovalifolium.*

2.4 Discussion

A total of 101 weed species belonging to 25 different families was enumerated over the entire study area. The Poaceae family had the highest number of 25 individual species followed by the Fabaceae which had a total of 17 individual species. It was observed that despite having very few individual species, the Tillaceae family has the highest average species density per hectare followed by the Cyperaceae family. The Tillaceae family was constituted of *Corchorus tridens, Corchorus asplinifolius* and *Corchorus olitorius*. Of the three, it was observed that *Corchorus tridens* was highly abundant and found in almost all the fields across the different cultivation frequencies. *Corchorus tridens* seems to be highly tolerant of soil tillage and somewhat tolerated by farmers due to its usefulness as a vegetable. *Corchorus tridens* is a drought resistant herbaceous plant but it also seems to tolerate a high level of rainfall. This was also supported by Dzerefos et.al. (1995) who stated that *C. tridens* may be tolerant of low availability of water and may even thrive in such conditions. Conditions under flood recession farming seem to offer a conducive environment for its growth and yield, hence its high abundance.

Cyperaceae had the second highest average species density. Most members of this family are predominantly found in the sedge lands in the Okavango Delta. *Cyperus sphaerospermus and Cyperus articulatus* were found to be indicator species of sedgeland of the Boro-Xudum distributary of the Okavango Delta (Murray-Hudson, 2011). Most species in this family tolerate flooding conditions. Flood recession farming areas are mainly located along and within the floodplain.This might explain the abundance of the species in the Cyperaceae family in terms of average species density per hectare. Most species in this family seem not to be tolerant of soil tillage except *Bulbostylis hispidula* which was found mainly in cultivated fields which flood occasionally with lighter soils. Most of the species in the Cyperaceae family were observed to be in high abundance in uncropped fields with *Cyperus* *esculentus* found at a higher density than *Fimbristylis dichotoma*, *Cyperus latifolius*, *Cyperus articulatus, Kyllinga erecta* and *Cyperus longus.*

Other plant families like the Verbenaceae, Portulacaceae, Nyctaginaceae, Onagraceae, Gisekiaceae, Lamiaceae, Euphorbiaceae, Cucurbitaceae, Campanulaceae and Aizoaceae were represented by a single species in each with lower density per hectare. *Heliotropium ovalifolium*, a flood tolerant species, was the single species belonging to the family Boraginaceae. It was found in abundance in most uncropped fields, and this might explain why the Boraginaceae family recorded the highest plant density per hectare despite having recorded a single species.

Weed species in flood recession farming areas were classified into four communities. These were *Sida cordifolia-Corchorus tridens, Sida Alba-Abitulon angulatum, Glinus oppositifolius –Heliotropium ovalifolium and Cynodon dactylon* - *Bulbostylis hispidula.* In this classification, *Cynodon dactylon- Bulbostylis hispidula* was observed to colonise *molapo* fields that were situated on the upper floodplain zone. It was also observed that the weed species in this community existed in fields across all the cultivation frequencies except the uncropped sites. Presence of some species in this community was reported in the previous studies. For example, (Tsheboeng et. al. 2014) found that *Cynodon dactylon, Nidorella resedifolia* and *Cyperus longus* existed together in the tertiary flooding zone in the Okavango Delta. Murray-Hudson et al. (2014a) also reported that *N. resedofolia* was one of the dominant species where flooding was more frequent in Boro-Xudum. The *Sida cordifolia-Corchorus tridens* community constitutes species that are more associated with dryland farming than flood recession farming and most of these species were found in abundance in uncropped fields. This is evident since elsewhere *Sida cordifolia* is found principally on disturbed lighter soils, and occurring as a weed in cultivated fields and degraded pastures (Parsons and Cuthbertson, 2001) while *Corchorus tridens* is a drought tolerant species with affinity to cultivated land (Dzerefos et al., 1995). Some species found in this community are *Indigofera flavicans, Ipomea coptica, Hibiscus cannabinus, Panicum coloratum* and *Chloris virgata*. According to Murray-Hudson et al. (2011*), Chloris virgata* and *Ipomea coptica* were found mainly on dry floodplain grassland which is mostly rain- sustained in the Okavango Delta. On the other hand, *Cynodon dactylon* mostly dominate areas that flood infrequently in the Okavango Delta (Ellery and Mc Carthy, 1998; Murray-Hudson, 2014a &Tsheboeng et al. 2014). *Bulbostylis hispidula* on the other hand was found to be intolerant to flooding and grows well on free draining sandy soils (Phillips, 1992), similarly it was one of the characteristic species of the community associated with silt-clay and intermediate sand content in the Savuti-Mababe-Linyanti ecosystem (Sianga and Fynn, 2017). This might explain why there was significant separation between *Sida cordifolia-Corchorus tridens community* and *Cynodon dactylon – Bulbostylis hispidula* community since they prefer different habitats.

The results of the study also revealed that most of the species co-existing in the *Sida alba – Abitulon angulatum* community were found in fields that were less frequently cultivated. These fields were also located mostly within the flood plains that frequently get inundated and fallowed, whereas the *Glinus oppositifolius - Heliotropium ovalifolium* community was comprised mostly of flood tolerant species most of which belong to the Cyperaceae family. It was also observed that most of the species in this community were found in abundance in uncropped fields and in fields that were less frequently cultivated (5 year cultivation frequency). Most of these fields lie within the seasonal flood plains and were frequently inundated.

The *Cynodon dactylon-Bulbostylis hispidula* community comprises of species like *Acanthospermum hispidum* which are noxious in Botswana (Phillips, 1992) and infest mostly fields under dryland farming. However, in seasonal flood plains where *molapo* farming is practiced it was found in abundance in fields that flood occasionally and located on the upper gradient of the floodplain. Other species found in this community were *Nidorella resedifolia, Phylla nodiflora*, *Triumfetta pentandra*, *Kyllinga erecta*, *Kohautia subverticillata*, *Cyperus longus, Spermacoce sinensis, Vernonia glabra, Eragrostis sarmentosa and Gomphrena celesiodes.* The co-existence of dryland weeds species with seemingly weeds species that commonly colonise damp sandy areas (*Kyllinga erecta*) and those found in margins of water channels and drying-out areas of the floodplains like *Cyperus longus* and *Vernonia glabra* might be due to the location of *molapo* fields. Some *molapo* fields are located transverse to flood plains which makes these fields to be partially flooded. Furthermore, during periods of low floods, these fields are cultivated as dryland due to lack of residual moisture resulting in crops being rainfed. A high density of weeds that are associated mainly with dryland farming in cultivated areas of the wetlands was realised. This might be an indication of a regime shift from permanently inundated, sedge dominated wetland to seasonally inundated annual herb-dominated wetland (Rooney et al. 2007).

In the *Sida cordifolia - Corchorus tridens* community, some species were found in fields with lighter soils and located on the upper gradient of the flood plains. These were *Ipomoea coptica*, *Ipomoea sinensis* and *Indigofera flavicans*. There was also *Panicum coloratum* which is a drought hardy perennial grass found in drainage courses, around pans or in depressions and *Digitaria dibelis*. A combination of these species in this community with seemingly diverse ecological habitats might be due to differences in the hydrology of the different study sites. Most fields in Shorobe and Makalamabedi were not inundated for a considerable length of time while some were partially flooded. As such, these fields were cultivated as dryland farming rather than flood recession farming. This might have led to colonisation of *molapo* fields by weeds that are normally associated with dry land farming. On the other hand, in the *Sida alba – Abitulon angulatum* community, *Indigofera tinctoria* was found in abundance in uncropped sites and localised in Lake Ngami rather than Shorobe and Makalamabedi suggesting that this species prefers habitats that have clay soils but not heavily waterlogged. Such conditions were observed to be prevailing in *molapo* fields located around Lake Ngami. Similarly *Xanthium strumarium* is a species of disturbed areas and waste ground which also favours wet areas and heavier soils (Phillips, 1991). This might explain its presence in this community. The other species found in this community were *Chenopodia carinatum, Chamaecrista biensis, , Eclipta prostrata, Hibiscus trionum, Digitaria eriantha, Amaranthus hybridus.* Most flood tolerant species belonging to the Cyperaceae family were found in the *Glinus oppositifolius – Heliotropium ovalifolium* community. These include *Fimbristylis dichotoma, Cyperus esculentus, Cyperus latifolius and Cyperus articulatus.* They are tolerant of damp and water logged conditions. There is also *Alternanthera sessilis* which belongs to the Amaranthaceae family. It is tolerant of prolonged flooding (Tsheboeng, 2013; Bonyongo, 1999). *Pavonia senegalensis, Portulaca oleracea, Echinochloa jubata, Kohautia virgata* and *Echinochloa colona* are found occasionally on damp areas and margins of seasonal pans and also in disturbed sandy areas (Roodt, 2011; Heath and Heath, 2009). Their presence in this community may suggest that some of the fields were located around dried out areas on edge of lagoons and in some instances, damp parts of the floodplain.

2.5. Conclusion

This study has revealed the most abundant and trouble-some weed species in flood recession farming in the Okavango Delta. Presence of common dryland farming weeds like *Cynodon dactylon, Sida cordifolia* and *Corchorus tridens* in the Delta ecosystem may pose a potential threat to its ecological functions. *Corchorus tridens* was found to be more tolerant of cultivated land than other troublesome weeds. But *Cynodon dactylon* which is a rhizomatous grass and has the potential to colonise large areas of the floodplains has proved to be difficult to eradicate by any tillage method which might be of great concern to farmers. This could lead to temptations of using herbicides thereby compromising ecological integrity of the wetlands. Such information underpins development of sound weed management strategies. The study has also demonstrated variations in the weed communities with different sites. Therefore future studies should take in consideration hydrological characteristics (flood frequency and duration) when describing the composition of weed species groups in flood recession farming.

Chapter 3

The influence of cultivation frequency on weed species composition and diversity in flood recession farming in the Okavango Delta

3.1 Introduction

Disturbance is a distinct event that can modify the composition of an ecosystem, plant community and may also influence resource availability or the physical environment (Powell 2000; Hobbs and Humphries 1995). For instance, cultivation can disrupt the soil and existing plant communities facilitating invasion of some plant species while others may fail to grow in the new or modified environment. Areas such as agro-ecosystems are examples of human induced disturbance. In such managed systems, non-crop plants (hereafter called weeds) have evolved in response to cropping system practices by adapting and occupying open niches (Dekker 1997). These species are pioneers that increase diversity of agricultural ecosystems by using their environmental potential (Bhowmik 1997) and sometimes may reduce the diversity by pushing the ecosystem towards a mono-dominant structure. Yadav (2005) found that the diversity and basal area of most woody species declined with increased human disturbance leading to their complete eradication from highly disturbed forests. The study also showed that species such as *Anogeissus pendula* exhibited high density in highly disturbed areas, which was in line with Hobbs (1991) who noted that the effect of disturbance is influenced by its size and frequency. However, in the Okavango Delta, it has not been established how soil tillage influenced species composition and diversity where *molapo* farming is practiced. Hence it was imperative to carry out this study to establish how the frequency of disturbance in terms of soil tillage impact on weed species communities.

While disturbance is widely recognized as a primary influence on plant community in agro-ecosystems, weed species diversity and composition may be influenced by a suite of factors with varying degrees of intensity. These factors include agricultural practices such as weeding, soil tillage and agro-chemicals (Pal et al. 2013; Armengot et al. 2011). Soil tillage has the potential to change the plant community composition and diversity. The frequency of cultivating the land influences changes in weed species richness and diversity (Shemdoe et al. 2008). Soil tillage promotes establishment of highly competitive plant species. It makes soil suitable for germination and seedling establishment (Handa et al. 2012). In minimum till systems, weed seeds accumulate on the soil surface where conditions are favourable for seed germination and thus have high species richness and diversity (Yenish et al. 1992; Shemdoe et al. 2008). Broadleaf weed species tend to dominate under conventional tillage systems and is thought to be stimulated by light as they are brought to the soil surface (Froud-Williams et al. 1983). A study by Yenish et al. (1992) showed that non tillage systems typically have higher populations of small seeded annuals weeds such as *Setaria* spp and *Amaranthus* spp while tillage systems using mouldboard ploughs have more large seeded annual weeds like *Xanthium strumarium L*. However, studies by Swanton et al. (1999) concluded that there was no consistent relationship between weed diversity and tillage system. This contradictory observation suggests that there may be factors other than tillage that may influence weed density. Such factors include crop rotation (Swanton and Weise 1991; Anderson and Milberg 1998; Legere and Sampson 1999), and cover crops which may have demonstrated allelopathic properties that inhibited weed establishment and growth (Putnam and DeFrank 1983; Mohler and Teasdale 1993). These cover crops have also been found to suppress weeds by competing for water, light and nutrients (Barnes and Putnam 1983). However, there has not been adequate information available on these factors on how they influence weed species composition and diversity in the agro-ecosystems of the seasonal floodplains in the Okavango Delta.

Thus, changes in land use and management practices can influence vegetation composition, especially weed flora in agro-ecosystems. Early studies by Kellman (1980) on geographic patterning in tropical weed communities and early secondary successions found that changing from shifting to intensive or permanent agriculture in the tropics eliminated many woody species and replaced them with aggressive herbaceous weed species. In flood recession farming plant species composition can be influenced by desiccation and/or reduced flooding. Handa et al. (2012) showed that facultative upland weeds completely dominated the drained cultivated sites as opposed to permanently inundated areas dominated by either obligate or facultative wetland species. Similarly, in the Okavango Delta, *Setaria sphacelata* was found to be more pronounced in areas subjected to shallow flooding (Bonyongo 1999) while *Eleocharis dulcis* and *Leersia hexandra* were found to be facultative wetland species as they were more tolerant to prolonged flooding (Tsheboeng et al. 2014). These studies were focused on the floodplains and no vegetation studies to date have been done in *molapo* farming. *Molapo farming* includes intensive cultivation of the floodplains (Oosterbaan et al. 1987; Petermann, 1989; Bendsen 2002 & Mmopelwa 2011). It is practiced along the edges of the river channels or seasonally flooded depressions on the fringes of the Okavango Delta (Bendsen 2002). Given that this farming system is an essential livelihood activity for a majority of the communities that reside along the Okavango Delta, it warrants that similar studies should also be conducted in *molapo* farming. Therefore this study was conducted to determine the influence of cultivation frequency on weed species composition and diversity in flood recession farming in the Okavango Delta.

3.2 Materials and methods

The study was conducted in the villages of Shorobe, Makalamabedi and Lake Ngami (Fig.1). The sites were chosen for their contrasting hydrology in terms of flooding patterns and the location of molapo fields. Shorobe is located in the eastern end of the Okavango Delta and its administrative boundary is 1,078 km^2 and lies 30 km east of Maun in Ngamiland District. It has a human population of 1,031 (Statistics Botswana 2011). *Molapo* fields are located in the northwest of the village and are inundated by the Santantadibe and Gomoti Rivers and by backflow from the Thamalakane River. The *molapo* fields in Shorobe are mainly found in islands with dense riparian woodlands and they have a saucer-shaped cross-section and they obtain moisture from spill over or back flow water from the main river channels (Bendsen, 2002). Normally this area experiences maximum flood extent between August and September and by the end of October the flood begins to recede. Lake Ngami occupies the northeast part of the shallow sedimentary basin bounded to the southeast by a low escarpment of Karoo and Ghanzi Formation rocks along an extension of the Kunyere Fault (Reeves 1978). Lake Ngami did not receive enough flood water between 1989 and 2004. And farmers did not cultivate their *molapo* fields during these dry periods (Mmopelwa 2011). As a result most *molapo* fields are relatively new and not permanently placed like those at Shorobe and Makalamabedi. The maximum flood extent is usually experienced on average in October. The lake is surrounded by Toteng, Sehithwa, Bodibeng and Bothatogo villages. At the last census, the human population for these villages was 902; 2 748; 778 and 555 respectively (Statistics Botswana 2011). Lastly, Makalamabedi lies 83 km South East of Maun along the Boteti River. The veterinary cordon fence that cuts through the village divides the village into two districts. Makalamabedi on the western side of the cordon fence lies on the Ngamiland District with a population of 1,010 while the Eastern side of the fence lies on the Central district with 1,674 people (Statistics Botswana 2011). Arable farming is done in fields allocated along the Boteti River. *Molapo* fields located on steep banks along the Boteti River are characterised as channel type (Bendsen 2002). This river is an ephemeral water channel which derives flood waters from the Okavango Delta through Thamalakane River. It flows in a south-easterly direction, and finally discharges into Lake Xau. The peak floods are between August and September.

3.2.1 Selection of molapo fields

Field visits were conducted to identify *molapo* fields at the different study sites. Once suitable fields had been identified, consent was sought from farmers and information gathered on tillage history in terms the number of years the field have been cultivated. The fields were categorised according to the historic frequency of continuous cultivation in years. The categories were defined as: continuous cultivation for the previous 5 years; 10 years and 15 years, while equivalent sites with no history of cultivation were used as a control. Simple random sampling (SRS) was then carried out using a random number generator in MS Excel to draw 3 fields from each stratum or cultivation frequency. A total of 12 fields per study site were selected.(Figure 6).

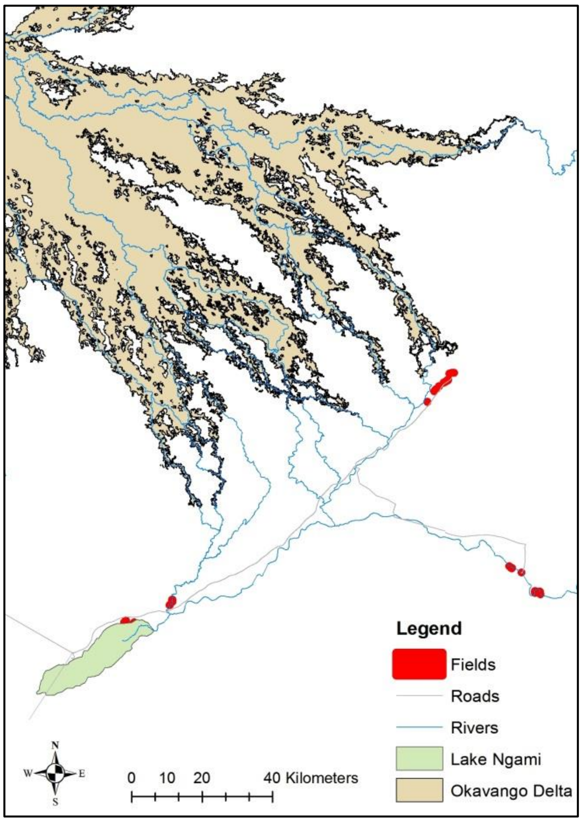

Figure 8: A map showing distribution of sampled *molapo* fields at Shorobe, Makalamabedi and Lake Ngami

3.2.2 Vegetation Sampling

Vegetation was surveyed at the three sites from March to the end of April 2016, when most plants were in flowering for easy identification. Since fields are relatively small fields, a 50m tape measure was used as a line transect in each field. The line transects were laid parallel to each other and spaced 20 m apart (Morgan 1998) from the lower to upper gradient in each *molapo* field. Weed species composition and abundance were then recorded in 1m^2 quadrats placed along each transect at 10m interval (Morgan 1998). Placement of transect and quadrats was through the modified stratified sampling adopted from Gillison and Brewer (1985) using gradient oriented transects. Because of small area and irregularly shaped, the number of quadrats surveyed differed from one site to the other. For instance, a total of 93 quadrats were surveyed at Shorobe, 86 at Makalamabedi and 74 at Lake Ngami. In each quadrat, all species were identified and the number of indivduals was counted (without accounting for vegetative reproduction). Unidentified plants were mounted and taken to the Peter Smith University of Botswana (PSUB) herbarium at the Okavango Research Institute for identification.

3.3 Data Analysis

Species diversity and evenness were determined for each frequency of cultivation within and across the study sites. The Shannon's diversity indices were determined using Paleontological Statistics (PAST) version 3.12. Kruskal-Wallis was used to test for statistically significant differences in species density across the cultivation frequencies as well as species diversity between frequency of cultivation within and across the study sites. Since Kruskal–Wallis is an omnibus test, Independent samples median test was conducted to establish which groups differ significantly (between group comparisons). This was performed in SPSS version 24. Rank/abundance plot was used to plot species abundance data to rank weeds species for each cultivation frequency. The species abundances were displayed in $\log_{10}$ format to accommodate species whose abundances span several orders of magnitude on the same graph (Magurran 2004). This assisted in determining the association between weeds and the cultivation frequencies and it was performed in PC-ORD 6.

3.4 Results

3.4.1 Species Diversity within Study sites

Lake Ngami

Lake Ngami did not have both 10 and 15 years cultivation frequencies. Uncropped sites had the highest Shannon's diversity index of 1.22 compared with 1.11 recorded at the 5 year cultivation frequency, but the difference was not statistically significant (Figure 9), suggesting that cultivation frequency does not have an effect on weed species diversity at Lake Ngami. Similarly, the species evenness was similar across the cultivation frequency ($p>0.05$), indicating that cultivation frequency did not have an effect on species evenness (Figure 10).

Makalamabedi

Uncropped and five year cultivation frequency had similar species diversity and were both higher than 10 and 15 year cultivation frequency (Figure 9). However, the five year cultivation frequency displayed significantly higher mean species diversity than both 10 year and 15 year cultivation frequencies at ($p < 0.05$). This showed a descending trend as the frequency of cultivation increased. However, uncropped sites showed a higher presence of species than both the 10 and 15 years cultivation frequencies but the difference was not significant ($p> 0.05$). There was no significant difference ($p > 0.05$) in mean species evenness across the cultivation frequencies, suggesting that Shannon's equitability index (species evenness) was not influenced by the frequency of cultivation at Makalamabedi (Figure 10).

Shorobe

Cultivation frequency did not influence species diversity. The 5 years cultivation frequency displayed higher species diversity and evenness than the 10 years and 15 years cultivation frequencies (Figure 9). However, this trend was not statistically significant ($p > 0.05$). Mean species evenness was significant across the cultivation frequencies ($p < 0.05$). The results suggested that cultivation frequency influences weeds species evenness in Shorobe. Further investigation through multiple comparison revealed that five year cultivation frequency (M =0.653, SD = 0.171) differed significantly with uncropped fields (M= 0.544, SD = 0.198). This indicated that species present at the 5 year cultivation frequency are more evenly distributed than in the uncropped fields (Figure10).

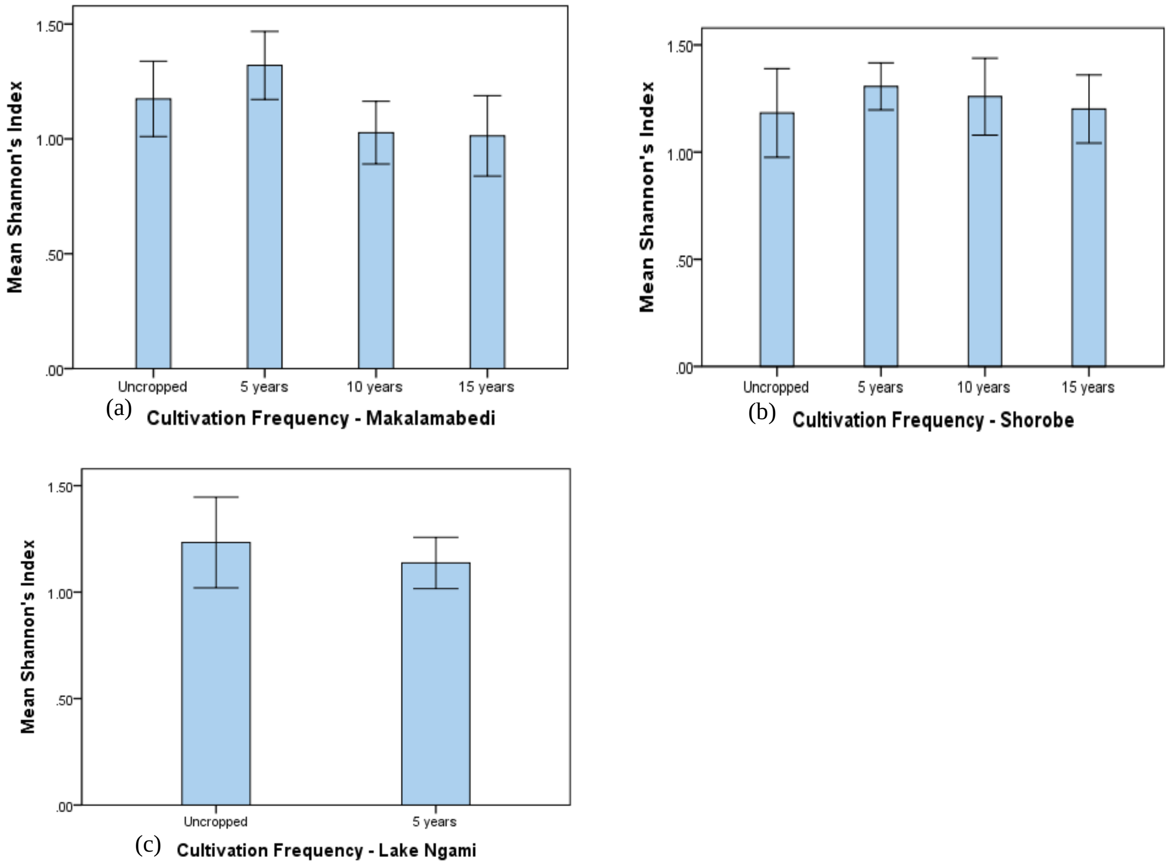

Figure 9: Mean species diversity with standard errors representing the influence of cultivation frequency on species diversity within the study sites (a = Makalamabedi; b = Shorobe; c = Lake Ngami).

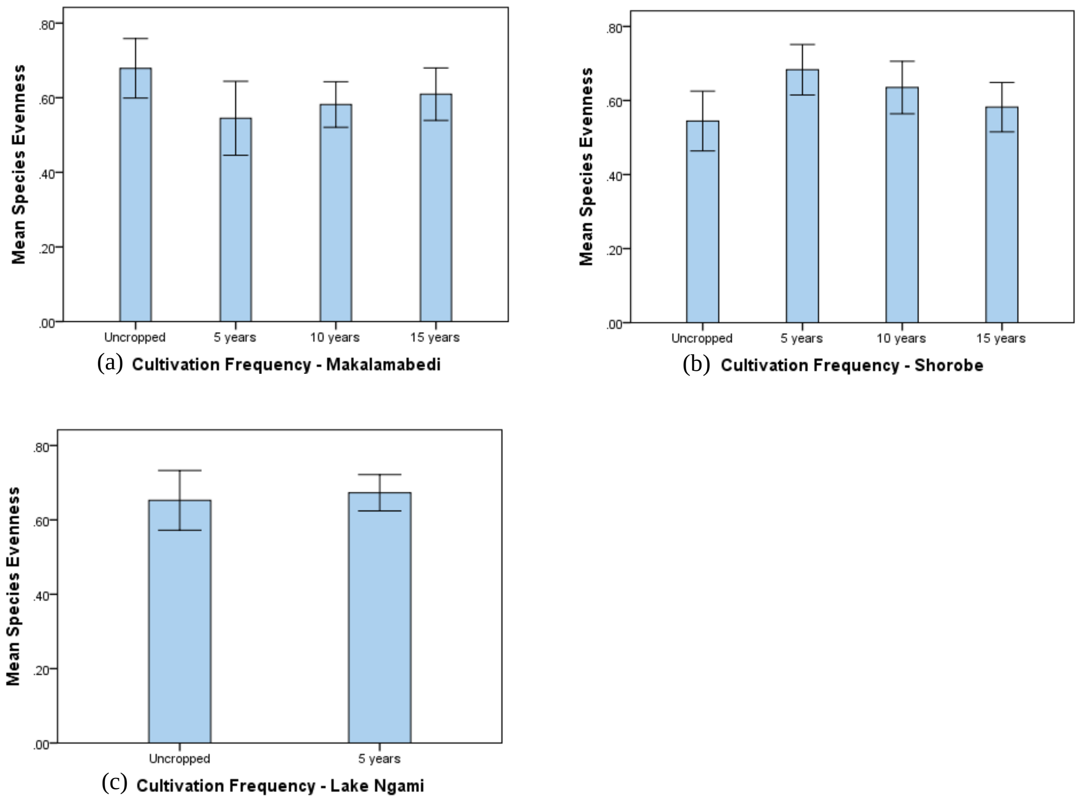

Figure 10: Mean species evenness with standard errors representing the influence of cultivation frequency on species evenness within the study sites (a = Makalamabedi; b = Shorobe; c = Lake Ngami).

3.4.2 Species Diversity indices across the study sites as defined by the different cultivation frequencies

Kruskal-Wallis was used to test the hypothesis that the distribution of Shannon's diversity is the same across categories of cultivation frequencies. The test revealed that there was a statistically significant difference in the diversity indexes across the 4 cultivation frequencies (uncropped, n = 38; 5 years, n =43; 10 years, n = 51; 15 years, n = 47), χ^2 (3, n = 179) = 8.217, p = 0.042 (Figure 11). The 5 year cultivation frequency has recorded a higher median score (Md = 1.352) than the other cultivation frequencies. The 15 years cultivation frequency recorded the least median score (Md = 1.035) compared to the other categories.

Kruskal-Wallis was also used to test the hypothesis that species evenness was the same across the cultivation frequencies. The test has shown that there was no statistically significant difference in equitable distribution of species across the cultivation frequencies (uncropped, n = 38; 5 years, n =43; 10 years, n = 51; 15 years, n = 47), χ^2 (3, n = 179) = 1.107, p = 0.775 (Figure 12).

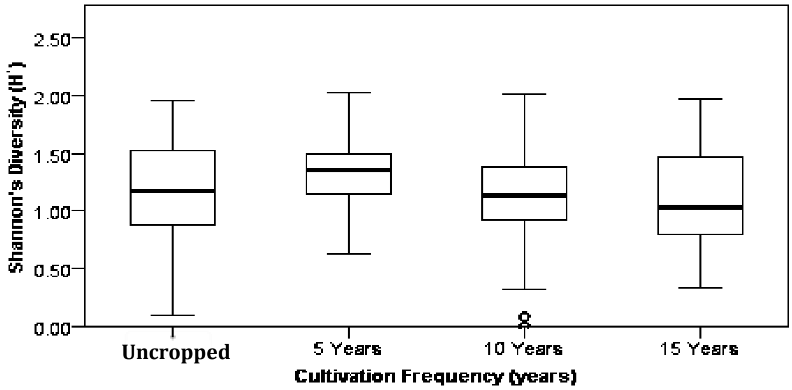

Figure 11: Graphical representation of the Independent-Samples Kruskal Wallis Test on Shannon's Diversity Index across the study sites.

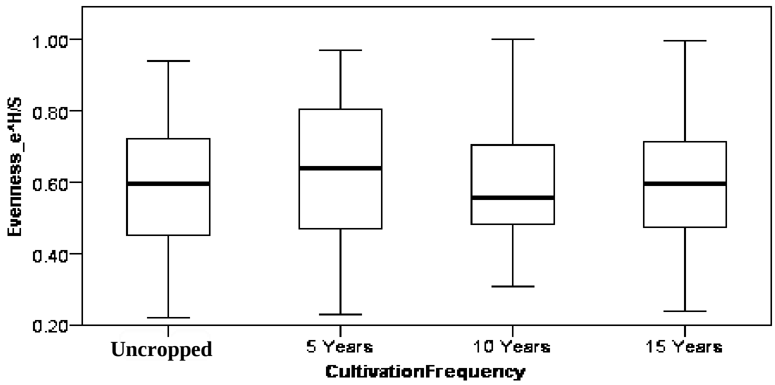

Figure 12: Graphical representation of the Independent-Samples Kruskal-Wallis Test on Species Evenness across the study sites

The association of weed species with the cultivation frequencies is presented in Table 8. *Cyperus esculentus*.,and *Cynodon dactylon*.. were the most abundant in uncropped sites and 10 years frequency respectively while *Corchorus tridens* was the most abundant in both 5 and 15 years frequencies. *Corchorus tridens* L. was found in all the frequencies except in uncropped. The uncropped fields have mostly species from the Cyperaceae family. *Digitaria debilis* (Desf.) is the only species from the Poaceae that forms part of five most abundant species in the uncropped fields. Rank/Abundance tables showing all the weeds species for each cultivation frequencies are in appendix 5, 6, 7 and 8 respectively.

Table 8: Five most abundant weeds species at each cultivation frequency.

Cultivation Frequency	Species	Family	Rank of Abundance
Uncropped	*Cyperus esculentus* L.	Cyperaceae	1
	Cyperus latifolius L.	Cyperaceae	2
	Digitaria debilis (Desf.)	Poaceae	3
	Fimbristylis dichotoma (L.) Vahl	Cyperaceae	4
	Cyperus longus L.	Cyperaceae	5
5 Years	*Corchorus tridens* L.	Tiliaceae	1
	Cynodon dactylon (L.) Pers.	Poaceae	2
	Bulbostylis hispidula (Vahl) R.W.Haines	Cyperaceae	3
	Ipomea sinensis (Desr)	Convolvulaceae	4
	Heliotropium ovalifolium Forssk.	Boraginaceae	5
10 Years	*Cynodon dactylon* (L.)Pers.	Poaceae	1
	Corchorus tridens L.	Tiliaceae	2
	Acanthospermum hispidum DC.	Asteraceae	3
	Sida cordifolia L.	Malvaceae	4
	Triumfetta pentendra A.Rich	Malvaceae	5
15 Years	*Corchorus tridens* L.	Tiliaceae	1
	Ipomea sinensis (Desr.)	Convolvulaceae	2
	Panicum coloratum L.	Poaceae	3
	Bulbostylis hispidula (Vahl) R.W.Haines	Cyperaceae	4
	Cyperus articulatus L.	Cyperaceae	5

3.5. Discussion

Previous studies in the Okavango Delta such as Tsheboeng et al.(2014); Murray-Hudson et al.(2011); McCarthy et al.(2005); Bonyongo (1999) and Ellery et al.(1993) have demonstrated that vegetation communities are influenced by flood duration, depth and frequency. In flood recession farming areas of the Okavango Delta, weed species composition and diversity is influenced by frequency of cultivation. It's suffice to suggest that cultivation frequency can be an important driver of weed species assemblages in flood recession farming. Species diversity decreased with increasing frequency of cultivation while species evenness was not affected. It is likely that cultivation over the years might have stimulated germination of weed seeds from the seed bank resulting in a decrease in the seed bank especially when there is no rain to replenish the seed bank. In support of this assertion, Froud-Williams (1983), stated that non- dominant buried seeds will be brought to the soil surface and germinate upon cultivation.

The study sites were dominated by different weed species probably as a result of differences in hydrology and soil types. The most dominant weed species were *Sida cordifolia* L, *Cynodon dactylon* (L)Pers and *Bulbostylis hispidula*(Vahl)R.W.Haines at Lake Ngami, Makalamabedi and Shorobe, respectively. *Cynodon dactylon* is a wide spread weed in Botswana in both dryland and irrigated farming (Abdullahi 2002). The relationship of weeds and cultivation frequencies was determined using rank of abundance. Five common weeds species were selected at each cultivation frequency as also demonstrated by (Shemdoe et al 2008). The uncropped sites were mostly dominated by species belonging to the Cyperaceae family. *Cyperus esculentus* L was the most frequently occurring species. Other species that occur more frequently in the uncropped sites were *Cyperus latifolius* L., *Fimbristylis dichotoma* (L.)Vahl and *Cyperus longus* L. In a similar study in the Okavango Delta, Bonyongo et al (2000) recorded *Cyperus* species in floodplain vegetation. They also linked the observed different plant communities to differences in flooding time and duration. Murray-Hudson et al.(2006) also noted that *Cyperus* species are wetland species that are able to tolerate some dry periods and as such are found in areas that are flooded on a seasonal basis such as flood recession farming fields.

All the species found in uncropped sites have rhizomes on which tubers develop and lie dormant in the soil for long periods of time. This might explain their coexistence and dominance in uncropped sites. *Digitaria debilis* (Desf.) is the only species of the Poaceae most dominant in uncropped sites. It shares a similar habitat with the species of the Cyperaceae which are mostly abundant in uncropped fields. According to Heath and Heath (2009), *Digitaria debilis* (Desf.) occasionally colonises damp areas of the flood plains and often rooted in water. Absence of these species at both the 5 and 10 year cultivation frequency might be due to the fact that tillage reduces regenerative potential of perennial weeds (Stoller and Sweet 1987) because the tubers are sensitive to cultivation. Studies by Bangarwa et al (2012) and Stoller et al (1972) indicated that tubers for species like *Cyperus esculentus* L are equally sensitive to soil disturbance despite the number of times the disturbance is repeated.

All the three cultivation frequencies were dominated by weed species such as *C. tridens* L., *C. dactylon*, *Ipomoea* species and *Acanthospermum hispidum* DC. *Corchorus* species are common weeds in Europe, Australia, Asia, and Africa (Holm et al. 1979). In Botswana *Corchorus* species are mostly found around the Okavango Delta (Phillips 1991) while *C. dactylon* is wide spread in Botswana as a weed in both dry land and irrigated fields (Abdullahi 2002). *Acanthospermum hispidum* is troublesome in agricultural fields. It is one of the top 10 common weeds in the US (Teuton et al. 2006). In Botswana it is found in cultivated fields and other disturbed places where it forms dense stands (Abdullahi 2006).

In other cultivation frequencies, *Corchorus tridens* L is the only species that appeared across all the frequencies except in uncropped fields. According to Dzerefos et al (1995), *Corchorus tridens* L has an affinity to cultivated land. This might explain why it occurred most frequently in all fields that have been cultivated for a period of 5 to 15 years. It is also one of the weeds that are commonly used as traditional vegetables (Maroyi et al 2013). The species that were more frequently occurring at the 5 year cultivation frequency were *Corchorus* *tridens, Cynodon dactylon, Bulbostylis hispidula, Ipomoea sinensis* and *Heliotropium ovalifolium.*

Cynodon dactylon is mostly abundant in the 5 year and 10 year cultivation frequencies. It was however observed that most fields at the 15 year cultivation frequency had no visibility of *C. dactylon* across all the study sites. It could be suggested that as the intensity of cultivation increases, the abundance of *Cynodon dactylon* also decreases. Since this weed species is rhizomatous (Labovitch 1978), the frequency of cultivation might interfere with its vegetative ability by disturbing the development of the rhizomes and hence there was reduction in its abundance from the 10 year to 15 year cultivation frequencies.

3.6 Conclusion

Cultivation frequency influenced weed species composition and diversity in flood recession farming areas of the Okavango Delta. Uncropped sites were composed of wetland species that tolerate some dry periods or seasonal flood plains. Flood recession farming fields were dominated by common weed species which are also troublesome in dryland arable farming. High cultivation frequency tends to suppress weeds hence reduction in their diversity. At a moderate cultivation frequency (5-10 years), weeds species were activated and newly created micro-climate favoured their germination and growth.

Chapter 4

Drivers influencing weed species composition and diversity in flood recession farming in the Okavango Delta

4.0 Introduction

In agro-ecosystems weed species communities are influenced by weeding, soil tillage, and use of agro-chemicals (Pal et al 2013; Armengot et al 2011). Other factors found to influence the build-up of weed communities include soil properties (Andreasen et al. 1991). Soil physico-chemical properties include the concentrations of soil nutrient elements such as nitrogen (N) and phosphorus (P), cations (Potassium (K), calcium (Ca), and Magnesium (Mg), soil carbon (C) or soil organic matter (SOM) and soil pH. In Central Europe, altitude, climatic changes, seasonal changes, soil types and pH were observed to be the main drivers of weed species composition (Lososova et al. 2004; Cimalova and Lososova 2008). Although Lawrence et al. (2005) stated that soil nutrients are also critical, they may not alone have a significant influence on weed species composition. Swanton et al. (1999) found that soil tillage was more effective in influencing weed flora composition than nitrogen and cover crop. Nonetheless, the results by Pysek and Leps (1991) have shown that nitrogen as an important element in plant growth can have a significant direct and indirect effect on weed species composition which can be increased competition with crops.

Soil pH as a fundamental chemical property, is said to be having an impact on weed species composition. Low pH inhibits availability and absorption of phosphorus, potassium, nitrogen and can induce the toxicity of aluminium. In such conditions, some weeds may be inhibited to grow while others may thrive (Buchanan et al. 1975). For instance, *Rumex acetosella, Portulaca oleracea* and *Phytolacca americana* were found to be mostly associated with acidic sandy soils (Fried et al. 2008). Similarly, *Reseda phyteum* and *Anagallis foemina* were found to be associated with basic clay rich soils. However, decreasing soil pH in agricultural fields may result in gradual long term changes in weed flora composition through competitive interactions rather than abrupt changes (Weaver and Hamill 1985).

Changes in weeds species composition could also be associated with the different crop types present in arable fields. For example, in a study by Cimalova and Lososova (2008) in the north eastern part of the Czech Republic crop type was found to be a major determinant of the weed flora. Moreover, the effect of crop diversity on weed communities were found to be mainly due to the presence of cover crops with strong effects on soil resources and light levels (Smith and Gross 2007).

In wetlands, of the Okavango Delta seasonal floodplain vegetation communities are influenced by flooding depth and duration, and timing of inundation (Bonyongo 1999; Robertson et al. 2001; Capon 2005; Tsheboeng et al. 2014). Soil chemistry, including pH has also been reported to be responsible for vegetation zonation (Dale et al. 1992; Ervio et al. 1994; Cimalova and Lososova 2009). Nutrient and sediment deposits similarly account for variability of the weed flora, for instance *Poa annua* and *Spergula arvensis* were most common in soils where extractable calcium concentration was below 1000 mg l^{-1} soil in Southern and Central Finland (Ervio et al. 1994). In addition to these environmental variables, floodplain vegetation community composition is controlled by individual plant species' adaptation to a given flooding regime (Nilsson and Svedmark 2002; Capon 2005). For example, Casanova and Brock (2000) mentioned that depth, duration and frequency of inundation influenced plant community composition. This was consistent with the findings by Oliveira-Filho et al. (1994) who reported that seasonal floodplain vegetation community composition is determined by flood pulses. Even though flood frequency had an effect on species richness and biomass, the results of the study by Casanova and Brock (2000) indicated that non-flooded areas along the floodplains displayed higher biomass and species richness than in flooded areas. Decreased flood frequency was observed to create environment increasingly suitable for plant adapted to drier conditions including exotic annual weeds (Stokes et al. 2010). Similarly, it may be suggested that increased flood frequency might promote regeneration of flood tolerant species which could be attributed to establishment of dormant seeds and vegetative propagules existing in the wetlands. This is brought about by variations in response to flood by the different species. For example, highly flood tolerant species were observed on lower floodplains and flood sensitive species on elevated parts of the floodplains (Bonyongo 1999). Most of the studies on vegetation of the Okavango Delta (Tsheboeng, et al. 2014; Murray-Hudson et al. 2011; Ellery et al. 2003; Wolski and Murray-Hudson 2006; Bonyongo 1999) were mostly on seasonal floodplains and none of these focused on flood recession farms. It is against this background that this study was conducted to determine the weed species composition and diversity in flood recession farming so as to come out with sound weeds management strategies.

4.1 Objective:

4.1.1 To determine the influence of soil properties on weed species composition and diversity in flood recession farming

4.1.2 To establish the main driver of weed species composition and diversity in flood recession farming areas

4.2 Materials and methods

4.2.1 Study sites

The study was carried out in *molapo* farming sites in three villages of Shorobe, Toteng and Makalamabedi in the Okavango Delta (Refer to chapter 2 for full description of the study sites).

4.2.2 Selection of molapo fields

Selection of the fields followed the same procedure as in chapter 2 (see this chapter for a detailed description of selection of *molapo* fields)

4.2.3 Vegetation Sampling

Vegetation sampling was the same as in chapter 2 (please refer to this chapter for a full description of the sampling strategy).

4.2.4 Soil sampling and Flood frequency.

The aim was to determine the influence of soil chemical properties on weed species composition and diversity in flood recession farming. The soil parameters were also used to determine the relationship between soil nutrient content and flood frequency on species composition and diversity. Soil samples were collected from each field using the technique applied by the Department of Agriculture Research (DAR), Botswana (Figure 13). A soil auger was used to draw soil samples at the 20 cm depth. The sampling points were at 10 m intervals along each line. Depending on the size of the field, the sub samples were mixed to make one composite sample for the field. A total of 49 composite samples were collected. The soil samples were packaged in polyethylene bags and analysed at the Okavango Research Institute Environmental Laboratory. A standard soil test (Anderson and Ingram 1989; Walworth 2006) was followed as applied by the DAR to analyse for soil pH, soil organic matter (SOM), total nitrogen (N), available phosphorus (P), potassium (K), calcium (Ca), sodium (Na) and magnesium (Mg). Phosphorus was analysed using the Bray-1 method. Ultra Violet Visible Spectrometer (UV-Vis Spec) was used to measure absorbance at 882 nm. The Kjeldahl method was used to determine the total nitrogen content using a Brant+Luebbe Auto analyser 3(AAIII). Cations Ca, Mg, K, and Na were determined using an Atomic Absorption Spectrophotometry (AAS). SOM was determined by Loss on Ignition (LoI) using a Macro furnace to heat 5g of soil sample at 450°C for 2 hours. A potentiometric method (Brady, 2008) was used to measure soil pH. A pH meter model 330i with glass electrode was used to determine soil pH in a soil: water suspension at a ratio of 1:1. The soil samples were sun dried prior to analysis.

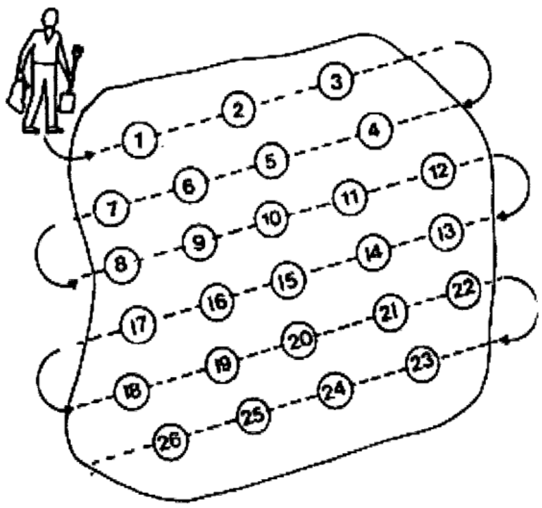

Figure 13: Soil sampling technique. Adopted from the Department of Agricultural Research (1990)

The global position system (GPS) coordinates for each field were recorded using a Garmin hand held device. The coordinates were recorded for the four corners of each field. This was used to determine the centroid for each field. The flood frequency parameters in (Table 9) were determined from pre classified LandSat images from 1984 to 2015 (Pekel et al. 2016). The water occurrence data set used show where surface water occurred between 1984 and 2015.

Table 9: Flood frequency for each study site. The flood frequencies where recorded as average percentage occurrence and average flood frequency in years for 32 years.

Site	Average occurrence (%)	Average Flood Frequency (Years)
Shorobe	2.00±0.825	0.64±0.264
Makalamabedi	5.75±2.931	1.84±0.938
Lake Ngami	2.83±1.153	0.91±0.369

4.3 Data Analysis

A One Way Multivariate Analysis of Variance (MANOVA) was used to investigate differences in soil nutrient elements (Na, Mg, Ca, K, P, and N) across the study sites (Shorobe, Makalamabedi and Lake Ngami) and across the cultivation frequencies (uncropped, 5 years, 10 years and 15 years). Preliminary tests for Normality, Linearity and Homogeneity of variance were carried out to test for violation of the assumptions. A multivariate test was identified using Wilks' lambda (λ). The significant differences on dependent variables were observed using the Bonferonni adjusted alpha level of 0.008. This was obtained by dividing the conventional alpha level of 0.05 by the number of dependent variables. One Way Analysis of Variance (ANOVA) was used to investigate mean differences in pH level and SOM content across the study site and across the different cultivation frequencies. The mean differences were tested at $p \leq 0.05$ level of significance. The magnitude of the differences between the groups was determined using eta squared (η^2). This was performed using SPSS software version 24.

Hierarchical cluster analysis (HCA) was carried out to determine weed species composition in the different study sites across different environmental gradients. Weed species were clustered into homogenous groups based on their site characteristics. It is an agglomerative cluster analysis. It was performed using Sorensen distance measure with flexible beta linkage; β = -0.25 in PC-ORD 6 software. The indicator values for the weeds species from cluster analysis were derived from indicator species analysis (ISA) (Dufrene & Legendre 1997). Each group was named using the weed species with the highest indicator value and a significant p-value ($p \leq 0.05$).

To determine which environmental variable (flood frequency, soil pH, SOM, Na, Mg, Ca, K, P and N) drives weeds species composition in flood recession farming area, Canonical Correspondence Analysis (CCA; ter Braak 1986) was used. A solution reached tolerance in Axis 1 at 50 iterations, axis 2 at 21 iterations and 487 iterations in axis 3. Monte Carlo testing was performed with 999 runs. CCA ignores community structure that is unrelated to the environmental variables (McCune and Grace 2002). The weed species were strongly related to environmental variables but not with general community structure. This was performed in PC-ORD 6 software.

4.4 Results

4.4.1 Soil nutrients elements content, pH and SOM across the study sites

Table 10: Mean (±standard error) soil nutrients concentrations of the flood recession farming areas for the different study sites.

Soil Nutrients Elements	Shorobe	Makalamabedi	Lake Ngami
Na (mg/kg)	9.79±1.47	38.12±10.14	30.03±6.25
K(mg/kg)	134.33±10.66*	381.58±56.29*	333.13±50.80*
Mg (mg/kg)	37.35±2.45	100.92±23.28	69.67±17.03
Ca (mg/kg)	303.96±22.85*	610.69±83.94*	506.47±62.76
Available P (mg/Kg)	0.84±0.21	0.93±0.252	2.23±0.652
Total Kj-N (mg/kg)	613.05±36.74*	1059.58±102.10*	1106.36±132.00*

* The mean difference is significant across the sites at the adjusted $p \leq .008$ level.

A One Way MANOVA was performed to investigate differences in soil nutrients element content across the study sites. The six dependents variables were Na, Mg, Ca, K, P and N. The independent variable was site (Shorobe Makalamabedi and Lake Ngami). There was a statistically significant difference between sites on the combined dependent variable, $F(12, 56) = 3.551$, $P = .001$; Wilks' $\lambda = .322$ and partial eta squared (η^2) = .432. Considering results for dependent variables separately using the Bonferonni adjusted alpha level of 0.008; K, Ca, and N were statistically significant $F(2,33) = 8.784$, $p = .001$; $\eta^2 = .347$, $F(2,33) = 6.341$, $p = .005$; $\eta^2 = .278$ and $F(2,33) = 7.619$, $p = .002$; $\eta^2 = .316$ respectively. Inspection of mean scores indicated that Makalamabedi had higher K levels (M= 381.58±56.29) and Ca levels (M= 610.69±83.94) than Shorobe and Lake Ngami (Table 10). Lake Ngami had the highest N level (M= 1106.36±132.00) while Shorobe had the lowest N level (M= 613.05±36.74).

(i) Soil pH

There was a statistically significant difference in soil pH between the study sites at $p \leq 0.05$ (Figure 14). A post hoc test revealed that the mean score for Shorobe (7.20± 0.055) was significantly different from mean score for Lake Ngami (6.60 ± 0.167). Makalamabedi did not differ significantly from Shorobe and Lake Ngami.

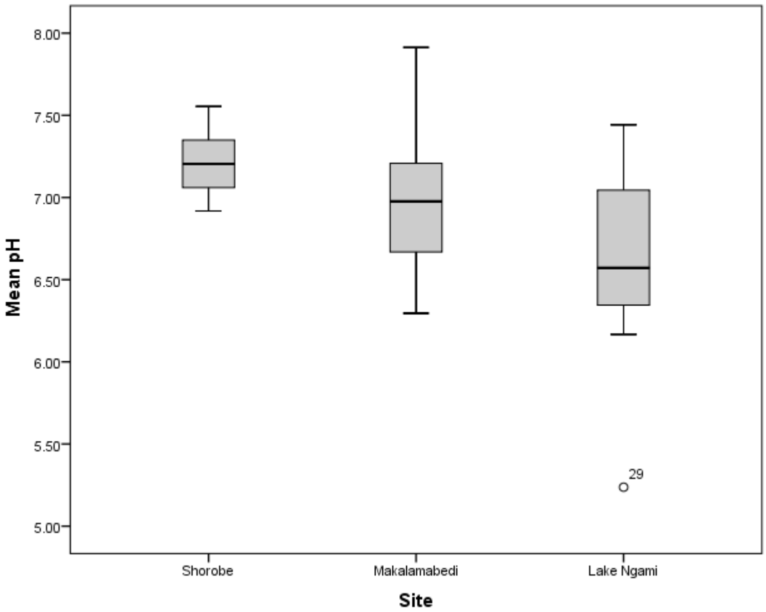

Figure 14: Mean soil pH values for the different study sites.

(ii) Soil Organic Matter (SOM)

The mean SOM content between Shorobe, Makalamabedi and Lake Ngami (Figure 15), was compared using One Way ANOVA. There was no statistical significance at F (2, 35) = 0.329, p = 0.722. SOM is similar across the study sites.

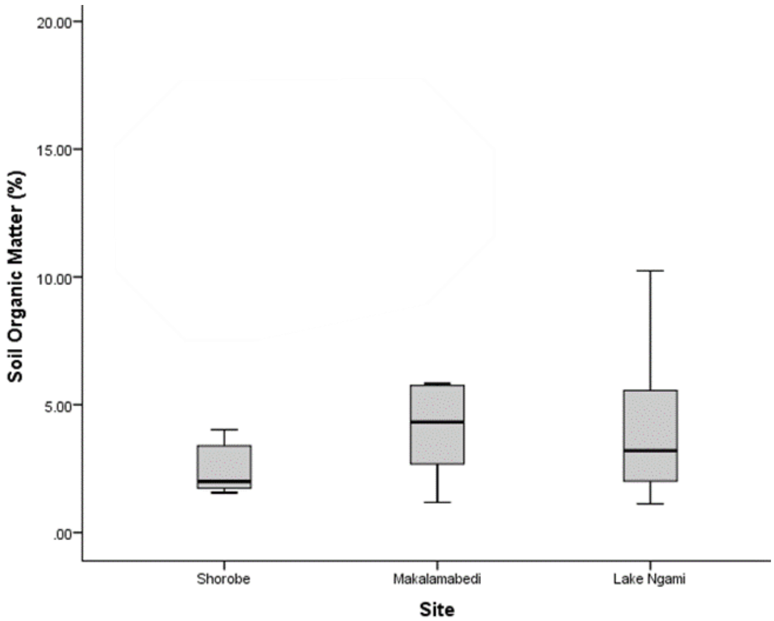

Figure 15: Mean SOM content across the study sites

4.4.2 Weed Species composition and diversity

Weeds in the Okavango Delta were grouped in six species assemblages with 2 plant communities at each study site (Appendix 9; Appendix 10 and Appendix 11). This showed that there was a spatial dissimilarity of weed species across the flood recession farming areas as influenced by the nutrient contents and flooding regime.

The mean diversity index for Shorobe was highest at 1.908 while Makalamabedi recorded the lowest mean Shannon diversity index of 1.650 (Figure 16). Kruskal-Wallis test revealed that there was no statistically significant difference χ^2 (2, n = 36) = 2.781, p = 0.249, in mean species diversity across the study sites. .

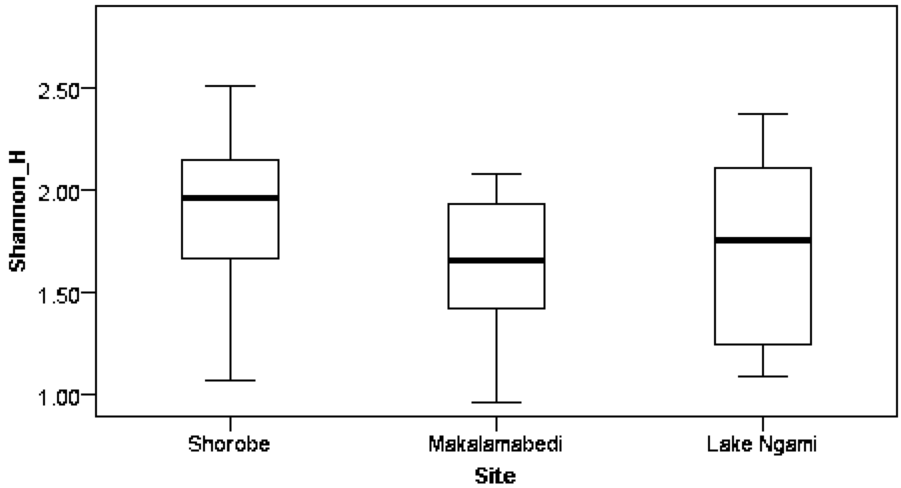

Figure 16: Mean species diversity in flood recession farming areas across different soil nutrient content at different sites

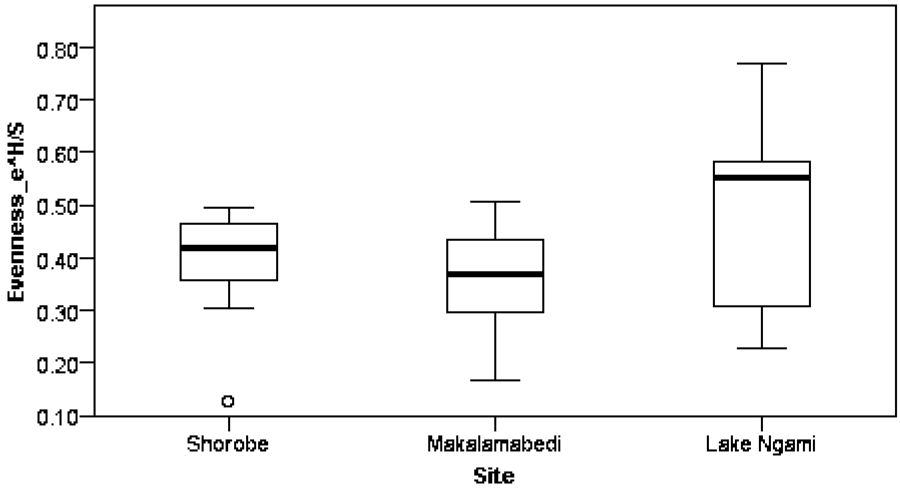

Figure 17: Mean species evenness in flood recession farming areas across different soil nutrient content at different sites

Lake Ngami recorded the highest mean species evenness of 0.471 while Shorobe and Makalamabedi recorded mean species evenness of 0.400 and 0.380 respectively (Figure 17). The Kruskal-Wallis was used to test if the distribution of species evenness is the same across the different study sites. There was no statistically significant difference in mean species evenness χ^2 (2, n = 36) = 3.561, p = 0.169.

4.4.3 Soil Nutrient element content, pH and SOM across the different cultivation frequencies

There was a statistically significant difference in soil pH ($p \leq 0.05$) between the different cultivation frequencies. The mean scores for uncropped fields (M = 6.613 SD = 0.331) differed significantly from mean scores for the 10 year cultivation frequency (M= 7.339 SD = 0.363). There was no difference in means scores between the other cultivation frequencies (Figure 18).

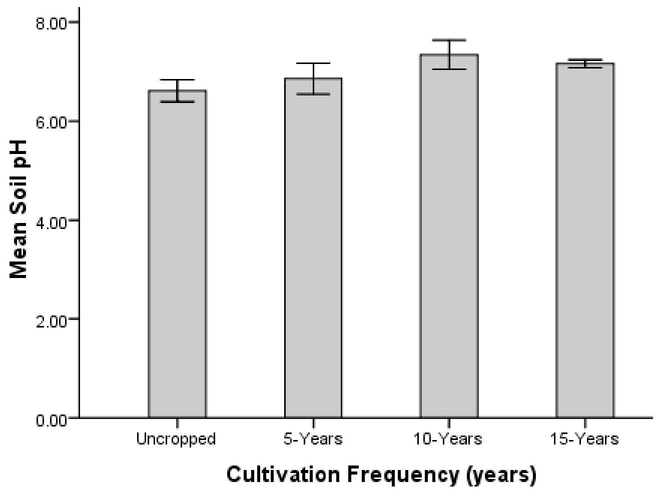

Figure 18: Mean soil pH values across the different cultivation frequencies

Soil organic matter content was generally low (>8%) in all fields sampled. There was no significant difference in mean scores for SOM content across the cultivation frequencies (Figure 19), although they differed widely.

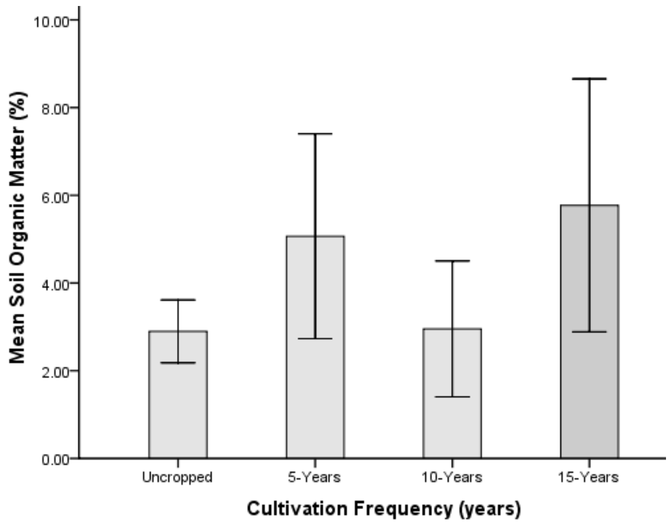

Figure 19: The mean SOM content across the cultivation frequencies in *Molapo* farms

The soil nutrient element content was similar across all the cultivation frequencies. There was no statistically significant difference in mean scores ($p > 0.05$) for Na, Mg, K, Ca, Total N and Available P in all the frequencies of cultivation, including non-cultivated fields (Figure 20).

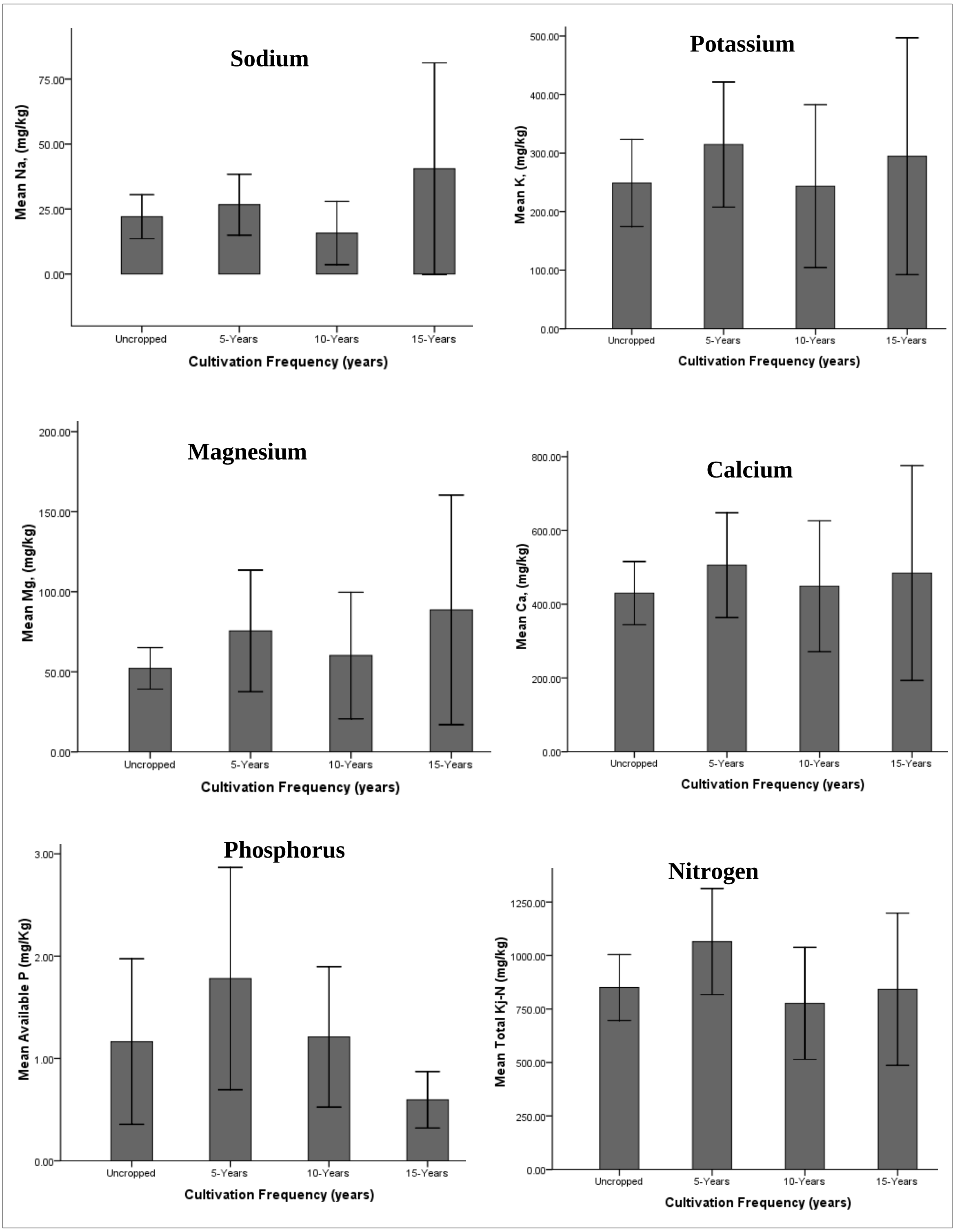

Figure 20: Mean soil nutrient concentrations across the cultivation frequencies in Molapo fields. The nutrient elements evaluated were Na, Mg, K, Ca, Total N and Available P.

4.4.4 Relationship between weed species composition and soil nutrient elements (Na, K, Mg, Ca, P and N), pH, SOM and flood frequency

CCA conducted shows that the variation in species composition was explained by 2 environmental variables (available phosphorus and flood frequency). Flood frequency was highly correlated with weed species composition on Axis 1 with a correlation coefficient of (-0.736) while phosphorus was intermediately correlated (0.466) with species composition on Axis 2 (Figure 21). There was a strong positive correlation between both axis and weed species composition in *molapo* farms at Shorobe, Makalamabedi and Lake Ngami. The correlation coefficients between weed species composition and axis 1, axis 2 were 0.953 and 0.883 respectively. The total variance in the species data explained by the environmental variables (Na, Ca, Mg, K, P, N, pH, SOM and flood frequency) was 7.73%. Species like *Ludwigia stolonifera*, *Cyperus longus, Zornia glochidiata, Alternanthera sessilis* were abundant in *Molapo* fields with high flood frequency, while *Sida cordifolia, Digitaria debilis, Nidorella resedifolia* were abundant in fields with intermediate flood frequency.

High phosphorus content in *Molapo* fields was preferred by weed species such as *Sida alba, Indigofera charlieriana, Phylla nodiflora, Panicum kalaharense, Waltheria indica, Schimidtia kalihariensis and Xanthium strumarium.* Species like *Hibiscus trionum, Eclipta prostrata, Sesbania bispinosa, Cyperus compressus and Panicum repens* preferred intermediate level of phosphorus content.

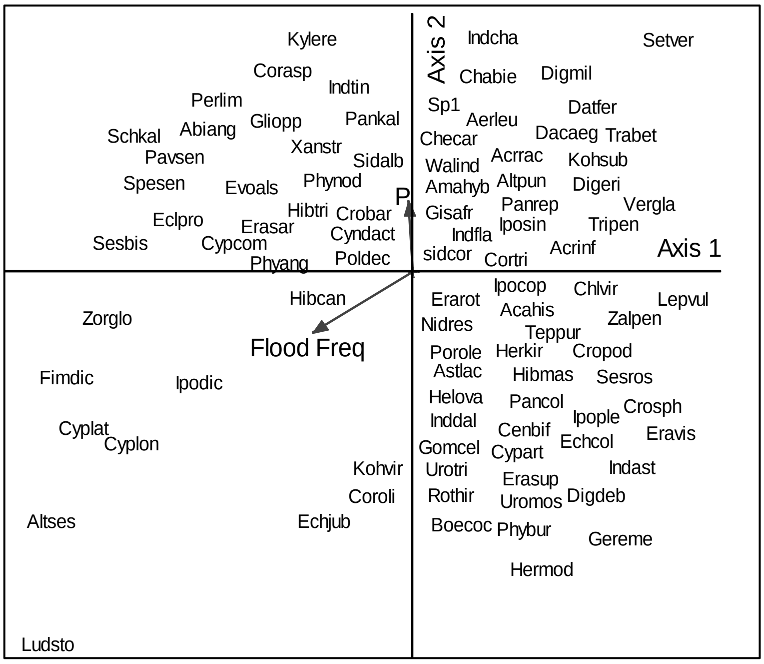

Figure 21: CCA bi-plot of weed species in *Molapo* farms across the study sites (Shorobe, Makalamabedi and Lake Ngami) from March to April 2016. The environmental variables are represented by arrows. Abbreviations for the species are given in full under appendix 12.

4.5 Discussion

The results of the study indicated that Makalamabedi had higher concentrations of potassium (K) and Calcium (Ca) than Shorobe and Lake Ngami. This could be due to that most *molapo* fields in Makalamabedi are located on the steep slopes of the Boteti River and do not get constantly flooded hence more susceptible to dry spells. Those in Lake Ngami and Shorobe are situated on the seasonal floodplains proper. As a result, there is likely to be less leaching of K and Ca in Makalamabedi than the other two study sites. In Shorobe, most *molapo* fields are located directly on the floodplains and mostly get inundated or have high moisture content. These results are consistent with findings by Tsheboeng et al. (2014) who indicated that in the Okavango Delta, Ca and K content increase in low flood conditions. Similarly, Strauss and Schicknoff (2007) observed that in Mongolian Lake, Ca decreased as moisture content increases.

Lake Ngami recorded lower pH than Shorobe. The results demonstrated that fields in Lake Ngami were slightly acidic compared to Shorobe which had recorded an average pH of 7.2 that is near neutral. There are no permanent allocations of fields in Lake Ngami. Farmers shift their fields depending on the extent and spread of lake water, hence most of the fields are relatively new. Some fields were observed to have been uncropped due to extended duration of field inundation. Inundation and prolonged flooding duration in fields at Lake Ngami might have created near acidity conditions due to poor aeration. For instance, Pezeshki and De Laune (2012) observed that inundation and long duration of flooding create severe barrier to gas diffusion leading to root energy deficiency due to inhibition of normal root respiration. It is probable that in this study these conditions contributed to lowered pH in fields at Lake Ngami creating slightly acidic conditions as compared to Shorobe.

There was a significant difference in soil pH between the uncropped fields and 10 year cultivation frequencies. Despite this difference, on average soil pH across the cultivation frequencies was 6.93, which is a near neutral soil. This suggests that frequency of cultivation does not significantly alter pH of soils in *molapo* fields. In this study, it was observed that there was a slight increase in pH from uncropped to 5 year frequency. The increase from uncropped to 10 year frequency was significant. A slight decline was also observed from 10 year frequency to 15 year frequency. Dick (1983) observed that in non-tillage treatments, there was a significant decrease in pH levels compared to conventional tillage throughout the soil profile in Hoytville soils. Similarly, uncropped fields like the no tilled treatment might have accumulation of organic matter leading to increased decomposition by soil microbes. As a result, this could lead to lowered pH in soils in the uncropped fields.

The soil organic matter was similar across the cultivation frequencies. Similar trend was also observed for the nutrient element availability. The results of the study indicated that cultivation frequencies do not affect the soil nutrients element content in *molapo* fields. This could be attributed to the natural fertilisation of the floodplains. Accumulation of organic matter in the floodplains which later decompose and improve soil nutrient status could explain similarities in soil nutrient content across the cultivation frequencies. This was also noted by Oosterbaan et al. (1987) & McCarthy et al. (2003) who observed that flooding in the Okavango Delta enhances ecosystem productivity by naturally supplying water and fertilising the floodplains where *molapo* farming is practiced.

In flood recession farming area, flood frequency and phosphorus were found to be the main drivers of weed species composition. The results of the study correspond with findings by Casanova and Brock (2000) & Filho et al. (1994) that frequency of inundation influences species community composition. Biggs (1976) also noted that primary floodplain in the Okavango Delta is dominated by sedges of *Scirpus inclinatus* and *Cyperus* species and the forb *Alternanthera sessilis*. Similarly, in this study it was found that species such as *Cyperus longus, Cyperus latifolius, Ludwigia stolonifera* and *Alternanthera sessilis* had a positive relationship with flood frequency. These species therefore tend to increase as flooding frequency increases and vice versa. Even though previous studies such as Ellery et al. (1993) & Bonyongo et al.(2000) observed that flood duration and depth influence vegetation community composition in the Okavango Delta in seasonal floodplains not subjected to seasonal cultivation, it is also likely to be the case in seasonal cultivated floodplains.

Flooding increases availability of resources like water and nutrients leading to increase in plant growth and productivity (Wright et al. 2014). The weed species will thrive in such conditions but it may depend on the severity of flooding and the amount of moisture available in the soil and sensitivity of species to flooding. For instance, (Bonyongo 1999) opined that flood tolerant species are found in prolonged flood duration while those species intolerant to flooding inhabit areas experiencing short flood duration. Lessons drawn here could be that flood recession fields with higher flooding frequencies will be infested by weed species that tolerate high moisture conditions and less so by species that are sensitive to such conditions. This observation is supported by the CCA results showing that weed species like *Sida cordifolia, Nidorella resedifolia, Acanthospermum hispidum* and *Corchorus tridens* tend to decrease as flood frequency increases.

4.6 Conclusion

The main drivers of weed species in flood recession farming in the Okavango Delta were flood frequency and phosphorus. It was evident that some weed species tolerated high flood frequency and phosphorus levels while some species were sensitive to these conditions. Generally, seasonal inundations of flood recession fields create near neutral soils.

CHAPTER 5

Effects of weed biomass on maize yield in flood recession farming, in the Okavango Delta

5.1 Introduction

Weeds may exhaust scarce resources essential for crop growth and present challenges to crop production (Sardan et al. 2017). They compete with crops for resources such as light, nutrients and water (Horvath et al. 2018). Weeds directly influence crop productivity through costs of labour, equipment and herbicides (van der Meulen and Chauhan 2017). Under weedy conditions due to ineffective control practices, crop yield losses due to weeds may surpass those of animal pests (arthropods, nematodes, rodents, birds, slugs, and snails), pathogens (fungi and bacteria), and viruses (Oerke 2006).

Competition between crop and weeds for limited resources is responsible for reduction in crop biomass and grain yield (Knezevic et al. 2001; Horvath et al. 2018). High weed density and biomass can result in intense competition with crops and subsequently, a significant reduction in crop yields (Blackshaw et al. 2002; Kristensen et al. 2008). In small-holder farming, yield losses in maize (*Zea mays* L.) can be up to 99% (Fanadzo 2007). In addition to crop yield losses, the economic cost of herbicides for weed control has been estimated to be U.S. $25 billion worldwide (Agrow 2003). In maize, yield losses are caused primarily by competition from weeds (Rajcan and Swanton 2001). For instance, in Bethlehem and Potchefstroom, South Africa, Thobatsi (2009) found that weed infestation resulted in 41.7% and 10.8% reduction in maize grain yield while in the absence of weeds yield was significantly higher at 4,136.4 kg ha^{-1} and 2,301.9 kg ha^{-1} respectively in 2006/2007 season. In sub-humid small-holder maize production zones of Zimbabwe, late weeding (30 days after crop emergence) resulted in 28% reduction in grain yield (Mashingaidze et al. 2009). In southern Zambia, hoe weeding alone was not effective and resulted in 30% reduction in maize yield (Vernon and Parker 1983). Yield components such as ear length, plant height and grain weight are negatively correlated to weed biomass but have a strong positive correlation to maize grain yield (Mahmood et al. 2015).

Weeds are part and parcel of almost all cropping systems and their economic significance is reflected in the amount of energy spent in controlling them (Blackshaw et al. 2005). In fact, more energy is expended in weeding crops than in any other single human task (Holm 1971). Seasonal variability in weed species infestation and weed biomass makes predictions about the weed community difficult and present a major problem in assessment of options for weed management (Milberg et al. 1999). Weed biomass production is strongly influenced by the choice of crop, its population density, row spacing and the degree of competition from the crop (Callaway 1992).

According to Ahmed (2014), low crop densities provide less canopy cover early in the growing season leaving resources available for weeds thus enabling them to establish and grow quickly. Conversely, high crop density produce enough cover to overshadow weeds and results in reduced weed biomass (Kristensen, 2008). In a study by Begna *et al*. (2001), an increase in crop population density resulted in a 40% reduction in biomass production of naturally occurring weeds. Likewise, Murphy *et al*. (1996) found that the biomass of late-emerging weeds was reduced by as much as 41% due to the increased corn population density and the decreased row spacing.

Conducive environment (natural irrigation and fertilization) in flood recession farming not only improve crop growth and yield but also encourage vigorous growth of weeds which compete with crops for resources. Previous studies (Bonyongo 1999; Ringrose et al 2005; Murray-Hudson et al 2011 & Tsheboeng et al 2014) have observed various herbaceous plant species in seasonal floodplains in the Okavango Delta and it is at these seasonal floodplains where *molapo* farming is practiced. The use of agro-chemicals, including herbicides for weed control is prohibited in *molapo* farming owing to their close proximity to the aquatic ecosystem, and concern over the impact of herbicides on non-target organisms (Santadino et al. 2014). Therefore farmers have to rely on slow and laborious hoe weeding (Chivinge 1990). Despite the fact that *molapo* farming is an important livelihood for the communities living on the fridges of the Okavango Delta, there is no study to date that was conducted to determine the effect of weed species on crop yields in *molapo* farming. The objective of this study therefore was to determine the effects of weed biomass on maize yield in *molapo* farming in the Okavango Delta.

5.2 Materials and methods

5.2.1 Study sites

The study was carried out in *molapo* farming sites at Shorobe and Lake Ngami in the Okavango Delta from March to April 2016. The sites were chosen basing on their similarities in crop production practices, differences in flooding patterns and the location and type of molapo fields. Shorobe is located in the eastern end of the Okavango Delta and lies 30 km east of Maun in Ngamiland District. It has a human population of 1,031 (Statistics Botswana 2011). *Molapo* fields are located in the northwest of the village and are inundated by the Santantadibe and Gomoti Rivers and by backflow from the Thamalakane River. The *molapo* fields in Shorobe are mainly found in islands with dense riparian woodlands and they have a saucer-shaped cross-section and they obtain moisture from spill over or back flow water from the main river channels (Bendsen, 2002). Normally this area experiences maximum flood extent between August and September and by the end of October the flood begins to recede. Lake Ngami occupies the northeast part of a shallow sedimentary basin bounded to the southeast by a low escarpment of Karoo and Ghanzi Formation rocks along an extension of the Kunyere Fault. The lake receives flood waters from the Kunyere and Nhabe rivers and the maximum flood extent is usually experienced in October. Farmers locate their fields on the fringes of the lake depending on the spread of the lake water and the fields are not permanently placed like those at Shorobe. At both sites, ploughing in molapo farming is by donkey drawn mouldboard ploughs. .

5.2.2 Biomass sampling

Biomass sampling was done in *molapo* fields at Shorobe and Lake Ngami. Selection of fields was done considering only those fields which had maize as the only crop stand. From both sites, two weeded and two weed-free fields were randomly selected. Weed free fields were fields that have been hoe weeded on several occasions. In each fields four quadrats of 1 m^2 were placed at the centre of the field at 5 m interval . Maize plants were sampled within the quadrat area for crop biomass analysis following procedure by Gaskin et al, (2015). Weed species in each quadrat were identified and recorded. Each species was clipped at the soil surface (Moore et al, 1994). The weeds were then packaged in oven proof envelopes. They were then dried in an oven at 80^0C for 72 hours. The dry biomass was then recorded. Maize in each quadrat was clipped at the soil surface using secateurs, and then packaged in oven proof envelopes. These samples were then oven dried at the ORI laboratory to determine the dry biomass of maize which was measured in gm^{-2} and later converted to kg ha^{-1}.

5.3 Data Analysis

An independent t-test was used to evaluate the effect of weed biomass on maize biomass. The mean differences were tested at $p \leq 0.05$. The effect size was used to find out if the difference is large enough to be practical meaningful. The importance of a significant finding was determined using the effect sizes which provided a measure of the magnitude of the difference. Mean differences were also explored between sites (Shorobe and Lake Ngami). The statistical analysis was performed using SPSS version 24.

5.4. Results

An independent t-test was conducted to evaluate the effect of weeds on maize biomass. Weed biomass had a significant effect ($t(14) = 7.553$, $p \leq 0.001$) on maize biomass (Figure 22). Maize growing under weed-free conditions had more biomass than one under weedy conditions. Lake Ngami had the highest mean weed biomass of 321.6±78.2 $kgha^{-1}$ compared to Shorobe with 83.5±15.5 $kgha^{-1}$ (Figure 23). There was a significant difference in mean scores for weed biomass between the two sites at $p \leq 0.05$.

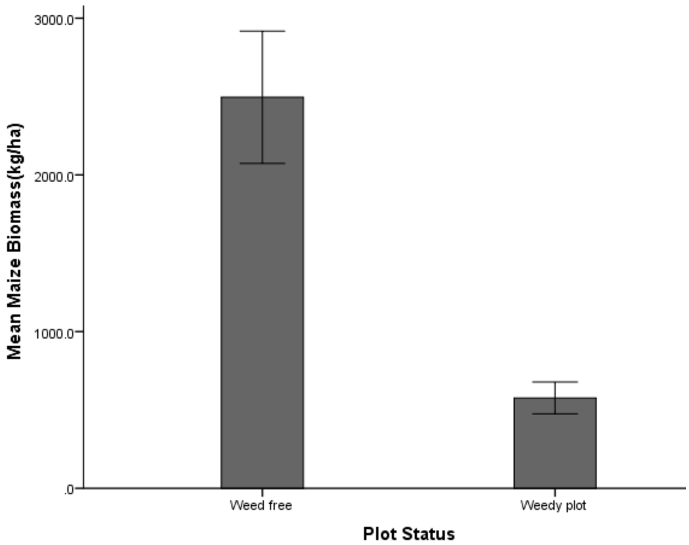

Figure 22: The mean maize biomass for plots that are weeds free and plots with weeds across the study sites.

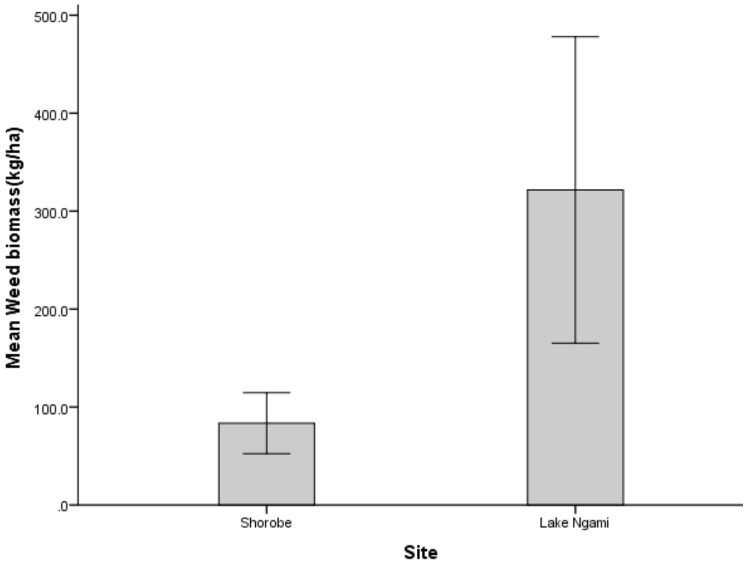

Figure 23: Mean weeds biomass within the study sites.

The most common weeds species found in weedy *molapo* fields at Shorobe were broad leaved weeds. *Crotalaria platycepala* recorded the highest biomass of 303.9 kg ha^{-1} followed by *Triumfetta pentendra* A.Rich. with 126.6kg ha^{-1} and *Indigofera flavicans* Baker. with 119.4 kg ha^{-1}. Other weeds such as *Momordica balsamina* L., *Indigofera charlieriana* Schinz and *Tephrosia purpurea* (L.)Pers. recorded a biomass of less than 50 kg ha^{-1} (Figure 24). At Lake Ngami, the members of the Poaceae family were mostly dominating in terms of biomass. *Urochloa mosambiscensis* (Hack) Dandy. recorded the highest weed biomass of 1079 kg ha^{-1} and *Setaria verticilliata* (L.)P.Beauv. recorded 864.9 kg ha^{-1}. Among the broad leafed weeds identified *Acanthospermum hispidum* DC. recorded a biomass of 326.5 kg ha^{-1}. Other weeds recorded a biomass of less than 30 kg ha^{-1} (Figure 25). Explored across the study sites (Figure 26), species from the Poaceae family recorded a high biomass with *Urochloa mosambiscensis* (Hack) Dandy. recording a mean biomass of 1079.6 kg ha^{-1}, while *Digitaria eriantha* Steud. recorded 680.5 kg ha^{-1}. For broad leafed weeds, *Acanthospermum hispidum* DC. and *Triumfetta pentandra* A.Rich. recorded higher mean biomass of 326.5 kg ha^{-1} and 203.4 kg ha^{-1} respectively.

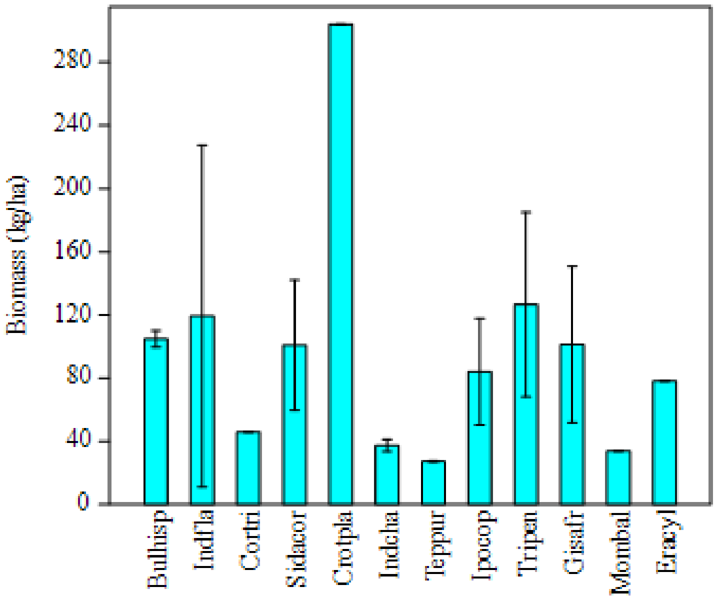

Figure 24: Mean weeds biomass of weeds species at Shorobe. Full names of weeds species are given in appendix 12.

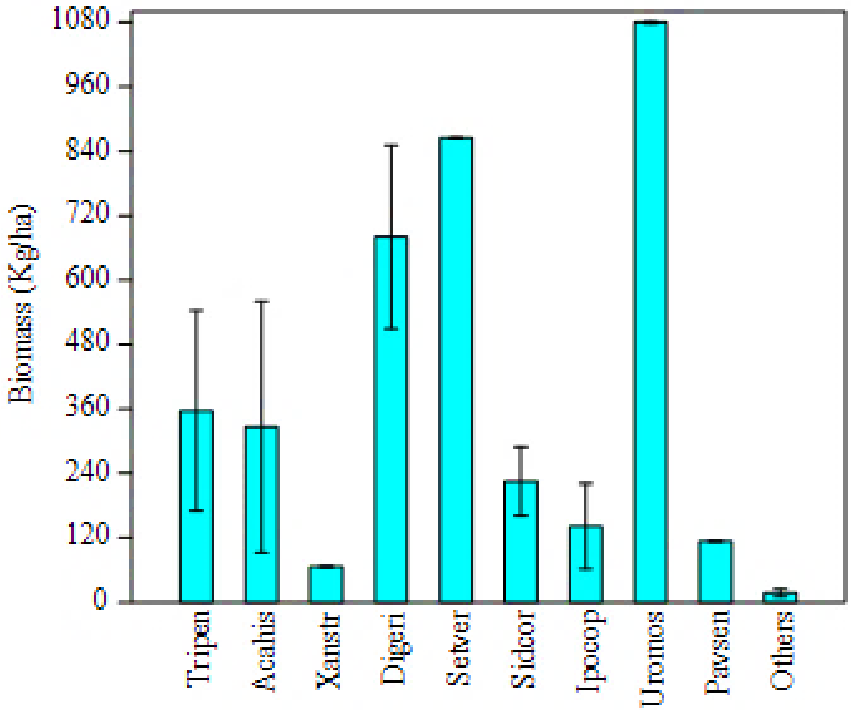

Figure 25: Mean weeds biomass of weeds species at Lake Ngami. Others refers the weeds that recorded biomass of less than 30 kgha^{-1}Weeds species names are given in full in Appendix 12.

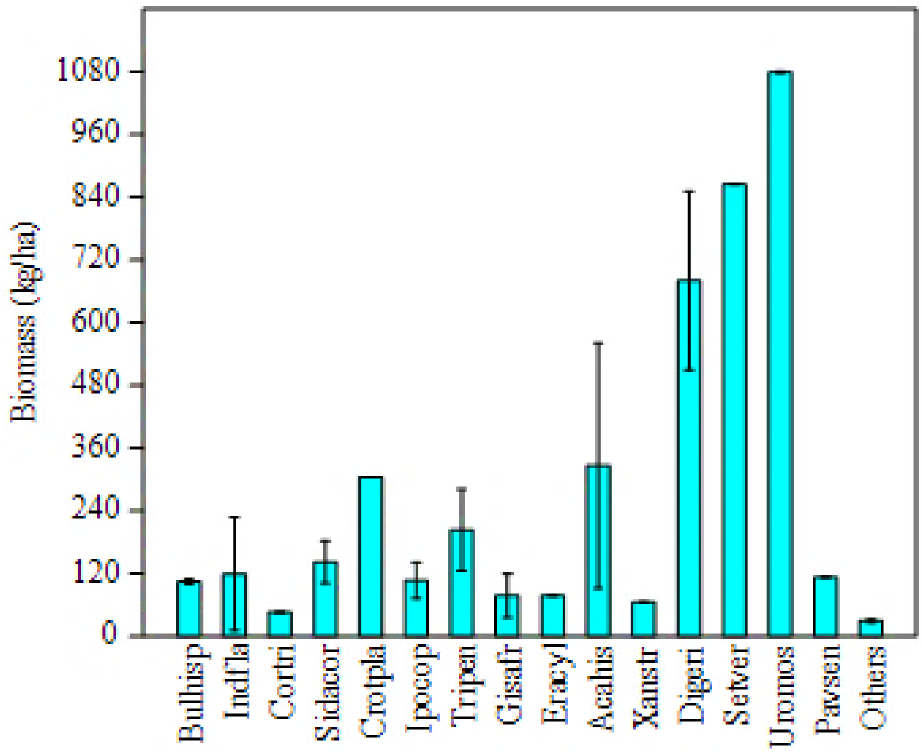

Figure 26: Mean weeds biomass of weeds species across the study sites. Other weeds species recorded biomass of less than 30 kg ha^{-1}.

5.5 Discussion

Previous studies (Blackshaw et al.2002; Kristensen et al. 2008 & Yeganehpoor et al. 2014) have indicated that yield losses are due to high weed pressure and heavy weed biomass. This was largely due to a negative correlation between weed biomass and yield components as was observed in others studies (Yagenehpoor et al 2014 & Mahmood et al 2014). In this study at both Shorobe and Lake Ngami, maize under weed-free conditions did not face any competition for resources from weeds and produced significantly higher biomass than that under weedy conditions. Presence of weeds such as *C. platycepala*, *T. pentandra*, *U. mosambiscensis*, *D. erientha* and *S. verticilliata* were largely responsible for 73.2% reduction in maize biomass. Heavy weed infestation was therefore largely responsible for poor maize biomass production. Weeds decrease water and nitrogen use efficiency (Fanadzo et al. 2010), the two most essential resources for high yields (Thomson et al. 2000).

Explored within the study sites, the results of the study indicated that Lake Ngami had the highest weed biomass compared to Shorobe. It was observed that most dominating weeds in weedy conditions in Lake Ngami were the dense and vigorous grass weeds such as *Urochloa mosambiscensis* (Hack) Dandy and *Setaria verticilliata* (L.)P.Beauv. However, in Shorobe weed species recorded in weedy conditions were broad-leafed weeds like *Triumfetta pentandra* A.Rich and *Sida cordifolia* L. Superior biomass could be linked to better soil fertility at Lake Ngami. For example, N at Lake Ngami was higher (1,106.36 mg kg^{-1}) than Shorobe (613 mg kg^{-1}). In a similar study Kashe et al. (2015) observed that late planting at Lake Ngami (November) coincided with abundant rainfall resulting in even and abundant moisture from planting to physiological maturity producing both higher weed and maize biomass at Lake Ngami than at Shorobe. As indicated in previous sections, such abundant supply of resources also facilitates heavy weed infestation resulting in low yields in weedy conditions.

If not weeded, weeds grow vigorously and out-compete crops. For instance, once it becames established, *Urochloa mosambicensis* can be difficult to eradicate (Phillips 1991). High density of weeds increases competition with crops leaving maize with little nutrients to sustain its growth. This leads to poor vegetative growth and low crop yields. Greater removal of nutrients and moisture by weeds and severe crop-weed competition result in poor crop yield components (Rasool and Khan, 2016).

Weeds that were mostly found in weedy plots were dominated by species from Poaceae, Fabaceae and Malvaceae families. Of the species present, *Urochloa mosambiscensis* recorded the highest biomass (1,079.6 kg ha^{-1}). It is one of the most important grass weeds in Botswana and is particularly a serious problem in *molapo* fields around the Okavango Delta (Phillips 1992). Its vigorous growth and high biomass production enhances its ability to out-compete crops like maize. *Setaria verticilliata* and *Digitaria eriantha* also recorded the highest biomass of 864.9 kg ha^{-1} and 680.5 kg ha^{-1} respectively. This shows that under favourable environment such as those in *molapo* farming, grass weeds can be detrimental in crop yields because of their ability to out compete crops in the utilisation of nutrients which they use to invest in high biomass.

5.6 Conclusion

High weed biomass was associated with low maize biomass in *molapo* farming in the Okavango Delta. High weed biomass was attributed to a favourable growing environment in the seasonal floodplains where *molapo* farming is practiced. *Urochloa mosambiscensis* was found to grow vigorously and produce higher biomass than other weed species at Lake Ngami. At Shorobe, broad-leaved weeds such as *Triumfetta pentendra* and *Sida cordifolia* produced higher biomass.

Chapter 6

6.1 Synthesis

The general aim of the study was to determine the weed species composition and diversity in flood recession farming in the Okavango Delta. The study generated information on:

(1) The weed species composition and diversity in flood recession farming

(2) The influence of cultivation frequency on weed species composition and diversity

(3) The main drivers of weed species composition and diversity in flood recession farming

(4) The effects of weed biomass on maize yield in flood recession farming, in the Okavango Delta.

Chapter 1 gave an overview and background information on farming systems in Botswana. These included flood recession farming commonly known as *molapo* farming. Emphasis was given on how agro-ecosystems create conducive environment for weed species to proliferate. Weeds were defined as plants growing where man wishes other plants or no plants to grow as they would have some economic, ecological or aesthetic implications for man and /or his activities (Bridges 1994). They are highly successful and competitive organisms (Finney 2004) and successfully colonise disturbed and potentially productive sites (Liebman 2001), suggesting that grasses and other herbaceous species that colonise arable farming areas are invigorated by conducive environment brought about by soil tillage. Discussion was also made on the association of weeds and humans, and how weeds impact on crop yield. For instance, weeds are said to be responsible for significant yield losses and financial losses in agriculture production of about 10% worldwide (Baucom, 2009). It was also demonstrated that agriculture in Botswana has become less sustainable due to increasing exposure to persistent drought, poor soil quality, unpredictable weather conditions, global warming and issues with pests and weeds. Common weed species of arable farming in Botswana were also discussed. For example, *Ipomea obscura, Ipomea sinensis, Xenostagia tridentata* were noted as common arable weeds in Botswana. *Cynodon dactylon* and *Xanthium strumarium* were mentioned as troublesome weeds and difficult to eradicate due to their specialised reproductive ability (Labovitch 1978). Other weeds of arable farming were *Chloris virgata, Tragus beteronianus* and *Urochloa mosambiscensis*. The latter was classified as a troublesome grass weed in *molapo* farming in the Okavango Delta. This was complemented by the results in Chapter 4.

Chapter 2 was aimed at determining the weed species composition and diversity in flood recession farming in the Okavango Delta. Twenty four families were identified during the vegetation survey consisting of 101 weeds species. The Poaceae family recorded the highest number (25) of species. This partly explains why grass weeds are common in arable fields. It was also consistent with the results by Shemdoe et al (2008), and also qualifies observation made by Odum and Barret (2005) and Oudtshoorm (1992) that grasses become common from the early stages of vegetation succession.

Weed species in flood recession farming were classified into 4 communities. A stronger separation was observed between *Cynodon dactylon-Bulbostylis hispidula* and *Sida cordifolia-Corchorus tridens* communities. This suggested that there were dissimilarities between the two communities in terms of habitat preference, location of *molapo* fields and effect of the cultivation frequencies. *Glinus oppositifolius-Heliotropium ovalifolium* community was observed to constitute species that are tolerant to high moisture content of which most are sedges such as *Cyperus esculentus, Cyperus latifolius* and *Fimbristylis dichotoma*. It occurred mainly in uncropped sites located on the lower gradient of the floodplains and get inundated during flooding. The 4 communities did not differ significantly in Shannon's diversity index, suggesting that growing conditions in *molapo* farming are conducive for a wide range of weed species which give them equal opportunity to thrive under such conditions. The mean species evenness was significantly different between the four communities. *Cynodon dactylon-Bulbostylis hispidula* community recorded lower mean species evenness of 0.533, while *Sida alba-Abitulon angulatum* recorded highest mean species evenness of 0.720. The differences in equitable distribution of weeds species across the four communities could have been influenced by dominance of some species which tend to thrive under different frequencies of cultivation which is in agreement with the results in Chapter 3.

Chapter 3 supported the hypothesis that frequency of cultivation influences weed species diversity. The survey explored the influence of cultivation frequency on weed species composition and diversity within and across the study sites. It was concluded that within the sites, cultivation frequency influenced species richness at Makalamabedi. In Shorobe and Lake Ngami, weed species richness was not influenced by the frequency of cultivation. Equitable distribution of weed species was not influenced by frequency of cultivation at both Makalamabedi and Lake Ngami. It was evident that weed species were more equitably distributed in the 5 year cultivation frequency than uncropped fields.

Explored across the study sites, weed species diversity was influenced by the frequency of cultivation. Fields with 5 year frequency recorded high Shannon diversity index than the fields categorised under the 10 and 15 year cultivation frequencies including fallowed fields (uncropped fields). Non- dominant buried seeds will be brought to soil surface and germinate upon cultivation (Froud-Williams 1983). This might explain why the 5 year frequency was richer in number of weeds because these fields were relatively new with a possibility of a higher seedbank than other frequencies. Even though other studies such as Shemdoe et al. (2008) and Dorado and Lopez-Fendo (2006) reported that non-tilled systems recorded high weed species richness and diversity.

Chapter 4 demonstrated that weed species composition and diversity in the Okavango Delta is mainly influenced by flooding frequency and available phosphorus. These environmental variables are usually positively correlated, that is an increase in flooding frequency leads to an increase available phosphorus. Both have been reported elsewhere that they influenced vegetation composition (Harry et al 2006 and Mitsch & Gosselink 2000). Brady and Weil (2008) explained that flooding, causes anoxic conditions which leads to increased release of P content from P-Fe, P-Ca and P-Al compounds. In *molapo* farming, most fields are located on the lower gradient of the flood plains with presumably high moisture content. Other plant nutrients such as K and Ca were significantly higher at Makalamabedi where fields are located mainly on the steeper slopes of Boteti river and susceptible to dry spells. Potassium and calcium were lower in fields at Shorobe and Lake Ngami than Makalamabedi probably due to leaching.

In Chapter 5, it was demonstrated that high weed biomass in weedy conditions in *molapo* farming in the Okavango Delta, significantly lowered crop biomass. Maize biomass was higher in weed-free conditions compared with weedy conditions. The results were consistent with previous studies (Blackshaw et al 2002; Kristensen et al 2008; Yagonehpoor et al 2014 and Ahmed et al 2014). Dominant weed species were from Poaceae, Fabaceae and Malvaceae families. This complements the results in Chapter 2, that reported a higher number of Poaceae species (25) followed by Fabaceae species (17) while other families had less than 10 individual species from 101 of species enumerated in the survey. *Urochloa mosambiscensis* and *Setaria verticilliata* recorded higher biomass of 1,079.6 kg ha^{-1} and 864.9 kg ha^{-1} respectively than other species found in un-weeded fields. These grass weeds compete vigorously for soil resources and develop dense vegetative growth that results in high biomass production. As a result they contribute immensely to reduction of crop biomass and subsequently low yields in *molapo* farming.

6.2 Limitations of the study

(i) In 2015 floods were too low and most *molapo* fields were not inundated. As a result, vegetation and crops in some cultivated fields were mostly rainfed. The rainfall data was also not available because there were no weather stations around the study sites as reference points. Some weeds species that are tolerant to flooding might not have been present during vegetation sampling.

(ii) Some fields were ravaged by elephants and were abandoned prior to vegetation sampling. Some weeds might have been absent due to destruction by elephants and other herbivores that had access to the fields.

(iii) Cultivation frequencies of individual fields were verbal information obtained from the current owners. There might be a possibility that some fields might have exchanged hands several years before. This could have placed some fields in wrong categories.

(iv) The findings of the study could not be generalised to the entire flood recession farming system in the Okavango Delta because it was conducted and confined to *molapo* farming in Shorobe, Makalamabedi and Lake Ngami in the distal end of the Delta.

Despite the limitations noted above, the study was adequately conducted and its conclusions are considered valid. The data and findings of the study are relevant, informative and provide reliable source of information about weed species composition and diversity in molapo farming. Finally, the findings of the study could assist in developing a sound and successful weed management program and policies in the Okavango Delta.

6.3 Future work

There still exist some questions which this study could not address because of resource limitations. The questions include:

(i) What are the soil moisture dynamics across the sites prior to vegetation sampling in *molapo* farming?

(ii) What is the influence of insect pests and their interaction with weeds in *molapo* farming?

(iii) What is the response of weeds to conservation agriculture in flood recession farming in the Okavango Delta?

(iv)What are the effects of tillage systems on viability of weeds seed bank in soils of the flood recession farming in the Okavango Delta?

Answers to these questions might add value to the findings of this study which could be generalised to the entire Delta and ensure effective weed management strategies. The strategies could also prevent the possible spread of alien invasive plants into the core area of the protected Okavango Delta and within its riverbeds where *molapo* farming is not practiced.

6.4 Conclusion

Cultivation frequency influenced weed species composition and diversity in flood recession farming in the Okavango Delta. Weed species were distributed differently according to the number of years the field was subjected to cultivation. The 5 year cultivation frequency was found to be more diverse compared to the other cultivation frequencies. Similarly, the 15 year cultivation frequency had the lowest Shannon's diversity index compared with other cultivation frequencies. Based on the assumption that the 5 year cultivation frequency is a moderate level of disturbance in arable fields, the results could thus support the intermediate disturbance hypothesis (Grime, 1973; Connell, 1978). Intermediate Disturbance Hypothesis

(IDH) states that species diversity is maximised when disturbance is neither too rare nor too frequent. Species diversity was maximised at the 5 year cultivation frequency and declined significantly with an increase in cultivation frequency. The uncropped sites also recorded lower species diversity than the 5 year frequency. This could be that at 5 year cultivation frequency, weed species were activated and newly created micro-climatic conditions favoured their germination and growth for a period of 5 years. According to Huston (1979), reduced levels of disturbance will lead to low diversity through competitive exclusion and dominance of long lived species while increased levels eliminate species incapable of rapid re-colonisation and growth. In arable fields, reduced levels of disturbance could be through fallowing. This could explain why weed species diversity was lower in fallowed (uncropped) fields and also lower at 15 year frequency where disturbance was higher.

Flooding frequency and available phosphorus were the main drivers of weed species composition and diversity in *molapo* farming. *Cyperus longus, Zornia glochidiata* and *Alternathera sessilis* were found mainly in *molapo* fields with high flooding frequency and/or those that get inundated more frequently. Similarly, weeds like *Nidorella resedifolia, Sida cordifolia* and *Digitaria debilis* preferred *molapo* fields with low flooding frequency. It may be reasoned that in *molapo* farming there are weeds that may thrive where there is constant inundation and those that are not tolerant to high moisture content are excluded. It was also observed that weeds that are common in dryland farming and intolerant to flooding like *Bulbostylis hispidula* and *Acanthospermum hispidum* were prevalent in *molapo* fields that were prone to dry spells due to low flooding especially those located on steeper slopes. Certain species were discovered to thrive in conditions with higher levels of P such as *Sida alba, Indigofera charlieriana, Xanthium strumarium* and *Schmidtia kalihariensis*. It was also observed that these species were localised in *molapo* fields that constantly get inundated and having high moisture content. High P in these *molapo* fields is consistent with findings by Bonyongo and Mubyana (2004).

References

Agrinews. (2013). Weeds and their control. *Ministry of Agriculture Farmers' Monthly Magazine, Vol.43 No.1*.

Abdullahi, A.E. (2002) *Cynodon Dactylon* control with tillage and glyphosate. *Crop Protection, Vol 21(10) 1093 - 1100*

Ahmed, S., Salim, M. and Chauhan, B.S. (214). Effects of weed mangement and seed rate on crop growth under direct dry seeded rice systems in Bangladesh. *Plos One, 9*(7).

Anderson, J. M., & Ingram, J. S. I. (Eds.). (1989). *Tropical soil biology and fertility* (p. 171). Wallingford: CAB international.

Andersson, L., & Milberg, P. (1998). Variation in seed dormancy among mother plants, populations and years of seed collection. *Seed Science research*, *8*(1), 29-38.

Andreasen, C., Streibig, J. C., & Haas, H. (1991). Soil properties affecting the distribution of 37 weed species in Danish fields. *Weed Research, 31*(4), 181-187.

Armengot, L., Jose´-Maria, L., Blanco-Moreno, J.M., Romaro-Puente, A. and Xavier Sans, F. (2011). Landscape and land use effects on weeds flora in Mediterranean cereal fields *Agriculture, Ecosystems and Environment* 142(3-4) 311-317,2011

Arias, M. E., Cochrane, T.A., Norton, D., Killen, T.J. and Khon, P. (2013). The Flood Pulse as the Underlying Driver of Vegetation in the Largest Wetland and Fishery of the Mekong Basin. *Ambio, 42*(7), 864 - 876. doi: 10.1007/s13280-013-0424-4

Auerbach, R. M. B. (1993). *A Farming Systems Research Evaluation of Maize Production Practices in Southern Kwazulu.* MSc, University of Natal, South Africa.

Baker, H. G. (1965). Characteristics and modes of origin of weeds. *In: Baker, H.G., Stebbins, G.L. (Eds.), The Genetics of Colonizing Species. Academic Press, New York,* . 147-72

Bangarwa, S. K., Norsworthy, J.k. and Gbur, E.E. (2012). The effect of shoot clipping -soil disturbance frequency and tuber size on above ground and below ground growth of purple and yellow nutsedge (Cyperus rotundus) and Cyperus esculentus. *Weed Technology*, *26*(4), 813-817.

Barnes, J. P., & Putnam, A. R. (1983). Rye residues contribute weed suppression in no-tillage cropping systems. *Journal of Chemical Ecology*, *9*(8), 1045-1057.

Barrow, C. J. (1999). *Alternative Irrigation: The Promise of Runoff Agriculture*. London: Earthscan Publications Ltd.

Batisani, N., & Yarnal, B. (2010). Rainfall variability and trends in semi-arid Botswana: implications for climate change adaptation policy. *Applied Geography*, *30*(4), 483-489.

Baucom, R. S., and Holt,J.S. (2009). Weeds of Agricultural Importance: Bridging the Gap between Evolutionary Ecology and Crop and Weed Science. *New Phytologist, Vol. 184, No. 4 (Dec., 2009)*, pp. 741-743.

Bendsen, H. M., T. (2002). The Dynamics of Land Use System in Ngamiland; Changing Livelihood Options and Strategies. Harry Oppenheimer Okavango Research Centre and German Development Service – DED, Maun, Botswana

Begna, H.S., Hamilton, R.I., Dwyer, L.M., Stewart, D.W., Cloutier, D., Assemat, L., Forout-pour, K., and Smith, D. L. 2001. Morphology and yield response to weed pressure by corn hybrids differing in canopy architecture. *Eur. J. Argon*

BIDPA. (2013). A study of the contribution of sustainable Natural Resources Management to Economic Growth, Poverty Eradication and Achievement of NDP 10 Goals *Sector Assessment: Tourism and Agriculture*. Gaborone, Botswana.

Bhowmik, P. C. (1997), Weed Biology: Importance to weed management. *Weed Science*,(45) 3: 349-356

Biggs, R. C. (1979). *The Ecology of Chief's Island and the adjacent floodplains of the Okavango Delta, Botswana.* Unpublished MSc Thesis, University of Pretoria, Pretoria, South Africa.

Blackshaw, R. E., Lemerle, D., Mailer, R. and Young, K.R. (2002). Influence of wild radish on yield and quality of Canola. *Weed Science, 50*, 334-349.

Blackshaw, R. E., Molnar, L. J., & Larney, F. J. (2005). Fertilizer, manure and compost effects on weed growth and competition with winter wheat in western Canada. *Crop Protection*, *24*(11), 971-980.

Bonyongo, C. (1999). *Vegetation Ecology of the Seasonal Floodplains in the Okavango Delta, Botswana.* MSc Thesis, University of Pretoria.

Bonyongo, M. C., Bredenkamp, G. J., & Veenendaal, E. (2000). Floodplain vegetation in the Nxaraga Lagoon area, Okavango Delta, Botswana. *South African Journal of Botany, 66*(1), 15-21.

Bonyongo, M. C., & Mubyana, T. (2004). Soil nutrient status in vegetation communities of the Okavango Delta floodplains. . *South African Journal of Science 100: 337-340*

Booth, B.D. and Swanton, C.J. (2002). Assembly theory applied to weed communities. *Weed Science, 50: 2-13*

Brady, N. C., and Weil,R.R. (2008). *The Nature and Properties of Soil*. New Jersey: Pearson Education Ltd.

Bridges, D. C. (1994). Impact of Weeds on Human Endeavors. *Weed Science Society of America, Vol. 8, No. 2 (Apr. - Jun., 1994),* , pp. 392-395.

Buchanan, G.A., Hoveland, C.S. and Harris, M. C. (1975). Response of weeds to soil pH. *Weed Science 23: 473 – 477.*

Callaway, M. B. 1992. A compendium of crop varietal tolerance to weeds. *American Journal of Alternative Agriculture.* **4**: 169–180.

Capon, S.J. (2005). Flood variability and spatial variation in plant community composition and structure on a large arid floodplain. *Journal of Arid Environments, 60*(2), 283-302.

Cardina, J., Herms, C.P. and Doohan, D.J. (2002). Crop rotation and tillage system effects on weed seedbank. *Weed Science 50(4): 448-460*

Casanova, M., & Brock, M. (2000). How do depth, duration and frequency of flooding influence the establishment of wetland plant communities? *Plant Ecology, 147*(2), 237-250.

Chapoto, A. and Chisanga, B. (2016). Zambia Agricultural Status Report 2016. Indaba Agricultural Policy Research Institute, Lusaka Zambia.

Chivinge, O.A. (1990). Weed Science Technological needs for for the communal areas of Zimbabwe. *Zambezia, 17(2):* 133-143

Cimalova, S., Lososova,Z. (2009). Arable weeds vegetation of the North Eastern part of Czech republic: Effects of environmental factors on species com[position. *Plant Ecology, 23*(No. 1), 45-57.

Connell, J. H. (1979). Intermediate-Disturbance Hypothesis. *Science, 204*(4399), 1345. doi: 10.1126/science.204.4399.1345

CSO. (2011). 2011 Population and Housing Census. Gaborone, Botswana.

Dale, M., Thomas, A., & John, E. (1992). Environmental factors including management practices as correlates of weed community composition in spring seeded crops. *Canadian Journal of Botany, 70*(10), 1931-1939

De Datta, S. K. (1979). Weeds Problems and Methods of Control in Tropical Rice. *Phillipines Journal for Agriculture and Resources Research*. 9-44

Dekker, J. (1997). Weed Diversity and Weed Management. *Weed Science Society of America, Vol. 45, No. 3 (May - Jun., 1997)*, pp. 357-363.

Dick, W.A. 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. *Soil Science Society of America Journal* 47:102-107.

Deloitte & Touche, (2016). Uganda Economic outlook 2016: The story behind the numbers. Deloitte Touche Tohmatsu Ltd.

Department of agriculture, forestry and fisheries (DAFF), (2016). The economic Review of the South African Agriculture 2015. DAFF, ISBN 978-1-8687-432-2.

Dixon J, Gulliver A, and Gibbon D. (2001). Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World. FAO, Rome, Italy; World Bank, Washington, DC;.

Dufrene, M., & Legendre, P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs, 61*, 53-73.

Donaldson, S.G. (1997) Flood borne Noxious Weeds: Impacts on Riparian Areas and Wetlands. California Exotic Post Plant Council. 1997 Symposium Proceeding.

Dzerefos, C.M., Shackleton, C.M. & Scholes, M.C. Seed germination, nitrogen nutrition and water requirements of the edible herb *Corchorus tridens*. *Economic Botany* (1995) 49: 380.

Ellery, W. N., Ellery, K., & McCarthy, T. S. (1993). Plant distribution in islands of the Okavango Delta, Botswana: determinants and feedback interactions. *African Journal of Ecology, 31*(2), 118-134.

Ellery, W. N., Ellery, K., Rogers, K. H., McCarthy, T. S., & Walker, B. H. (1993). Vegetation, hydrology and sedimentation processes as determinants of channel form and dynamics in the northeastern Okavango Delta, Botswana. *African Journal of Ecology, 31*(1), 10-25.

Ellery, W. N., McCarthy, T. S., & Dangerfield, J. M. (1998). Biotic factors in mima mound development: evidence from the floodplains of the Okavango Delta, Botswana. *International Journal of Ecology and Environmental Sciences, 24*(2-3), 293-313

Ellery, W.N., McCarthy, T.S and Smith, N.D., 2003. Vegetation, hydrology and sedimentation patterns on the major distributary system of the Okavango, fan, Botswana: *The Society of Wetland Scientists* 23: 357-375

Ervio, R., Hyvarinen, S., Ervio, L.R., and Salonen, J. (1994). Soil Properties Affecting Distribution in Spring Cereal and Vegetable fields. *Agricultural Science in Finland, 3 (5), 497-504.*

Fanadzo, M. (2007). Weed management by small-scale irrigation farmers-the story of Zanyokwe. *SA Irrigation*, *29*(6), 20-24.

Fanadzo, M., Mashingaidze, A. B., & Nyakanda, C. (2007). Narrow rows and high maize densities decrease maize grain yield but suppress weeds under dryland conditions in Zimbabwe. *Journal of Agronomy, 6*(4), 566.

FAO. (1994). Weed Management for Developing Countries. In R. Labrada, Caseley, J.C., & Parker, C. (Ed.), (Vol. Paper 120). Rome: FAO Plant Production and Protection.

FAO. (2005). Aquastat survey, http://www.fao.org/nr/water/aquastat/main/index.stm. Botswana.

Finney, D. M., and Creamer, G.N. (2004). Weed Management on Organic Farms: North Cardina Cooperative Extension Service.

Fox, J., and Ledger-wood,J. (1999). Dry-Season flood recession rice in the Mekong Delta: Two Thousand years of Sustainable Agriculture. *Asian Perspectives, 38: No 1*.

Fried, G., Norton, L. R., & Reboud, X. (2008). Environmental and management factors determining weed species composition and diversity in France. *Agriculture, ecosystems & environment, 128*(1), 68-76.

Froud-Williams, R.J., Drennan, D.S.H. and Chancellor, R.J. (1983) Influence of cultivation regime on weeds floras of arable cropping systems. *Journal of applied ecology, Vol 20, No. 1, doi 102307/2403385, pp 187-197*

Gaskin, J. W., Hancock, D., Saha, U. and Chatam, K. (2015). Cover crop biomass sampling. UGA Extension.

Germishuizen, G., & Meyer, N. L. (2007, Jan 2007). Plants of Southern Africa: an online checklist: http://posa.sanbi.org

Gillison, A.N. and Brewer, K.R.W. (1985). The use of gradient directed transects of gradsects in natural resource surveys. *Journal of Environmental Management 20: 103-127*

Gilman, S. (2002). *Organic Soil-fertility and Weed Management*. Chelsea Green Publishing.

Grigg, D. B. (1974). *The agricultural systems of the world: an evolutionary approach* (Vol. 5). Cambridge University Press.

Grime, J. P. (1973). Competitive exclusion in herbaceous vegetation. *Nature* 242: 344-347.

Gumbricht, T., McCarthy, J., & McCarthy, T. S. (2004). Channels, wetlands and islands in the Okavango Delta, Botswana, and their relation to hydrological and sedimentological processes. *Earth Surface Processes and Landforms, 29*(1), 15-29.

Haeussler, S., Bedford, L., Leduc, A. Bergeron, Y. and Kranabetter, J.M. (2002). Silvicultural Disturbance Severity and Plant Communities of the Southern Canadian Boreal Forest. *Silvi Fennica, 36*(Ringrose, Jellema, Huntsman-Mapila, Baker, & Brubaker), 307 - 327.

Haluschak, P. (2006). Laboratory Methods of Soil Analysis. In C.-M. S. Survey (Ed.).

Handa, C., Alvarez, M., Becker, M., Oyieke, H., Moseler, BM., Mogha, N. and Kamiri, H. (2012). Opportunistic vascular plant introductions in agricultural wetlands of East Africa. *International Journal of Agricultural Science*. 2(9) 810-830.

Harrington, L., & Tow, P. (2011). Types of rainfed farming systems around the world. In *Rainfed Farming Systems* (pp. 45-74). Springer, Dordrecht.

Heath, A. and Heath, R. (2009)**.** *Field Guide to the Plants of Northern Botswana including the Okavango Delta* Kew Publishing

Hobbs, R.J. and Huenneke, L.F. (1992). Disturbance, diversity and invasion: Implications for conservation. *Conservation Biology*, 6(3)

Hobbs, R. J., & Humphries, S. E. (1995). An integrated approach to the ecology and management of plant invasions. *Conservation Biology*, *9*(4), 761-770.

Holm, L., Pancho, J. V., Herberger, J. P., & Plucknett, D. L. (1979). *A geographical atlas of world weeds*. John Wiley and Sons..

Horvath, D. P., Bruggeman, S., Moriles-Miller, J., Anderson, J. V., Dogramaci, M., Scheffler, B. E. & Clay, S. (2018). Weed presence altered biotic stress and light signalling in maize even when weeds were removed early in the critical weed-free period. *Plant Direct*, *2*(4), e00057.

Huston, M. (1979). A General Hypothesis of Species Diversity. *The American Naturalist* 113 (1): 81-101

ICRISAT-ILRI. (2005). Botswana country report ICRISAT-ILRI Project Priorities for future Research on Crop-livestock Systems *Crop-Livestock Systems development in Southern Africa: Priorities for future Reseach*. Gaborone: Center for Applied Research.

Juraimi, A. S., Muhammad Saiful ,A.H., Kamal Uddin, M., Anuar, A.R. & Azmi, M. (2011). Diversity of weed communities under different water regimes in bertam irrigated direct seeded rice field *Australian Journal of Crop Science* 5(5) 595-604.

Kashe, K., Mogobe, O., Moroke, T. and Murray-Hudson, M. (2015). Evaluation of maize yield in flood recession farming inthe Okavango Delta, Botswana. *African Journal of AgriculturalResearch, 10*(16), 1874-1879.

Kellman M (1980) Geographic patterning in tropical weed communities and early secondary successions. *Biotropica* 12(2):34-39

Khanthavong P, Oudthachit S, Souvannalat A, Matsumoto N (2016) Effect of Weed Biomass on Cassava Yield Related to Weeding Times. *Advances in Plants and Agriculture Res*earch 5(5): 00194. DOI: 10.15406/apar.2016.05.00194

Knezevic, S. Z., Evans, S. P., Blankenship, E. E., Van Acker, R. C., & Lindquist, J. L. (2002). Critical period for weed control: the concept and data analysis. *Weed Science, 50*(6), 773-786.

Kristensen, L., Olsen, J. and Weiner, J. (2008). Crop Density, Sowing Pattern and Nitrogen Fertilisation Effects on WeedsSuppression and Yield in Spring Wheat. *Weed Science, 56*(1), 97-102.

Kunze, W. and Loos, H. (1990). Interrelationship between male labour shortage and use of animal draft power: A case study from Botswana *Colloquium on donkeys, mules and horses*. Center for tropical veterinary medicine: University of Endinburgh.

Labovitch, L. (1978). Traditional and new methods of dealing with arable weeds in Botswana. Botswana Notes and Records 10 (1978): 187-197.

Labrada, R., Caseley, J.C., & Parker, C. (1994). Weed Management for Developing Countries. Rome: FAO.

Lawrence, D., Suma, V., & Mogea, J. P. (2005). Change in species composition with repeated shifting cultivation: limited role of soil nutrients. *Ecological Applications, 15*(6), 1952-1967.

Legere, A. and N. Samson. 1999. Relative influence of crop rotation, tillage, and weed management on weed associations in spring barley cropping systems. *Weed Science* 47:112-122.

Liebman,M., Mohler, C.L. and Staver, C.P. (2001). Ecological Management of Agricultural Weeds. New York: Cambridge University Press

Lososová, Z., Chytrý, M., Cimalova, S., Kropáč, Z., Otýpková, Z., Pyšek, P., & Tichý, L. (2004). Weed vegetation of arable land in Central Europe: Gradients of diversity and species composition. *Journal of Vegetation Science*, *15*(3), 415-422.

Magole, L., & Thapelo, K. (2005). The impact of extreme flooding of the Okavango River on the livelihood of the molapo farming community of Tubu village, Ngamiland Sub-district, Botswana. *Botswana Notes & Records*, *37*(1), 125-137.

Magole, L. B. (2009). An Introduction to Okavango Management. Maun, Botswana: HOORC and DEA.

Magurran, A. (2004). Measuring Biological Diversity. Oxford, RU: Blackwell Publishing. ISBN: 0 – 632- 05633 – 9.

Mahmood, A., Khaliq, A., Ihsan, M.Z., Naeem, M., Daur, I., Matloob, A. and El-Nakhlawy, F.S. (2015). Estimation of weed dry biomass and grain yield as a function of growtrh and yield traits under allelopathic weed management in Maize. *Planta Daninah, 33*(1), 23-31.

Maroyi, A. (2013). Use of weeds as traditional vegetables in Shurugwi District, Zimbabwe. *Journal of ethnobiology and ethnomedicine*, *9*(1), 60.

Mashingaidze, A. B., Van Der Werf, W., Lotz, L. A. P., Chipomho, J., & Kropff, M. J. (2009). Narrow rows reduce biomass and seed production of weeds and increase maize yield. *Annals of Applied Biology*, *155*(2), 207-218.

McCarthy, T. S., Cooper, G. R. J., Tyson, P. D., & Ellery, W. N. (2000). Seasonal flooding in the Okavango Delta, Botswana - Recent history and future prospects. *South African Journal of Science, 96*(1), 25-33.

McCarthy, J., Gumbricht, T., & McCarthy, T. S. (2005). Ecoregion classification in the Okavango Delta, Botswana from multitemporal remote sensing. *International Journal of Remote Sensing, 26*(19), 4339 - 4357.

McCarthy, T. S. (2005). Groundwater in the wetlands of the Okavango Delta, Botswana, and its contribution to the structure and function of the ecosystem. *Journal of Hydrology, 320(2006)*, 264-282.

McCune, B., Grace, J. B., & Urban, D. L. (2002). *Analysis of Ecological Communities*. Oregon State University: MjM Software Design.

Milberg, P., Hallgren, E., & Palmer, M. W. (2000). Inter-annual variation in weed biomass on arable land in Sweden. *Weed Research-, 40*(3), 311-321.

Mmopelwa, G., Vanderpost,C.,Wolski,P., Kgathi,D.L. (2011). *The impact of environmental change on ecosysterm services supporting human livelihoods: the case of the Okavango and Boteti basins, Botswana* Okavango Research Institute.

Molefe, C., Cassidy, L., Chimbari, and Magole,L. (2014). Influence of Flood Variation on *Molapo* Farming Field Size in the Okavango Delta, Botswana. *International Journal of Agricultural Research and Review, 2:* 027 - 037.

Moore, M. J., Gillespie, T.J. and Swanlo, C.J. (1994). Effects of cover crop mulchies on weed emergence, weed biomass and soya bean(Glycine max) development. *Weed Technology, 8*(3), 512 - 518.

Motsholapheko, M. R., Kgathi, D.I. and Vanderpost,C. (2011). Rural Livelihoods and Household adaptation to extreme flooding in the Okavango Delta, Botswana. *Physics and Chemistry of the Earth*, 984-995.

Motsumi, S., Magole,L. and Kgathi, D. (2012). Indigenous Knowledge and Land use policy: Implications for livelihoods of flood recession farming communities in the Okavango Delta, Botswana. *Physics and Chemistry of the Earth, 50-52 (2012)*, 185-195.

Mueller-Dombois, D., & Ellenberg, H. (1974). *Aims and Methods of Vegetaion Ecology* (1st ed.). New York: John Wiley and Sons.

Morgan, J.W. (1998). Patterns of invasion of an urban remnant of species-rich grassland in south eastern Australia by non-native plant species. *Journal of Vegetation Science, 9: 181-190.*

Murphy, S. D., Yakubu, Y., Weise, S. F., and Swanton, C. J. 1996. Effect of planting patterns and inter-row cultivation on competition between corn and late emerging weeds. *Weed Science* **44**: 865–870.

Murray-Hudson, M., Wolski, P., & Ringrose, S. (2006). Scenarios of the impact of local and upstream changes in climate and water use on hydro-ecology in the Okavango Delta, Botswana. *Journal of Hydrology. Water Resources in Regional Development: The Okavango River, 331*(1-2), 73-84.

Murray-Hudson, M., Combs, F., Wolski, P., and Brown, M.T. (2011). A vegetation-based hierarchical classification for seasonally pulsed floodplains in the Okavango Delta, Botswana. *African Journal of Aquatic Science, 36(Ringrose et al.)*, 223-234.

Murray-Hudson, M., Wolski, P., Cassidy, L., Brown, M. T., Thito, K., Kashe, K., & Mosimanyana, E. (2014). Remote Sensing-derived hydroperiod as a predictor of floodplain vegetation composition. *Wetlands Ecology and Management*, 1-14. doi: 10.1007/s11273-014-9340-z

Nilsson, C and Svedmark, M., 2002. Basic principles and Ecological consequences of changing water regimes: Riparian plant communities. *Environmental management* 30: 468-480

Odum, E. P., & Barrett, G. W. (2005). *Fundamentals of Ecology* (5 ed.). Toronto, Canada: Thomson Brooks/Cole.

Oerke, E.-C. (2006). Crop losses to pests. *The Journal of Agricultural Science, 144*(01), 31-43.

Ogwuike, P., Diagne, A., Agboh-Noameshie, A.R. and Amovin-Assagba, E. . (2014). Weed management in upland rice in sub-Saharan Africa: impact on labor and crop productivity. *Food Security, 6*(Ringrose et al.), 327-337.

Oliveira-Filho, A.T., Vilela, E.A., Gavilanes, M.L and Carvalho, D.A., 1994. Effects of flooding on understorey Bamboos on the physiognomy and Tree species composition of a tropical semi deciduous forest in Southern Brazil. *Vegetation*, 113: 99-124

Oosterbaan, R. J., Kortenhorst, L. F., & Sprey, L. H. (1987). Development of flood-recession cropping in the *molapo*s of the Okavango Delta, Botswana. *Annual report 1986. International Institute for Land Reclamation and Improvement, Wageningen, Published by Gower; IAAE, Occasional Paper, 4*, 8-29.

Pal, R. W., Pinke, G., Botta-Dukát, Z., Campetella, G., Bartha, S., Kalocsai, R., & Lengyel, A. (2013). Can management intensity be more important than environmental factors? A case study along an extreme elevation gradient from central Italian cereal fields. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology, 147*(2), 343-353.

Pekel, J. F., Cottam, A., Gorelick, N., & Belward, A. S. (2016). High-resolution mapping of global surface water and its long-term changes. *Nature*, *540*(7633), 418.

Petermann, K., Sabure. (1989). Distribution of molapo farming areas in Boro-Shorobe flood plains: MoA.

Pezeshki, S. R., & DeLaune, R. D. (2012). Soil Oxidation-Reduction in Wetlands and Its Impact on Plant Functioning. *Biology*, *1*(2), 196221 http://doi.org/10.3390/biology1020196

Phillips, M. (1991). *A guide to the arable weeds of Botswana*: Ministry of Agriculture.

Phillips, M. C. (1992) A survey of the arable weeds of Botswana, Tropical Pest Management, 38:1, 13-21, DOI: 10.1080/09670879209371638

Powell, D. C. (2000). *Potential vegetation, disturbance, plant succession, and other aspects of forest ecology*. US Department of Agriculture, Forest Service, Pacific Northwest Region, Umatilla National Forest.

Putnam, A. R., & DeFrank, J. (1983). Use of phytotoxic plant residues for selective weed control. *Crop protection*, *2*(2), 173-181.

Pysek, P. and Leps, J. (1991). Response of a weed community to Nitrogen fertilisation: A multivariate analysis. *Journal of Vegetation Science, 2(2): 237 – 244.*

Quinn, G., and Keough, M. (2001). *Design and Analysis for Biologists*.

Rajcan, I., & Swanton, C. J. (2001). Understanding maize–weed competition: resource competition, light quality and the whole plant. *Field Crops Research*, *71*(2), 139-150.

Rasool, S. a. K., M.H. (2016). Growth and Yield of Maize (Zea mays L.) as influenced by integrated weed management under temperate conditions of North Western Himalayas. *American Journal of Environmental Agriculture*, *14*(1), 1-9.

Reeves, C V. (1978) The gravity survey of Ngamiland, 1970-71. Geological Surveys Department Dept.

Rencher, A. C. (2002). *Methods of Multivariate Analysis* (Second Edition ed.). New York: John Wiley & Sons, Inc.

Richter, B. D. P., S.; Revenga, C.; Scudder, T.; Lehner, B.;Churchill, A. and Chow, M. (2010). Lost in development's shadow:The downstream human consequences of dams. *Water Alternatives 3*, 14-42.

Ringrose, Susan [1], Jellema, Andre [1], Huntsman-Mapila, Philippa [1], Baker, Lauren [2], & Brubaker, Kristin [3]. (2005). Use of remotely sensed data in the analysis of soilvegetation changes along a drying gradient peripheral to the Okavango Delta, Botswana. [doi:10.1080/01431160500113575]. *International Journal of Remote Sensing, 26*, 4293-4319.

Robertson, A.I., Bacon, P., and Heagney, G. (2001). The response of flood plain primary production to flood frequency and time. *International Journal of Remote Sensing*(24), 1029 - 1052.

Ruto, W. K. S., Kinyamario, J.L., N'getich, N.K., Akunda, E. and Mworia J.L.C. (2012). Plant Species Diversity and Composition of the Two Wetlands in the Nairobi National Park, Kenya. *Journal of Wetland Ecology, 6,* 07 -15.

Saha, H. M. (2017). Agro-Economic Benefits of Weed Biomass and Crop Residue in Maize Production Systems in Coastal Kenya. *Journal of Agriculture and Veterinary Science, 10*(2), 71-76.

Santadino, M., Coviella, C. and Momo, F. (2014). Glyphosate sublethal effects on the population dynamics of earthworm (Eisenia fetida). *Water, Air and Soil Pollution,* 225:2207

Sardana, V., Mahajan, G., Jabran, K., & Chauhan, B. S. (2017). Role of competition in managing weeds: An introduction to the special issue. *Crop Protection*, *95*, 1-7.

Scudder, T. (1991). The need and justification for maintaining transboundary flood regimes: The Africa case. . *Special Issue of Natural Resources Journal on the International Law of the Hydrologic Cycle 31(Ringrose et al.)*, 75-107.

Seleka, T. B. (1999). The performance of Botswana's traditional arable agriculture: growth rates and the impact of the accelerated rainfed arable programme (ARAP). *Agricultural Economics*, *20*(2), 121-133.

Shea, K., Roxburg, S.H. and Ranschert, E.S.J. (2004). Moving from pattern to process: Coexistence mechanisms under Intermediate Disturbance regimes. *Ecological Letters.* 7:491-508

Shemdoe, RS., Mbago, FM., Kikula, S., and Van Damme, PL. (2008). Weeds species diversity on arable land of the dryland areas of central Tanzania: Impact of continuous application of traditional tillage practices. *GeoJournal* 71(2/3): 107-115

Shorr, N. (2000). Early utilization of flood-recession soils as a response to the intensification of fishing and upland agriculture: resource-use dynamics in a large Tikuna community. . *Human Ecology*, 28 (1): 73-107.

Sianga, K. and Fynn, R., 2017, 'The vegetation and wildlife habitats of the Savuti- Mababe-Linyanti ecosystem, northern Botswana', *Koedoe* 59(2), 1406.

Sinden, J., and Jones,R., Hester,S., & Odom,D., Kalisch,C., James,R. and Cacho,O. (2004). The economic impact of weeds in Australia (C. f. A. W. Management, Trans.) *CRC for Australian Weed Management Technical Series*.

Smith, R.G. (2006). Timing of tillage is an important filter on the assembly of weed communities. *Weed Science 54(4): 705-712*

Smith, R. G. and Gross, K. L. (2007). Assembly of weeds communities along a crop diversity gradient. *Journal of Applied Ecology,* 44(5), 1046 – 1056.

Society for Range Management, 1989. A Glossary of terms used in Range Management, Denver, CO, 3rd Edition.

Staring, G.J. (1978). Soils of the Okavango Delta. BOT 72/019, Field Document 14. Gaborone.

Statistics Botswana. (2012). The 2012 Annual Agricultural Survey Report. Ministry of Finance and Development Planning. Gaborone.

Statistics Botswana. (2014). Gross Domestics Product: Second Quarter of 2014 (Vol. No. 2014/3). Ministry of Finance and Development Planning, Gaborone.

Stoller, E., Nema, D., & Bhan, V. (1972). Yellow Nutsedge Tuber Germination and Seedling Development. *Weed Science, 20*(1), 93-97.

Stoller, E. and Sweet, R. (1987). Biology and Life Cycle of Purple and Yellow Nutsedges (*Cyperus rotundus* and *Cyperus esculentus*). *Weed Technology*, 1(1) 66-73

Stokes, K., & Collot, M.,. (2009). Weeds Management on Floodplains: A guide for Natural Resource Managers *CSIRO Land and Water Australia*.

Stokes, K., Ward, K. and Collot, M. (2010). Alteration in flood frequency increase in exotic and native species richness of understorey vegetation in a temperate floodplain eucalypt forest. Plant Ecology, 211 (2), 219 – 233.

Storkey, J., Moss, S.R. and Cussans, J.W. (2010). Using Assembly Theory to explain changes in weed flora in response to Agricultural Intensification. *Weed Science Society of America*, *58*, 39-46.

Strauss, A. and Schickoff, U. (2007) Influence of soil-ecological conditions on vegetation zonation in a western Mongolian Lake shore-semi-desert ecotone. Erdkunde. 61(1):72–92. http://dx.doi.org/10.3112/erdkunde.2007.01.05

Swanton, C. J., & Weise, S. F. (1991). Integrated weed management: the rationale and approach. *Weed Technology*, *5*(3), 657-663.

Swanton C J., Shrestha, A., Roy, RC., Ball-Coelho, BR. And Knezevic, SZ. (1999). Effect of tillage systems, N and cover crop on the composition of weeds flora. *Weed Science.* 47 (4) 454-461

Teasdale, J. R., & Mohler, C. L. (1993). Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. *Agronomy Journal*, *85*(3), 673-680.

Ter Braak, C. J. F., & Looman, C. W. N. (1986). Weighted averaging, logistic regression and the Gaussian response model. *Vegetatio*, *65*, 3-11.

Teuton, T. C., MacDonald, G. E., Main, C. L., & Brecke, B. J. (2006). Characterization of fluazifop-P-butyl activity on bristly starbur (Acanthospermum hispidum). *Weed Technology*, *20*(3), 717-721.

Thobatsi, T. (2009). *Growth and yield responses of Maize (Zea mays L.) and Cowpeas (Vigna unguiculata) in an intercropping system.* MSC, University of Pretoria.

Thompson, T.L., Doerge, T.A. and Godin, R.E. (2000). Nitrogen and Water interactions in subsurface drip irrigated cauliflower. Soil Science *Society of America Journal*, *64: 412-418*

Townsend, C. R., and Scarsbrook, M.R. (1997). The Intermediate Disturbance Hypothesis, Refugia and Biodiversity in Streams. *Limniology and Oceaniography, 42*(5), 938 - 949.

Tsheboeng, G. (2013). *Response of Seasonal Floodplain Vegetation Communities and Soil Nutrient Status to Flood Variation in the Okavango Delta, Botswana.* Master of Philosophy, Okavango Research Institute (University of Botswana).

Tsheboeng, G., Bonyongo, M. C., & Murray-Hudson, M. (2014). Influence of flood variation on seasonal floodplain vegetation communities in the Okavango Delta, Botswana. *African Journal of Aquatic Science, 39,* 77-87.

Turpie, J., Barnes,J., Arntzen, J., Nherera, B., Glenn-Marie Lange, and Buzwani, B. (2006). Economic value of the Okavango Delta, Botswana, and implications for management

Uhl, C. (1987). Factors Controlling Succession Following Slash-and-Burn Agriculture in Amazonia. *Journal of Ecology,* 75 (2), 377-407

UNDP-UNEP. (2012). Agriculture and Food Security Policy Brief: Reflecting on the Challenges of Attaining a Green Economy 1 for Botswana In S. C. Consultancy (Ed.). Gaborone.

Van Looy, K., Honnay, O., Bossuyt, B. and Hermy, M. (2003). The effects of river embarkment and forest fragmentation on the plant richness and composition on floodplain forests in the Meuse valley, Belgium. *Belgian Journal of Botany, 136*: 97 - 108.

van Oudtshoorm, F. (1992). *Guide to grasses of South Africa*. Capetown: BRIZA Publikasies.

van Reeuwijk, L. P. (2002). Procedures for Soil Analysis (6 ed.): ISRIC - FAO.

VanderPost, C. (2009). *Molapo* Farming in the Okavango Delta. Maun: HOORC.

van der Meulen, A., & Chauhan, B. S. (2017). A review of weed management in wheat using crop competition. *Crop Protection*, *95*, 38-44.

Vernon, R., and Parker, J.M.H. (1982). Maize Herbicides for smallholder farmers in Zambia. *Tropical Pest Management, 28*, 259-265.

Walworth, J. L. (2006). Soil Sampling and Analysis: University of Arizona Cooperative Extension.

Weaver, S.E. and Hamill, A.S. (1985). Effects of soil pHon competitive abilityand leaf nutrition content of corn (Zea mays) and three weed species. *Weed Science, 33(4), 447 – 451*.

Wolski, P and Murray-Hudson, M., 2006. Flooding dynamics in a large low-gradient alluvial fan

Wright, A. J. *et al*. Flooding disturbances increase resource availability and productivity, but reduce stability in diverse plant communities. *Nat. Commun.* 6:6092 doi: 10.1038/ncomms7092 (2015).

Yadav, A. S., and Gupta,S.K. (2005). Effect of micro environment and human disturbance on the diversity of woody species in the Sariska Tiger Project in India. *Forest Ecology and Management, 22 (2006)*, 178-189.

Yeganehpoor, F., Salmasi, S.Z., Abedi, G., Samadiyan, F. and Beyginiya, V. (2014). Effects of cover crops and weed management on corn yield. *Journal of the Saudi Society of Agricultural Sciences* (14)2, 178-181

Yenish J.P., Doll, J.D., and Buhler, D.D. (1992). Effects of tillage on vertical distribution and viability of weed seed in soil. *Weed Science* (40)3, 429-433

Appendices

Appendix 1: ***Cynodon dactylon – Bulbostylis hispidula*** Community

Species	Indicator Value	p-value	No. of Individuals	Density (m^{-2})	Family
Cynodon dactylon	50.0 ±2.68	0.0002	3319	13.119±2.647	Poaceae
Bulbostylis hispidula	28.9 ± 2.74	0.0004	645	2.549±0.620	Cyperaceae
Acanthospermum hispidum	21.3 ± 2.70	0.0024	515	2.036±0.580	Asteraceae
Triumfetta pentandra	20.0 ±2.83	0.0054	486	1.921±0.548	Malvaceae
Nidorella resedifolia	12.5 ± 1.82	0.0024	155	0.613±0.289	Asteraceae
Phylla nodiflora	12.4 ± 1.98	0.0046	204	0.806±0.510	Verbenaceae
Kyllinga erecta	7.1 ± 1.41	0.0242	274	1.083±0.602	Cyperaceae
Kohautia subverticillata	6.2 ± 1.74	0.0516	18	0.071±0.031	Rubiaceae
Cyperus longus	5.6 ± 1.99	0.1328	765	3.024±1.036	Cyperaceae
Tephrosia purpurea	3.9 ± 2.64	0.8006	137	0.542±0.257	Fabaceae
Vernonia glabra	3.6 ±1.24	0.1372	2	0.008±0.006	Asteraceae
Spermacoce senensis	3.6 ± 1.24	0.1372	7	0.028±0.024	Rubiaceae
Eragrostis sarmentosa	3.6 ± 1.28	0.1648	167	0.660±0.494	Poaceae
Gomphrena celesiodes	3.5 ± 1.36	0.1930	20	0.079±0.057	Amaranthaceae
Indigofera astragalina	3.5 ±1.68	0.3447	50	0.198±0.167	Fabaceae
Indigofera charlieriana	3.0 ± 2.31	0.7610	79	0.312±0.150	Fabaceae
Crotalaria sphaerocarpa	2.8 ± 1.37	0.3121	8	0.032±0.017	Fabaceae
Eragrostis viscosa	2.1 ± 1.82	0.7532	34	0.134±0.065	Poaceae
Hermannia kirkii	1.8 ±1.00	0.3149	3	0.012±0.009	Sterculiaceae
Urochloa trichopus	1.8 ± 1.00	0.3149	1	0.004±0.004	Poaceae
Ipomea plebeia	1.8 ± 1.01	0.3001	1	0.004±0.004	Convolvulaceae
Corchorus asplenifolius	1.8 ± 1.00	0.2991	6	0.024±0.024	Tiliaceae
Dactyloctenium giganteum	1.8 ± 1.04	0.3121	1	0.004±0.004	Poaceae
Zaleya pentandra	1.8 ± 1.00	0.3073	4	0.016±0.016	Aizoaceae
Phyllanthus burchelli	1.8 ± 1.02	0.2969	1	0.004±0.004	Euphorbiaceae
Tragus beterionianus	1.8 ±1.02	0.3143	1	0.004±0.004	Poaceae
Cenchrus biflorus	1.7 ± 1.50	0.7818	5	0.020±0.010	Poaceae
Mollugo cerviana	1.6 ± 1.76	0.7920	126	0.498±0.346	Molluginaceae
Indigofera daloides	1.5 ± 1.76	0.8838	15	0.059±0.027	Fabaceae
Boerhavia coccinea	0.9 ±1.29	0.6949	5	0.020±0.016	Nyctaginaceae

Appendix 2: *Sida cordifolia – Corchorus tridens* Community

Species	Indicator Value	p-value	No. of Individuals	Density (m^{-1})	Family
Sida cordifolia	37.2 ±3.45	0.0004	1573	6.217±1.64	Malvaceae
Corchorus tridens	35.4 ±3.43	0.0026	1648	6.513±0.97	Tiliaceae
Ipomea sinensis	27.2 ±3.15	0.0030	832	3.289±0.68	Convolvulaceae
Digitaria debilis	23.6 ±2.77	0.0020	438	1.731±0.289	Poaceae
Ipomea coptica	15.2 ±3.04	0.0640	519	2.051±1.13	Convolvulaceae
Hibiscus cannabinus	14.4 ±3.26	0.1236	325	1.285±0.405	Malvaceae
Sp1	11.8 ±2.29	0.0154	61	0.241±0.103	
Indigofera flavicans	9.5 ±2.52	0.0642	143	0.565±0.35	Fabaceae
Panicum coloratum	7.7 ±2.06	0.0652	223	0.881±0.340	Poaceae
Acrachne racemosa	4.0 ±2.04	0.3519	93	0.368± 0.171	Poaceae
Sesbania bispinosa	3.5 ±2.40	0.7185	51	0.202±0.074	Fabaceae
Chloris virgata	3.1 ±1.36	0.2068	10	0.040±0.026	Poaceae
Eragrostis rotifer	3.1 ±1.44	0.2501	5	0.020± 0.013	Poaceae
Alternanthera pungens	3.1 ±1.36	0.2126	7	0.028± 0.018	Amaranthaceae
Aerva leucura	2.1 ±1.39	0.4517	5	0.020± 0.013	Amaranthaceae
Crotalaria podocarpa	1.9 ±1.45	0.5901	11	0.043±0.025	Fabaceae
Vigna anguiculata	1.0 ±1.01	1.0000	1	0.004±0.004	Fabaceae
Gunillaea emirnensis	1.0 ±0.98	1.0000	1	0.004±0.004	Campanulaceae
Cassia occidentalis	1.0 ±1.00	1.0000	1	0.004±0.004	Fabaceae
Eragrostis aspera	1.0 ±0.99	1.0000	5	0.020± 0.020	Poaceae
Leptocarydion vulpiastrum	1.0 ±0.99	1.0000	7	0.028± 0.028	Poaceae
Corchorus olitorius	1.0 ±1.35	0.8826	27	0.107± 0.081	Tiliaceae
Eragrostis superba	1.0 ±0.99	1.0000	1	0.004± 0.004	Poaceae
Rothia hirsuta	1.0 ±1.01	1.0000	1	0.004± 0.004	Poaceae
Datura ferox	1.0 ±1.01	1.0000	3	0.012± 0.012	Solanaceae
Physalis angulata	1.0 ±0.99	1.0000	3	0.012± 0.012	Solanaceae
Crotalaria steudneri	1.0 ±0.99	1.0000	2	0.008± 0.008	Fabaceae
Hermannia modesta	1.0 ±1.00	1.0000	1	0.004±0.004	Sterculiaceae

Appendix 3: *Glinus oppositifolius – Heliotropium ovalifolium* Community

Species	Indicator Value	p-value	No. of Individuals	Density (m^{-1})	Family
Glinus oppositifolius	26.2 ±2.15	0.0002	114	0.451±0.135	Molluginaceae
Heliotropium ovalifolium	18.0 ± 30.5	0.0218	374	1.478±0.619	Boraginaceae
Cyperus esculentus	15.0 ±2.17	0.0044	1039	4.107±1.781	Cyperaceae
Fimbristylis dichotoma	13.8 ±2.02	0.0040	101	0.399±0.150	Cyperaceae
Cyperus latifolius	13.6 ±2.08	0.0058	82	0.324±0.104	Cyperaceae
Pavonia senegalensis	12.2 ±2.14	0.0074	174	0.688±0.189	Malvaceae
Alternanthera sessilis	11.2 ±1.96	0.0072	40	0.158±0.059	Amaranthaceae
Cyperus articulatus	7.8 ±1.94	0.0406	346	1.368±0.554	Cyperaceae
Panicum repens	5.3 ±2.32	0.3951	519	2.051±0.538	Poaceae
Echinochloa jubata	3.8 ±1.36	0.1284	30	0.119±0.100	Poaceae
Portulaca oleracea	3.8 ±1.36	0.1266	29	0.115±0.070	Portulacaceae
Kohautia virgata	3.7 ±1.79	0.2278	217	0.858±0.581	Rubiaceae
Cucumis anguira	3.4 ±1.92	0.3941	9	0.036±0.013	Cucurbitaceae
Echinochloa colona	3.2 ±1.70	0.3037	61	0.241±0.130	Poaceae
Digitaria milanjiana	2.2 ±1.56	0.4687	47	0.186±0.159	Poaceae
Evolvulus alsinoides	2.1 ±1.35	0.3831	7	0.028±0.016	Convolvulaceae
Urochloa mosambiscensis	2.1 ±2.06	0.8534	93	0.368±0.240	Poaceae
Persicaria limbata	2.1 ±1.36	0.4315	5	0.020±0.013	Polygonaceae
Crotalaria barkae	1.9 ±2.58	0.9846	65	0.257±0.103	Fabaceae
Polygonum decipiens	1.8 ±1.53	0.5835	7	0.028±0.015	Polygonaceae
Sesbania rostrata	1.2 ±1.01	0.6207	2	0.008±0.008	Fabaceae
Astripomoea lachnosperma	1.2 ±0.97	0.6329	1	0.004±0.004	Convolvulaceae
Schimidtia kalihariensis	1.2 ±1.19	0.7433	8	0.032±0.022	Poaceae
Panicum kalaharense	1.2 ±0.99	0.6219	2	0.008±0.008	Poaceae
Ipomoea dichroa	1.2 ±1.21	0.6731	7	0.028±0.017	Convolvulaceae
Ludwigia stolonifera	1.2 ±0.97	0.6221	3	0.012±0.012	Onagraceae
Hibiscus mastersianus	1.1 ±1.63	0.9002	19	0.075±0.047	Malvaceae
Setaria verticillata	1.1 ±1.16	0.7976	3	0.012±0.012	Poaceae
Zornia glochidiata	0.9 ±1.35	0.9086	11	0.043±0.029	Fabaceae

Appendix 4: *Sida alba – Abitulon angulatum* Community

Species	Indicator Value	p-value	No. of Individuals	Density (m^{-2})	Family
Sida alba	80.8 ± 3.15	0.0002	515	2.036±0.385	Malvaceae
Abitulon angulatum	47.7 ±2.60	0.0002	510	2.016±0.788	Malvaceae
Xanthium strumarium	28.3 ± 3.88	0.0038	202	0.798±0.185	Asteraceae
Chenopodia carinatum	19.0 ± 1.42	0.0002	13	0.051±0.032	Amaranthaceae
Eclipta prostrata	17.3 ±3.13	0.0136	67	0.265±0.068	Asteraceae
Chamaecrista biensis	13.5 ±2.06	0.0030	55	0.217±0.095	Fabaceae
Hibiscus trionum	9.1 ± 1.65	0.0140	12	0.047±0.023	Malvaceae
Amaranthus hybridus	8.6±2.15	0.0350	38	0.150±0.048	Amaranthaceae
Digitaria eriantha	7.9 ± 1.77	0.0212	11	0.043±0.019	Poaceae
Indigofera tinctoria	7.5 ± 2.40	0.1156	46	0.182±0.081	Fabaceae
Waltheria indica	6.8 ± 2.57	0.2507	29	0.115±0.040	Malvaceae
Cyperus compressus	5.7 ± 2.12	0.1852	43	0.170±0.060	Cyperaceae
Dactyloctenium aegyptium	3.7 ± 1.76	0.2927	17	0.067±0.033	Poaceae
Gisekia africana	1.9 ± 2.43	0.9994	166	0.656±0.327	Gisekiaceae
Acrotome inflata	1.9 ± 2.12	0.9062	14	0.055±0.021	Lamiaceae

Appendix 5: Rank of abundance to indicate the association of weeds species with uncropped fields.

Cultivation Frequency	Species	Family	Rank of Abundance
	Cyperus esculentus L.	Cyperaceae	1
Uncropped	*Cyperus latifolius* L.	Cyperaceae	2
	Digitaria debilis (Desf.)	Poaceae	3
	Fimbristylis dichotoma (L.) Vahl	Cyperaceae	4
	Cyperus longus L.	Cyperaceae	5
	Cyperus articulatus L.	Cyperaceae	6
	Sida cordifolia L.	Malvaceae	7
	Corchorus tridens L.	Tiliaceae	8
	Panicum repens L.	Poaceae	9
	Heliotropium ovalifolium Forssk	Boraginaceae	10
	Alternanthera sessilis (L.) DC.	Amaranthaceae	11
	Sesbania bispinosa (Willd) Pers.	Fabaceae	12
	Cynodon dactylon (L) Pers	Poaceae	13
	Triumfetta pentandra A.Rich	Malvaceae	14
	Glinus oppositifolius (L.) Aug.DC	Molluginaceae	15
	Panicum coloratum L.	Poaceae	16
	Hibiscus cannabinus L.	Malvaceae	17
	Xanthium strumarium L.	Asteraceae	18
	Eclipta prostrata (L.)	Asteraceae	19
	Portulaca oleracea L.	Portulacaceae	20
	Hibiscus mastersianus Hiern.	Malvaceae	21
	Sida alba L.	Malvaceae	22
	Ludwigia stolonifera (Guill. & Perr.) P.H. Raven	Onagraceae	23
	Kohautia virgata (Willd.) Bremek.	Rubiaceae	24
	Bulbostylis hispidula (Vahl) R.W.Haines	Cyperaceae	25
	Indigofera daloides Benth. ex harv.	Fabaceae	26
	Ipomea coptica (L.) Roem. & Schult	Convolvulaceae	27
	Pavonia senegalensis Cav.	Malvaceae	28
	Ipomoea dichroa Hochst. ex Choisy	Convolvulaceae	29
	Chloris virgata Sw.	Poaceae	30
	Amaranthus hybridus L.	Amaranthaceae	31
	Panicum decipiens Nees ex Trin.	Poaceae	32
	Dactyloctenium aegyptium (l.) Willd.	Poaceae	33
	Ipomea sinensis (Desr.)	Convolvulaceae	34
	Waltheria indica L.	Malvaceae	35
	Acanthospermum hispidum DC.	Asteraceae	36
	Crotalaria sphaerocarpa Perr. ex DC.	Fabaceae	37
	Evolvulus alsinoides (Linn.) Linn.	Convolvulaceae	38
	Gomphrena celesiodes Mart.	Amaranthaceae	39
	Zornia glochidiata Rchb. ex DC.	Fabaceae	40
	Cenchrus biflorus Roxb.	Poaceae	41
	Tephrosia purpurea (L.) Pers.	Fabaceae	42
	Cyperus compressus L.	Cyperaceae	43

Eragrostis sarmentosa (Thunb.)	Poaceae	44
Acrachne racemosa (Roem. & schult.)	Poaceae	45
Rothia hirsuta (Guill. & Perr.) Baker	Fabaceae	46
Echinochloa jubata Stapf	Poaceae	47
Gunillaea emernensis(A.DC.) Thulin.	Campanulaceae	48
Indigofera astragalina DC.	Fabaceae	49
Urochloa mosambicensis (Hack) Dandy	Poaceae	50
Astripomea lachnosperma (Choisy)	Poaceae	51

Appendix 6: Rank of abundance to indicate the association of weeds species with the 5 year cultivation frequency.

Cultivation Frequency	Species	Family	Rank of Abundance
	Sida cordifolia L.	Malvaceae	1
5 years	*Corchorus tridens* L.	Tiliaceae	2
	Cynodon dactylon (L) Pers	Poaceae	3
	Bulbostylis hispidula (Vahl) R.W.Haines	Cyperaceae	4
	Sida alba L.	Malvaceae	5
	Ipomea sinensis (Desr.)	Convolvulaceae	6
	Abitulon angulatum (Guill&Perr) Mast	Malvaceae	7
	Digitaria debilis (Desf.)	Poaceae	8
	Hibiscus cannabinus L.	Malvaceae	9
	Triumfetta pentandra A.Rich	Malvaceae	10
	Heliotropium ovalifolium Forssk	Boraginaceae	11
	Xanthium strumarium L.	Asteraceae	12
	Pavonia senegalensis Cav.	Malvaceae	13
	Ipomea coptica (L.) Roem. & Schult	Convolvulaceae	14
	Cyperus esculentus L.	Cyperaceae	15
	Panicum repens L.	Poaceae	16
	Sesbania bispinosa (Willd) Pers.	Fabaceae	17
	Glinus oppositifolius (L.) Aug.DC	Molluginaceae	18
	Acrachne racemosa (Roem. & schult.)	Poaceae	19
	Cyperus compressus L.	Cyperaceae	20
	Chenopodia carinatum R.Br.	Amaranthaceae	21
	Waltheria indica L.	Malvaceae	22
	Eclipta prostrata (L.)	Asteraceae	23
	Dactyloctenium aegyptium (l.) Willd.	Poaceae	24
	Kyllinga erecta Schumach.	Cyperaceae	25
	Indigofera charlieriana Schinz.	Fabaceae	26
	Gisekia africana (Lour.) Kuntze	Gisekiaceae	27
	Panicum coloratum L.	Poaceae	28
	Acanthospermum hispidum DC.	Asteraceae	29
	Indigofera daloides Benth. ex harv.	Fabaceae	30
	Chamaecrista biensis (Steyaert) Lock.	Fabaceae	31
	Phylla nodiflora (L.)	Verbenaceae	32
	Cyperus longus L.	Cyperaceae	33
	Digitaria eriantha Steud.	Poaceae	34

Cyperus latifolius L.	Cyperaceae	35
Hibiscus trionum L.	Malvaceae	36
Cucumis anguira L.	Cucurbitaceae	37
Setaria verticilliata (L.) P.Beauv.	Poaceae	38
Aerva leucura Moq.	Amaranthaceae	39
Amaranthus hybridus L.	Amaranthaceae	40
Crotalaria barkae Schweinf.	Fabaceae	41
Indigofera tinctoria L.	Fabaceae	42
Kohautia subverticillata (K.Schum.)	Rubiaceae	43
Persicaria limbata (Meisn.) H.Hara	Polygonaceae	44
Alternanthera sessilis (L.) DC.	Amaranthaceae	45
Eragrostis viscosa (Retz.) Trin.	Poaceae	46
Evolvulus alsinoides (Linn.) Linn.	Convolvulaceae	47
Mollugo cerviana (L.) Ser.	Molluginaceae	48
Cenchrus biflorus Roxb.	Poaceae	49
Tephrosia purpurea (L.) Pers.	Fabaceae	50
Crotalaria sphaerocarpa Perr. ex DC.	Fabaceae	51
Acrotome inflata Benth.	Lamiaceae	52
Chloris virgata Sw.	Poaceae	53
Kohautia virgata (Willd.) Bremek.	Rubiaceae	54
Urochloa mosambicensis (Hack) Dandy	Poaceae	55
Vernonia glabra (Steetz) Vatke	Asteraceae	56
Eragrostis rotifer Rendle	Poaceae	57
Tragus berteronianus Schult.	Poaceae	58
Panicum decipiens Nees ex Trin.	Poaceae	59
Zornia glochidiata Rchb. ex DC.	Fabaceae	60
Nidorella resedifolia DC	Asteraceae	61
Indigofera flavicans Baker.	Fabaceae	62
Physalis angulata L.	Solanaceae	63
Ipomea plebeia R.Br	Convolvulaceae	64
Hermania kirkii Mast.	Sterculiaceae	65
Urochloa trichopus (Hochst) Stapf	Poaceae	66
Gomphrena celesiodes Mart.	Amaranthaceae	67
Corchorus asplenifolius Burch.	Tiliaceae	68
Indigofera astragalina DC.	Fabaceae	69

Appendix 7: Rank of abundance to indicate the association of weeds species with the 10 year cultivation frequency.

Cultivation Frequency	Species	Family	Rank of Abundance
	Cynodon dactylon (L) Pers	Poaceae	1
10 Years	*Corchorus tridens* L.	Tiliaceae	2
	Acanthospermum hispidum DC.	Asteraceae	3
	Sida cordifolia L.	Malvaceae	4
	Triumfetta pentandra A.Rich	Malvaceae	5
	Ipomea coptica (L.) Roem. & Schult	Convolvulaceae	6
	Digitaria debilis (Desf.)	Poaceae	7
	Cyperus longus L.	Cyperaceae	8
	Indigofera flavicans Baker.	Fabaceae	9
	Gisekia africana (Lour.) Kuntze	Gisekiaceae	10
	Bulbostylis hispidula (Vahl) R.W.Haines	Cyperaceae	11
	Tephrosia purpurea (L.) Pers.	Fabaceae	12
	Echinochloa colona (L.) Link	Poaceae	13
	Ipomea sinensis (Desr.)	Convolvulaceae	14
	Amaranthus hybridus L.	Amaranthaceae	15
	Mollugo cerviana (L.) Ser.	Molluginaceae	16
	Eragrostis sarmentosa (Thunb.)	Poaceae	17
	Crotalaria barkae Schweinf.	Fabaceae	18
	Hibiscus cannabinus L.	Malvaceae	19
	Phylla nodiflora (L.)	verbenaceae	20
	Heliotropium ovalifolium Forssk	Boraginaceae	21
	Schmidtia kalihariensis Stent.	Poaceae	22
	Nidorella resedifolia DC	Asteraceae	23
	Sida alba L.	Malvaceae	24
	Cyperus esculentus L.	Cyperaceae	25
	Cucumis anguira L.	Cucurbitaceae	26
	Panicum kalaharense Mez.	Poaceae	27
	Xanthium strumarium L.	Asteraceae	28
	Urochloa mosambicensis (Hack) Dandy	Poaceae	29
	Spermacoce senensis (Klotzsch)	Rubiaceae	30
	Acrotome inflata Benth.	Lamiaceae	31
	Alternanthera pungens Kunth	Amaranthaceae	32
	Kohautia subverticillata (K.Schum.)	Rubiaceae	33
	Boerhavia coccinea Mill.	Nyctaginaceae	34
	Hermania kirkii Mast.	Sterculiaceae	35
	Eclipta prostrata (L.)	Asteraceae	36
	Panicum repens L.	Poaceae	37
	Hibiscus mastersianus Hiern.	Malvaceae	38
	Crotalaria steudneri Schweinf.	Fabaceae	39
	Sesbania rostrata Bremex & Oberm.	Fabaceae	40
	Hermannia modesta (Ehrenb.) Mast.	Sterculiaceae	41

Zaleya pentandra (L.) C. Jeffrey	Aizoaceae	42
Crotalaria podocarpa DC.	Fabaceae	43
Vigna anguiculata (L.) Walp.	Fabaceae	44
Pavonia senegalensis Cav.	Malvaceae	45
Waltheria indica L.	Malvaceae	46
Cassia occidentalis (Linn.)	Fabaceae	47
Vernonia glabra (Steetz) Vatke	Asteraceae	48
Phyllanthus burchelli Mull. Arg.	Euphorbiaceae	49

Appendix 8: Rank of abundance to indicate the association of weeds species with the 15 year cultivation frequency.

Cultivation Frequency	Species	Family	Rank of Abundance
	Corchorus tridens L.	Tiliaceae	1
15 Years	*Ipomea sinensis* (Desr.)	Convolvulaceae	2
	Panicum coloratum L.	Poaceae	3
	Bulbostylis hispidula (Vahl) R.W.Haines	Cyperaceae	4
	Cyperus articulatus L.	Cyperaceae	5
	Digitaria debilis (Desf.)	Poaceae	6
	Cynodon dactylon (L) Pers	Poaceae	7
	Panicum repens L.	Poaceae	8
	Urochloa mosambicensis (Hack) Dandy	Poaceae	9
	Sida alba L.	Malvaceae	10
	Kohautia virgata (Willd.) Bremek.	Rubiaceae	11
	Hibiscus cannabinus L.	Malvaceae	12
	Acanthospermum hispidum DC.	Asteraceae	13
	Corchorus olitorius L.	Tiliaceae	14
	Chamaecrista biensis (Steyaert) Lock.	Fabaceae	15
	Sida cordifolia L.	Malvaceae	16
	Triumfetta pentandra A.Rich	Malvaceae	17
	Cyperus compressus L.	Cyperaceae	18
	Indigofera astragalina DC.	Fabaceae	19
	Tephrosia purpurea (L.) Pers.	Fabaceae	20
	Digitaria eriantha Steud.	Poaceae	21
	Sesbania bispinosa (Willd) Pers.	Fabaceae	22
	Digitaria milanjiana (Rendle) Stapf	Poaceae	23
	Acrachne racemosa (Roem. & schult.)	Poaceae	24
	Indigofera flavicans Baker.	Fabaceae	25
	Ipomea coptica (L.) Roem. & Schult	Convolvulaceae	26
	Eragrostis viscosa (Retz.) Trin.	Poaceae	27
	Amaranthus hybridus L.	Amaranthaceae	28
	Alternanthera sessilis (L.) DC.	Amaranthaceae	29
	Crotalaria podocarpa DC.	Fabaceae	30
	Ipomea dichroa Hochst. ex Choisy	Convolvulaceae	31
	Echinochloa jubata Stapf	Poaceae	32

Gomphrena celesiodes Mart.	Amaranthaceae	33
Heliotropium ovalifolium Forssk	Boraginaceae	34
Xanthium strumarium L.	Asteraceae	35
Eragrostis rotifer Rendle	Poaceae	36
Cyperus esculentus L.	Cyperaceae	37
Leptocarydion vulpiastrum (De Not.) Stapf	Poaceae	38
Glinus oppositifolius (L.) Aug.DC	Molluginaceae	39
Gisekia africana (Lour.) Kuntze	Gisekiaceae	40
Eragrostis sarmentosa (Thunb.)	Poaceae	41
Alternanthera pungens Kunth	Amaranthaceae	42
Chloris virgata Sw.	Poaceae	43
Pavonia senegalensis Cav.	Malvaceae	44
Cucumis anguira L.	Cucurbitaceae	45
Dactyloctenium giganteum B.S. Fisher & Schweick.	Poaceae	46
Waltheria indica L.	Malvaceae	47
Kohautia subverticillata (K.Schum.)	Rubiaceae	48
Aerva leucura Moq.	Amaranthaceae	49
Dactyloctenium aegyptium (l.) Willd.	Poaceae	50
Hibiscus trionum L.	Malvaceae	51
Eclipta prostrata (L.)	Asteraceae	52

Appendix 9: Indicator Species Analysis showing the indicator species for the weeds species communities in flood recession farming areas across different soil nutrient content, pH and Flood frequency at Lake Ngami. IV = indicator value and ±standard deviation. SP1= unidentified weed species

Site	Weeds species	IV	p value
Lake Ngami	***Sida cordifolia - Triumfetta pentandra* Community**		
	Sida cordifolia L	84.4±10.69	0.024
	Triumfetta pentandra A.Rich	66.7±13.37	0.0622
	Crotalaria barkae Scweinf	66.7±13.08	0.065
	Corchorus tridens L.	59.4±15.01	0.3955
	Ipomea sinensis (Desr.)	54.4±12.18	0.5057
	Panicum repens L.	50.0±12.6	0.1854
	Hibiscus trionum L.	50.0±12.62	0.1854
	Sp1	37.5±14.75	0.6973
	Digitaria debilis (Desf.) Willd	37.0±13.28	0.3937
	Waltheria indica L.	33.3±8.42	0.4431
	***Abitulon angulatum - Glinus oppositifolius* Community**		
	Abitulon angulatum (Guill.& Perr.) Mast.	99.9±12.46	0.0014
	Glinus oppositifolius (L.) Aug.DC.	83.3±13.68	0.0176
	Eclipta prostrata (L.) L.	82.3±14.75	0.0294
	Sida alba L.	71.6±9.26	0.0938
	Indigofera tinctoria L.	66.3±14.40	0.0652
	Heliotropium ovalifolium Forssk	60.3±13.40	0.1098
	Xanthium strumarium L.	57.7±14.62	0.2731
	Sesbania bispinosa (Willd.) Pers	50±11.75	0.1732
	Pavonia senegalensis (Cav.) Leistner	50±11.75	0.1814
	Ipomea coptica (L.)	34.6±14.58	0.9488

Appendix 10: Indicator Species Analysis showing the indicator species for the weeds species communities in flood recession farming areas across different soil nutrient content, pH and Flood frequency at Makalamabedi. IV = indicator value and ±standard deviation.

Site	*Species*	IV	p value
Makalamabedi	***Fimbristylis dichotoma – Alternanthera sessilis* Community**		
	Fimbristylis dichotoma (L.) Vahl	100±12.19	0.0052
	Alternanthera sessilis (L.) R.Br. ex DC.	100±12.57	0.0052
	Cyperus latifolius Poir.	100±13.17	0.005
	Eclipta prostrata (L.) L.	96.4±15.77	0.005
	Sesbania bispinosa (Willd.) Pers	85.4±15.44	0.0174
	Hibiscus cannabinus L.	80.4±12.95	0.057
	Cyperus longus L.	59.5±14.98	0.0596
	Glinus oppositifolius (L.) Aug.DC.	33.3±9.58	0.246
	Echinochloa jubata Stapf.	33.3±9.61	0.2488
	Ludwigia stolonifera (Guill. & Perr.) P.H. Raven	33.3±9.61	0.2488
	Ipomea dichroa Hochst.	32.2±12.06	0.2464
	Zornia glochidiata Rchb. ex DC.	30±10.05	0.2464
	Heliotropium ovalifolium Forssk	25±15.28	1.000
	Xanthium strumarium L.	21.4±15.99	0.9094
	Panicum repens L.	19.2±14.73	0.9678
	***Ipomea sinensis - Corchorus tridens* Community**		
	Ipomea sinensis (Desr.)	100±14.22	0.005
	Corchorus tridens L.	95.7±11.38	0.0248
	Acanthospermum hispidum DC.	62.3±16.07	0.2991
	Bulbostylis hispidula (Vahl) R.W.Haines	55.6±15.13	0.2579
	Cynodon dactylon (L)	55.6±16.10	0.1974
	Waltheria indica L.	55.6±15.75	0.2056
	Acrachne racemosa (Roem.& Schult.)	55.6±15.13	0.3277
	Sida cordifolia L	51.3±15.49	0.4873
	Ipomea coptica (L.)	44.4±14.92	0.3819
	Acrotome inflata Benth.	44.4±14.74	0.3625

Appendix 11: Indicator Species Analysis showing the indicator species for the weeds species communities in flood recession farming areas across different soil nutrient content, pH and Flood frequency at Shorobe. IV = indicator value and ±standard deviation.

Site	*Spp*	IV	p value
Shorobe	***Cyperus esculentus - Heliotropium ovalifolium***		
	Cyperus articulatus L.	94.1±16.14	0.0160
	Heliotropium ovalifolium Forssk	86.3±16.16	0.0862
	Sesbania bispinosa (Willd.) Pers	50±15.17	0.1742
	Portulaca oleracea L.	50.0±15.17	0.1742
	Astripomea lachnosperma (Choisy)	50±15.17	0.1742
	Alternanthera sessilis (L.) R.Br. ex DC.	45.4±13.27	0.1652
	Ipomea sinensis (Desr.)	41.6±16.73	0.5659
	Eclipta prostrata (L.) L.	40.2±15.18	0.2078
	Glinus oppositifolius (L.) Aug.DC.	33.5±14.75	0.7636
	Cenchrus biflorus Roxb.	30±13.47	0.3313
	Sida cordifolia - Corchorus tridens		
	Sida cordifolia L	85.1±14.55	0.1534
	Corchorus tridens L.	80.8±12.84	0.2519
	Bulbostylis hispidula (Vahl) R.W.Haines	79.6±16.81	0.137
	Triumfetta pentandra A.Rich	79.1±16.08	0.124
	Ipomea coptica (L.)	77.3±14.88	0.229
	Pavonia senegalensis (Cav.) Leistner	57.7±16.19	0.4073
	Tephrosia purpurea (L.) Pers.	53.7±16.33	0.3999
	Hibiscus cannabinus L.	53±16.71	0.5219
	Digitaria debilis (Desf.) Willd	52.1±14.77	0.7862
	Cynodon dactylon (L)	45.9±14.81	0.8218

Appendix 12: Codes for the species as used in the CCA bi-plot of weed species in *Molapo* farms

Weeds Species	Code
Sida cordifolia L.	sidcor
Triumfetta pentandra A.Rich	Tripen
Bulbostylis hispidula (Vahl) R.W.Haines	Bulhis
Cenchrus biflorus Roxb.	Cenbif
Abitulon angulatum (Guill&Perr) Mast	Abiang
Indigofera daloides Benth. ex harv.	Inddal
Gisekia africana (Lour.) Kuntze	Gisafr
Hermania kirkii Mast.	Herkir
Corchorus tridens L.	Cortri
Heliotropium ovalifolium Forssk	Helova
Cynodon dactylon (L) Pers	Cyndact
Eclipta prostrata (L.)	Eclpro
Ipomea coptica (L.) Roem. & Schult	Ipocop
Indigofera flavicans Baker.	Indfla
Tephrosia purpurea (L.) Pers.	Teppur
Xanthium strumarium L.	Xanstr
Ipomea sinensis (Desr.)	Iposin
Nidorella resedifolia DC	Nidres
Gomphrena celesiodes Mart.	Gomcel
Acanthospermum hispidum DC.	Acahis
Waltheria indica L.	Walind
Vigna anguiculata (L.) Walp.	Vigang
Crotalaria barkae Schweinf.	Crobar
Crotalaria podocarpa DC.	Cropod
Cucumis anguira L.	Cucang
Indigofera astragalina DC.	Indast
Glinus oppositifolius (L.) Aug.DC	Gliopp
Crotalaria sphaerocarpa Perr. ex DC.	Crosph
Cyperus latifolius L.	Cyplat
Cassia occidentalis (Linn.)	Casocc
Echinochloa colona (L.) Link	Echcol
Sesbania rostrata Bremex & Oberm.	Sesros
Eragrostis viscosa (Retz.) Trin.	Eravis
Dactyloctenium aegyptium (l.) Willd.	Dacaeg
Eragrostis aspera (Jacq.) Nees	Eraasp
Leptocarydion vulpiastrum (De Not.) Stapf	Lepvul
Cyperus articulatus L.	Cypart
Corchorus olitorius L.	Coroli
Echinochloa jubata Stapf	Echjub
Digitaria eriantha Steud.	Digeri
Digitaria milanjiana (Rendle) Stapf	Digmil
Dactyloctenium giganteum B.S. Fisher & Schweick.	Dacgig
Portulaca oleracea L.	Porole
Sida alba L.	Sidalb
Amaranthus hybridus L.	Amahyb
Sesbania bispinosa (Willd) Pers.	Sesbis
Panicum decipiens Nees ex Trin.	Poldec
Chloris virgata Sw.	Chlvir
Gunillaea emernensis(A.DC.) Thulin.	Gereme
Evolvulus alsinoides (Linn.) Linn.	Evoals
Panicum repens L.	Panrep
Pavonia senegalensis Cav.	Pavsen
Indigofera charlieriana Schinz.	Indcha
Acrotome inflata Benth.	Acrinf
Kohautia subverticillata (K.Schum.)	Kohsub
Phylla nodiflora (L.)	Phynod
Kohautia virgata (Willd.) Bremek.	Kohvir
Hibiscus mastersianus Hiern.	Hibmas
Hibiscus trionum L.	Hibtri
Indigofera tinctoria L.	Indtin
Mollugo cerviana (L.) Ser.	Molcer
Digitaria debilis (Desf.)	Digdeb
Urochloa mosambicensis (Hack) Dandy	Uromos
Urochloa trichopus (Hochst) Stapf	Urotri
Ipomea plebeia R.Br	Ipople
Hibiscus cannabinus L.	Hibcan
Panicum coloratum L.	Pancol
Cyperus compressus L.	Cypcom
Cyperus esculentus L.	Cypesc
Alternanthera sessilis (L.) DC.	Altses
Eragrostis rotifer Rendle	Erarot
Zaleya pentandra (L.) C. Jeffrey	Zalpen
Vernonia glabra (Steetz) Vatke	Vergla
Spermacoce senensis (Klotzsch)	Spesen
Schmidtia kalihariensis Stent.	Schkal
Cyperus longus L.	Cyplon
Panicum kalaharense Mez.	Pankal
Eragrostis sarmentosa (Thunb.)	Erasar
Phyllanthus burchelli Mull. Arg.	Phybur
Alternanthera pungens Kunth	Altpun
Boerhavia coccinea Mill.	Boecoc
Chamaecrista biensis (Steyaert) Lock.	Chabie
Datura ferox L.	Datfer
Ipomea dichroa Hochst. ex Choisy	Ipodic
Fimbristylis dichotoma (L.) Vahl	Fimdic
Ludwigia stolonifera (Guill. & Perr.)	Ludsto

		P.H. Raven	
Astripomea lachnosperma (Choisy)	Astlac	*Persicaria limbata* (Meisn.) H.Hara	Perlim
Eragrostis superba Peyr.	Erasup	*Tragus berteronianus* Schult.	Trabet
Acrachne racemosa (Roem. & schult.)	Acrrac	*Chenopodia carinatum* R.Br.	Checar
Rothia hirsuta (Guill. & Perr.) Baker	Rothir	*Setaria verticilliata* (L.) P.Beauv.	Setver
Kyllinga erecta Schumach.	Kylere	*Physalis angulata* L.	Phyang
Zornia glochidiata Rchb. ex DC.	Zorglo	*Crotalaria steudneri* Schweinf.	Croste
Aerva leucura Moq.	Aerleu	*Hermannia modesta* (Ehrenb.) Mast.	Hermod
Corchorus asplenifolius Burch.	Corasp	Sp1	Sp1