THE ECOLOGY AND RELATIVE ABUNDANCE OF *CLARIAS* SPECIES IN RELATION TO LAND USE CHANGE IN THE MPOLOGOMA RIVERINE WETLAND, UGANDA

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A Thesis submitted to the Graduate School in Partial Fulfilment of the requirements for the Award of the Degree of Doctor of Philosophy in Limnology of Egerton University

Egerton University

OCTOBER 2015

DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is my original work and has not been submitted or presented for examination in any other university.

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RECOMMENDATION

This thesis has been submitted for examination with our approval as University supervisors.

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DEDICATION

To Ms. Scovia Nanyondo. This is the first fruit of your moral and parental guidance for me to achieve a formal education you always wished for your children. As an expression of gratitude, I dedicate this thesis to your Name.

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ABSTRACT

Land use change influences wetland's services through effects on structure, physico-chemical environment and the biota. This consequently affects the ecology and relative abundance of individuals or populations of certain fish species. This calls for concerted efforts to understand the wetlands' response to land use change impacts if a sustainable balance between demand and wetland resources is to be achieved. The ecology and relative abundance of the endemic small *Clarias* species in relation to land use change were examined at selected sites in the Mpologoma riverine wetland. The main objective of the study was to investigate the small *Clarias* species' life history biometrics, movement patterns, wetland fishery production and its socio economics at different sites in relation to land use. Four sites exposed to different disturbance levels ranging from intact wetland, least disturbed, moderately and highly disturbed were identified. Selected physico-chemical parameters were determined to differentiate the sites further. Field sampling for fish habitat attributes, wetland fish biometrics and catch, and a socio-economic survey were done in 2012. Land use, water quality and fish catch models were used to predict land use and the fishery production change with time. Water conductivity was significantly higher at the highly disturbed site than less disturbed sites (one way ANOVA and Tukey's HSD test; $p < 0.05$). The total phosphorus content was higher at the least disturbed sites. Two small *Clarias* species were identified. Mean total length and weight of *Clarias liocephalus* (Boulenger 1902), the most abundant species (66%), were 16.81 ± 4.03 cm and 33.77 ± 19.63 g, respectively, whilst those for *Clarias alluaudi* (Boulenger, 1906) (34%) were 17.83 ± 4.49 cm and 39.94 ± 22.99 g, respectively. The total length, weight and fecundity of both species were significantly higher at the highly disturbed sites than at the least disturbed sites (between the weight of *C. alluaudi* at less disturbed and highly disturbed sites with ANOVA and Tukey's HSD test at $p = 0.003$, and between weight of *C. liocephalus* at less disturbed and highly disturbed sites at $p = 0.013$). The fish weight positively correlated with conductivity ($R^2 = 0.22$; $p = 0.001$) and negatively related to total phosphorus ($R^2 = -0.357$; $p = 0.001$). The female individuals of the both species matured faster at the highly disturbed Nsango site than at the less disturbed sites. The small *Clarias* fish associated more with habitats of 0.5 m depth and their prey items were dominated by chironomid larvae at the highly disturbed sites and adult insects at the less disturbed sites. Their movement pattern did not significantly vary with sites but moved downstream in dry season. The small scale wetland fishery was dominated by *Clarias gariepinus* (Burchell, 1815) and *Protopterus aethiopicus* (Heckel, 1851) with higher catch at the less disturbed sites than at highly disturbed sites, accounting for 91.5% of total wetland fish production. As the wetland cover was changing to other land uses, an increasing trend of catch per unit effort of the small clariids was predicted at the highly disturbed sites with subsequent increase from 516 to 1114 g/trap/night. The findings were mainly attributed to habitat disturbance that provided population-level benefits and pollution tolerance of the small *Clarias* species. Wetland disturbance negatively impacted the large wetland fish species ecology given the observed significant decline in the weight of *C. gariepinus* and *P. aethiopicus* at the highly disturbed site (ANOVA and Tukey's test; $p < 0.05$). *Clarias* fishery resource was important to the livelihoods of the riparian communities as major bait for the large wetland fish species and a cheap fish source, contributing to poverty alleviation in the area. However, Mpologoma riverine wetland was undervalued by policy makers, there was no management strategy associated to it. The information generated illustrated that there is need to formulate appropriate wetland specific and small scale fisheries management strategies for the Mpologoma riverine wetland in order to maintain its relevance to riparian community and the region at large.

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LIST OF SYMBOLS/ABBREVIATIONS

ANOVA	Analysis Of Variance
APHA	American Public Health Association
CCA	Canonical Correspondence Analysis
CMR	Captute Mark and Recapture
Cms	Cubic Metres per Second
CPUE	Catch per Unit Effort
DEM	Digital Elevation Model
ETM	Enhanced Thematic Mapper
FI	Fullness Index
FAO	Food and Agriculture Organisation
GSI	Gonado Somatic Index
HEC-HMS	Hydrologic Engineering Centre-Hydrologic Modelling System
HSD	Honestly Significant Difference
HRU	Hydrologic Response Unit
HSPF	Hydrologic Simulation Package Fortran
IBA	Important Bird Area
K	Coefficient of condition
KMO	Kaiser-Meyer-Olkin
LSD	Least Significant Difference
LULC	Land Use/Land Cover
LVFO	Lake Victoria Fisheries Organisation
MAAIF	Ministry of Agriculture Animal Industry and Fisheries
MLWE	Ministry of Lands Water and Environment
MEI	Morpho-Edaphic Index
MT	Metric Tonnes
NAADS	National Agricultural Advisory Services
NaFIRRI	National Fisheries Resource and Research Institute
NMDS	Non-Metric Multi Dimensional Scaling
NO_3-N	Nitrate Nitrogen
NSE	Nash-Sutcliffe Efficiency
Ortho	Orthophosphate
PCA	Principal Component Analysis
S.D	Standard Deviation
SE	Standard Error
SRP	Soluble Reactive Phosphorus
SWAT	Soil water and Assessment Tool
TP	Total Phosphorus
UBOS	Uganda Bureau of Statistics

CHAPTER ONE:
GENERAL INTRODUCTION

1.1 Introduction

Wetlands are areas saturated by surface or ground water that is static or flowing, fresh, brackish, or salt at a frequency and duration sufficient to support vegetation typically adapted for life in saturated soil conditions at depth that does not exceed 6 metres (Ramsar, 2004). Based on hydrology, freshwater wetlands can be categorized as riverine (associated with streams) and lacustrine (associated with lakes and reservoirs). These ecosystems have multiple functions and attributes representing values to humanity (Denny, 1995; Kipkemboi, 2006). Wetland fisheries form an important source of income and proteins for many communities living around them. This study was conducted on small *Clarias* species (locally known as Ensozi) fishery of the Mpologoma riverine wetland in Eastern Uganda from 2011 to 2013. These clariids (*Clarias liocephalus and C. alluaudi*) are referred as small species because they are the only species in the Kyoga basin which grow to a maximum length of 30 cm only. This chapter provides the background to the study, problem statement, the objectives and hypothesis of the study, study sites in the Mpologoma wetland and the justification of the study.

1.2 Background of Lake Kyoga basin wetland fisheries

Wetland habitats are very varied and widely distributed across virtually all continents, playing fundamental roles for a broad range of plant and animal communities, including many fish species (Cucherousset et al., 2008). The Kyoga basin has the largest expanse of wetlands in Uganda, offering important hydrological and ecological functions. Some of the major functions include retaining water and releasing it slowly hence maintaining stream base flow, providing refugia, and serving as nursery and feeding grounds for fish and other organisms (Ogutu-Ohwayo et al., 2013). Wetlands support important subsistence, commercial and recreational fisheries, thus playing important roles in rural livelihoods of many developing countries (Arthington et al., 2004; FAO, 2009). There are also areas within the wetland where agriculture and animal husbandry growth thrive. In sub-Saharan Africa, less than 1% of irrigated agricultural land depends on water diversions from wetlands (Galbraith et al., 2005). These various uses give rise to conflicting demands that are detrimental to entire aquatic ecosystems and their dependent fisheries (Torell et al., 2010).

In recent decades, aquatic habitats have suffered severe degradation due to resource exploitation and harvesting, urban and agricultural encroachment and global climate change (Williams et al., 2008; Cucherousset et al., 2008). The high population growth rate of over 3% in Uganda has increased the number of food insecure people from 12 million in 1992 to 17.7 million in 2007 (MAAIF, 2010). To address the food demand, many rice varieties were introduced in East Africa where rice was not a traditional staple crop (Miyamoto et al., 2012). Because of their fertile soils and abundant water supply especially during the dry season, wetlands are intensively targeted for rice growing (Madebwe and Madebwe 2005). Overall rice production in Uganda increased from 41,896 in 2000 to 880,000 metric tonnes in 2006 (MAAIF, 2010). The area under rice production in eastern Uganda increased from 39,000 in 1990 to 80,000 hectares in 2004 (Musiime et al, 2005). Often this rice area is within the Kyoga basin wetlands (Anon, 2004). Wetland farming has expanded rapidly due to the influx of people from marginal areas into wetlands due to climate-related vulnerability of terrestrial agriculture and civil upheavals (Kangalawe and Liwenga, 2005). These agricultural activities in wetlands come with changes in both land cover and hydrology (Martin et al., 2011). Many of the hydrological changes interfere with the flood control and land drainage, resulting in a substantial net loss of wetland habitat (Nguyen Khoa et al., 2005). The high demand for irrigation water often occurs during the dry season leading to draining of local wetlands which is a major threat to wetland fisheries (Abell et al., 2007; Hoagstrom et al., 2010).

The fishery of the Kyoga basin changed over the past four decades with a profound decline in the preferred wetland fish species; the catfishes (*Bagrus docmak* and *C. gariepinus*) and the lungfish (*Protopterus aethiopicus*). In 1977, the mean catches of *Bagrus*, *Clarias* and *Protopterus* were 4,645, 1,620 and 2,035 metric tonnes, respectively. In 2000, these values had been reduced to 152, 69 and 469 metric tonnes, respectively (Muhoozi, 2003). Declining fish populations, wetland loss and compromises lead to inadequate protein for local consumption, thus affecting the socio-economic welfare of majority of the rural population in the region (van der Knaap et al., 2002). Wetland hydrological modification, fish habitat degradation, loss of macrophytes and introduction of exotic species (both plants and fish) are important causal factors contributing to the declining fisheries production (Ogutu-Ohwayo et al., 2013). It is not clear which of these stressors is the most important and should be targeted in the development and management of fisheries and fish habitats (Kolding et al., 2008).

In comparison to the highly studied Lake Victoria system, other East African aquatic ecosystems; lakes, rivers and their wetlands structure and functioning are far less understood and yet they are undergoing drastic ecological changes in a much shorter time frame (Bugenyi and Balirwa, 2003). Mpologoma riverine wetland ecosystem found within the Kyoga basin is increasingly being converted to rice farms at the expense of macrophytes which support the small scale fishery. Environmental and food security issues are linked to inland fisheries and affect directly the productivity and diversity of fisheries (Nguyen-Khoa et al., 2005). There is therefore need for research on small scale fisheries sectors in poverty prevalent areas (Bene et al., 2010).

The aim of this study was to assess endemic small *Clarias* species' habitats, movement patterns, life history biometrics, small scale wetland production and the socio economic perspective in relation to land use in the Mpologoma riverine wetland. An observational study designed and conducted as a comparison of small *Clarias* species fish habitat characteristics, fish life history biometrics, their movement patterns, small scale fishery socio-economics between wetland sites with different levels of disturbance was done. Information obtained from this study will contribute to better understanding of land use impacts on individual fish species population dynamics in wetlands for appropriate management and sustainability.

1.3 Statement of the problem

Since its introduction in the 1960s in Kibimba, rice farming expanded to cover over 80,000 hectares of wetlands in north-eastern Uganda, particularly in the Mpologoma riverine wetland. Over these years, fish yield begun declining due to habitat changes and wetland loss. *C. gariepinus* mean catch declined from 1,620 metric tonnes in the 1980s to 1.35 metric tonnes in 2000 (Muhoozi, 2003). Several indigenous non-cichlids, catfish species and cyprinids that migrate upstream seasonally and into the wetlands to spawn during the rainy season are now rare. Small *Clarias* species which are usually the major baits for large wetland fishery and open lake Nile perch fishery and additionally the most affordable protein for the riparian communities, have also been declining. Reduction in wetland fishery catches could have implications on the food security, economy and livelihoods of the local populations dependent on this wetland. The cause of the observed decline is not clearly known but it is thought that the conversion of the natural wetlands to rice farms and the subsequent loss of riverine migratory routes and the areas deep within the fringing swamp that are important in the maintenance of migratory fishes are some of the major factors. Therefore, the present study focussed on bridging the knowledge gap on the impact of wetland degradation on specific fish species populations and small scale fisheries, so as to provide information that will enable formulation of an appropriate and effective wetland management strategy.

1.4 Objective of the study

1.4.1 Main objective

The main objective of the study was to assess the ecology and production of *Clarias* species in relation to land use and the socio-economic dimension within the Mpologoma river wetland, Eastern Uganda.

1.4.2 Specific objectives

The specific objectives of the study were to:

a) determine the response of *Clarias liocephalus* and *C. allauadi* life history parameters to variation in land use in the Mpologoma riverine wetland;
b) assess the small *Clarias* species' habitat attributes and variations in their movement patterns among wetland sites with different land uses;
c) evaluate the variation of the small scale wetland fishery and potential relative abundance of *Clarias* species with land use change in the Mpologoma riverine wetland; and
d) identify and interpret the social and economic indicators of land use change impacts on the small scale fishery of the Mpologoma wetland.

1.5 Null Hypotheses

1. The variability of land use among the different wetland sites did not significantly affect the life history parameters of small clariid species.
2. Wetland disturbance intensity levels did not change the small endemic *Clarias* species' habitat attributes and movement patterns in the Mpologoma riverine wetland.

3. Land use related disturbance did not significantly reduce the quantity of landings of the small scale wetland fishery in the Mpologoma riverine wetland.
4. The socio-economic dimension of land use did not affect the ichthyological structure of the small wetland fishery in the Mpologoma system.

1.6 Justification

The primary threat to the ecological integrity of most inland tropical wetlands and the long-term survival of their fish fauna is degradation by land use change. Natural wetlands of the Mpologoma river basin have been converted into farmland to enhance food security in the region where the population growth rate is above 3.0% (MAAIF, 2010). In wetland areas with large scale farming, agricultural implements and heavy machinery are used, hence changing the physical and chemical characteristics of the wetland with consequent negative impacts on the fisheries resource. Land change use impacts on wetland integrity may not be always easily observable in the short-term (Nguyen Khoa et al., 2005) but may take sometime before the impact of change in land use on particular species can be observed. Several studies have investigated land use change on temperate fishes population parameters, but information on impacted tropical systems is limited (Paukert and Makinster, 2009). Differences in socio-economic factors, conservation and management practices between developed and developing countries can result in different impacts of land use changes on wetlands or their fisheries. Previous studies (e.g. Bugenyi and Balirwa, 2003) have focussed on major lake fishery often destined for local and external markets with less effort in understanding other fishes used for subsistence and support marginalised aquatic systems' fisheries, particularly wetlands. Research has indicated that the physico-chemical conditions, channel hydraulics, pool-riffle complexity and substrate composition of the riverine systems are affected by land use changes (Wang et al., 2006). Individuals or population of certain fish species ecology could be affected differently, with the less resilient endemic fish species with small foraging ranges being likely to be significantly affected. Several studies (e.g. de Graaf, 2003; Offem et al., 2010; Okogwu, 2011) have been done on *Clarias* species, particularly, *C. gariepinus*, *C. anguillarus* and *C. lazera* breeding and habitat use within Lake Victoria wetlands and other tropical systems. Further taxonomy and ecology of small *Clarias* species have also been done in the Congo basin (Hanssens, 2009). However, studies on the response of these small *Clarias* ecology and abundance in relation to land use are limited. This study focuses on the land use change impact on a typical tropical wetland fishery and on the endemic *Clarias* fish species therein.

Unlike Lake Victoria wetlands, there is limited information on Lake Kyoga basin wetlands. Mpologoma wetland which forms part of the Lake Kyoga system is marginalised in terms of research investment and yet it plays an important role in Uganda's fishery sector. The wetland is an important source of preferred wetland fishes such as *Bagrus docmak, Clarias* spp. and *P. aethiopicus* for livelihood and protein source of the rural poor riparian communities in Eastern Uganda. Increasing conversion of wetland into rice and maize farms escalate the degradation of the wetland and cause further decline in fish production (Ogutu-Ohwayo et al., 2013). This will consequently lead to loss of livelihood to over 3.6 million people in the nearby districts. The mechanisms of fish population distribution and movement patterns are often misunderstood yet it is an important aspect in the development of fisheries management strategies. This study addresses the knowledge gap of small *Clarias* species' (*C. alluaudi* and *C. liocephalus*) habitat use, life history parameters and production in relation to land use change within the wetlands of the Mpologoma system. The present research provides an insight into the structure of catfish populations in the Lake Kyoga basin. The information gathered could in future be used to model the system for maximum sustainability of the fisheries in the event of upscaled uncontrolled land use or future climate-driven changes in the riverine system.

1.7 Scope and limitations of the study

This study investigated three aspects in relation to land use change: ecology of selected wetland endemic *Clarias* species (*C. liocephalus* and *C. alluaudi*), the *Clarias* species production and the socio-economic dimension of the wetland fishery. The two clarids were referred to as small clarias species during the study and in the whole document. Among the *Clarias* species in the Lake Kyoga basin, *C. liocephalus* and *C. alluaudi* grow to a maximum of 30 cm only. Investigation of catfish ecology focused on life history biometrics including length-weight relationships, body condition and fecundity measurements. The study on habitat use focused on the movement patterns and the fish stomach contents in relation to invertebrate assemblages in the wetland. The wetland fishery production assessment was limited to the catch and catch per unit effort (CPUE) of the major fish species. Wetland sites of different land use change and intensities were discriminated using the water quality parameters and dominant vegetation areal cover. The water and fish sampling were replicated at each of the four differently disturbed sites and fairly a large sample size (268 water samples and 1086 fish samples) was achieved during the entire study duration.

Human drivers and pressures that cause land use change within the wetlands were identified. This study was limited to rice growing areas within the wetland and varied sites between intact natural wetland, moderately disturbed with small scale rice farms to high disturbance with large scale irrigation scheme. This was meant to reduce excessive environmental variation among different land uses and therefore prior knowledge on the location of small scale rice farms and the large scale rice irrigation scheme was important in choosing the study sites.

The study was conducted within twelve months that was not possible to provide exhaustive information on fish biometrics and production in relation to land use. Fish movement patterns are readily studied using very expensive techniques such as acoustic and radio telemetry. In this study, the low cost floy tagging method was used. The time, location and date of the recovered tag depended on the reliability of the fishermen whom we had on control over. Bbecause migration patterns are inferred from recaptured fish only, and fail to make account of missing fish which may have died, emigrated beyond the limits of sampling area, the method suffers from poor temporal resolution of fish location which generates further underestimation of migration (Hojesjo et al., 2007). It also requires a large sample size over a large study area and yet the tags recovery is very low. District fisheries historical data and records provided limited information about the wetland fish species abundance and catch, greatly attributed to poor record keeping by the local fish dealers and mongers.

1.8 Study area

1.8.1 The Mpologoma riverine wetland

Mpologoma riverine wetland is a part of the Lake Kyoga complex, located at 1º12’ N and 34º40’ E (Figure 1.1). It has tributaries connecting many minor lakes and an extensive permanent swamp which extends up to 102 km upstream from Lake Kyoga. The river discharges into Lake Kyoga over 610 million m^3 of water annually from eastern parts of Uganda. The average annual basin precipitation is about 1,300 mm. The highest precipitation falling over the whole catchment is received over elevated areas (0°42' N / 34°10' E) surrounding Mt. Elgon with an average annual rainfall of over 1800 mm, while the valleys in Iganga and Butaleja receives lesser amounts ranging from 900 – 1180 mm (Kigobe et al., 2011). The catchment has two rainy seasons extending from March to May and late September to November. High evapotranspiration from the swamp vegetation and differences in elevation also exerted a significant influence on rainfall distribution in the area (Figure 1.2). During the study period,

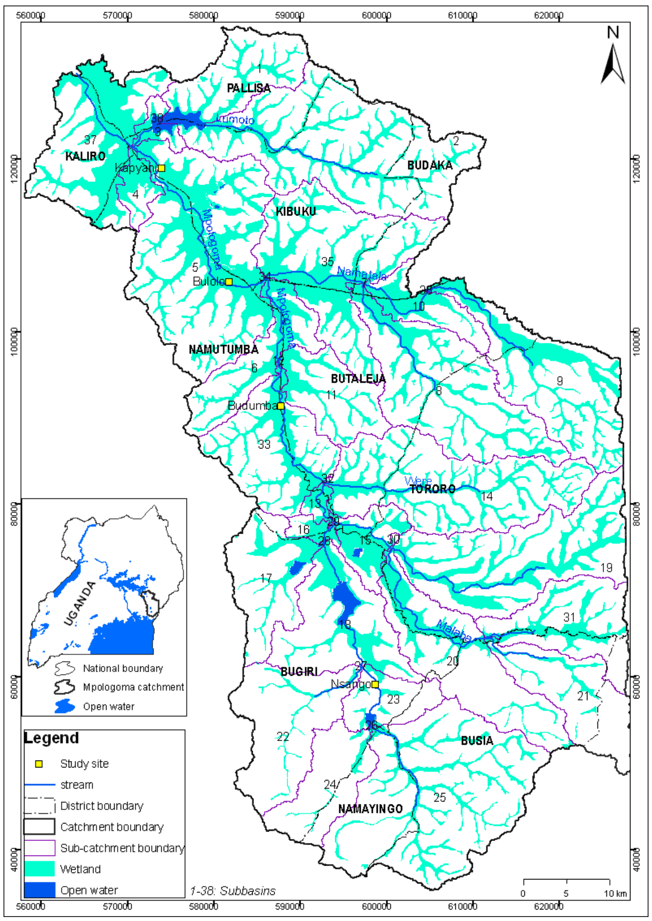

Figure 1.1: Drainage pattern and wetlands in the Mpologoma River catchment in Eastern Uganda.

there was high rainfall variability; the range between minimum and maximum rainfall was often larger than twice the mean. This resulted in the progressively drier climate from east to west making the downstream part of the river potentially vulnerable to both droughts and floods. The maximum temperature range is 27 – 32 ºC and the minimum was 16 – 18 ºC.

The permanently flooded wetland is dominated by papyrus (C*yperus papyrus*), hippo grass (*Vossia cuspidata*) and reeds (*Phragmites*), while seasonal floodplains have less flood tolerant herbaceous vegetation with some trees in the less deeply inundated areas (Ogutu-Ohwayo et al., 2013). The occurrence of these life forms is affected by edaphic features such as the presence of undifferentiated alluvium soils from the black and grey clay river deposits. The brown and grey sandy-loams mainly in the valleys offer lower agricultural productivity compared to the swamp areas with dark clays. The fish species of economic importance in the Kyoga complex include *Oreochromis variabilis, B. docmak, C. gariepinus, C. liocephalus, C. werneri, C. alluaudi, P. aethiopicus, Barbus altianalis, Schibe mystus* and several species of Haplochromines and Tilapia (Vanden-Bossche and Bernacsek, 1990; NaFIRRI, 2007).

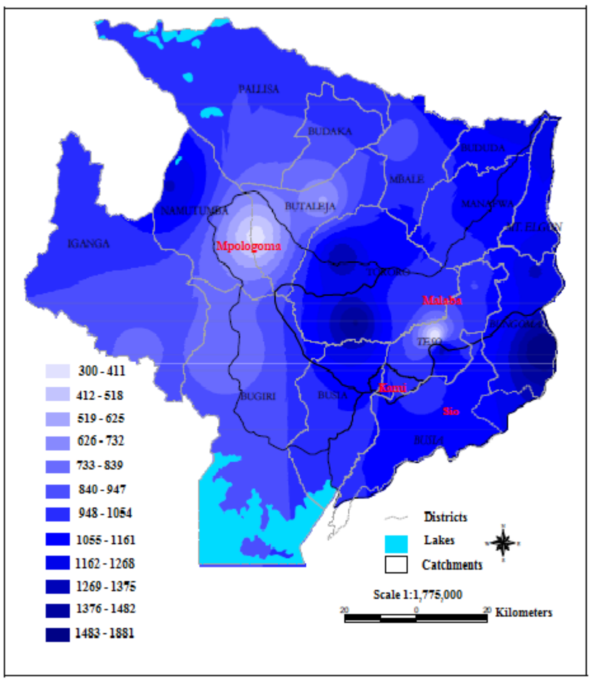

Figure 1.2: Spatial distribution of rainfall in a dry year for selected stations in eastern Uganda (Source: WERM, 2008)

1.8.2 The economic and scientific significance of the Mpologoma riverine wetland

The Mpologoma riverine wetland was previsouly an invaluable natural and socioeconomic resource for the local communities living adjacent to it. Its ecosystem functions and services include natural water purification, water flow, storage and recharge, shoreline stabilisation, micro-climate regulation and biodiversity habitat provision. The wetland is also an important biodiversity hotspot where endemic, endangered, and threatened flora and fauna were found. Large sized mammals in the wetland include semi-aquatic species *Aonyx capensis, Atilax paludinosus, Hippopotamus amphibius* and *Lutra maculicollis* and the swamp dwelling antelope *Tragelaphus spekei* (NEMA, 2006). The wetland complex is also an Important Bird Area (IBA) with over 300 bird species including some endangered bird species; papyrus yellow warbler, shoebill stock *(Balaeniceps rex) a*nd the papyrus Gonolex *(Laniarius mufumbiri*). The riverine wetland supports agriculture, animal husbandry and important commercial fisheries, including several species of tilapias and catfish as well as lungfish. In addition, the fisheries sub-sector around Lake Kyoga supports a large number of people (Ogutu-Ohwayo et al., 2013). Such profitable small scale fishery supply the local market with fish, thus improving the per capita fish consumption in developing countries to 6 kg $person^{-1}$ yr^{-1} although it is far below the world average per capita consumption of 16 kg $person^{-1}$ yr^{-1} (FAO, 2009). In addition, there are areas within the wetland in which agriculture and animal husbandry thrive. The surge in wetland cultivation has lead to a loss of over 14.25% of wetland cover of the eastern Uganda (Egeru et al., 2010). This wetland complex forms an important water source for human consumption, agriculture and livestock and papyrus biomass harvesting. As the human population increases, these use values give rise to conflicting demands that are detrimental to the entire aquatic ecosystem and its dependent fisheries (Torell et al., 2010).

1.8.3 Degradation in the Mpologoma wetland

The effects of climate variability and high population growth with concomitant pressure on ecosystem goods and services particularly in eastern Uganda are probably the main contributors to the increasing wetland degradation. Climate change has made terrestrial land less suitable for rain fed agriculture, necessitating reconsideration of land use decisions (Verburg et al., 2011). Eastern Uganda wetlands were found to have a significant potential for increased agricultural productivity through investments in modern agricultural practices, use of high yielding and disease resistant rice varieties, and development of irrigation infrastructure (WREM, 2008). Consequently, the natural wetland areas continued to be cleared, paving way for increased small scale fragmented irrigation agricultural investments and the small scale rain fed systems. Within the Mpologoma river catchment, Kibimba/Tilder and Doho which are large-scale irrigation rice schemes in Bugiri and Butaleja districts, respectively, were established. There are also informal small-scale irrigation practices in the fringes of the wetland mainly in Namutumba and Pallisa districts. Over 1000 hectares of the wetland has been converted into farm lands (NEMA, 2006). Loss of natural wetland affected not only natural ecosystem functions including fishery, but also led to inadequate fish protein for local consumption. Water levels and quality are affected, leading to profound and adverse impacts on the ecological and hydrological services provided by the wetlands (Simonit et al., 2005).

1.8.4 Management of the Mpologoma wetland

Uganda has an elaborate National Wetlands Management policy and law (MLWE, 2004). This is a legal instrument that provides a mechanism for permitting uses of wetlands and calls for "no drainage of wetlands unless more important environmental management requirements supersede." However, the "no drainage policy" implementation has proved impracticable within Mpologoma river wetland, where the wetland has continually been drained for rice cultivation purposes. The Land Act which provides for the tenure, ownership and management of land, recognizes four types of ownership: customary, mailo, freehold and leasehold tenure (GOU, 2003). Customary tenure is dominant in this catchment and is associated with increasing fragmentation as the number of household members grows (WREM, 2008). The Land Act stipulates that a person who acquires land is required to manage and utilize it in accordance with the existing environmental laws, and any land use must conform to planning laws. However, there is a general lack of coordination of policies related to environmental management and land resources. In remote areas like the Mpologoma wetland which have been marginalised and overlooked by government agencies in the past, local communities do not adhere to the laws on matters of land use and environmental management. In addition, the low penalties to law offenders are partly responsible for intensifying illegal activities within and around wetlands (Banadda et al., 2009). Currently, there is lack of sustainable management plan for the

Mpologoma wetland. There is need for immediate attention by local leaders and policy makers to conserve the remaining intact wetland for sustainability of the *Clarias* fishery.

1.8.5 Study sites

The study sites were located within a network of small vegetated valley bottoms in an undulating landscape, surrounded by Butaleja, Namutumba, Bugiri, Kaliro and Pallisa districts (Figure 1.3). Using the Digital Elevation Model (DEM) of the ArcGIS (version 10.0 Eris$^{@}$), a map of the Mpologoma river catchment was delineated. Land use cover at each site was derived from Landsat ETM images of July 2011, verified by field survey data. Land use classes of 20 polygon hectare area surrounding each site were obtained to identify the variation in land use pattern at the sites (Table 1.1). Based on this information, the study sites profiled below were selected to capture different levels of disturbance, ranging from least disturbed, moderately disturbed with small scale farming system to highly disturbed site with mechanised farming systems, within the wetland.

Site 1: Budumba

This was considered the least disturbed site with intact natural wetland, located at 0º83'N and 33º79'E. *Cyperus papyrus* was dominant at this site, with patches of less than 3m deep water enabling canoes to pass through the swamp (Plate 1.1). Floating papyrus mats, aquatic grass and rooted floating leaved water lilies were common along the river channel in the middle of the swamp. At the edge of the swamp were small gardens (< 1 acre) of vegetables and yams.

Site 2: Mazuba

This was also considered a least disturbed site with intact natural wetland, located at 0º97'N and 33º74'E. The site was characterised by healthy papyrus vegetation with patches of hippo grass (*Vossia cuspidata*) at the fringe of the wetland. The water pools were less than 3 m deep, allowing fishermen movement about the wetland. Along the river channel deep inside the wetland were water lilies (*Nymphaea lotus* and *N. caerulea*) and water cabbage (Plate 1.1).

Site 3: Kapyani

This was considered a moderately disturbed site, located at 1º09' N and 33º64'E. It was associated with small scale rice and maize farms of 2 – 6 acres inside the wetland, using low implement agriculture and rain-fed lowland systems (MAAIF 2009). During the wet season of April to June when the wetland was flooded, the wetland gardens were abandoned and natural vegetation re-established (Plate 1.2). In contrast, during water recession, farmers clear the natural wetland vegetation to plant rice and maize (Plate 1.3).

Site 4: Nsango

This was considered a highly disturbed site, located at 0º58'N and 33º96'E. It was associated with a large scale rice scheme occupying over 3,000 hectares of the wetland (Plate 1.4). It was characterised by large scale rice farming utilising chemical fertilisers, rain-fed lowland and mechanised irrigation systems. There are also small scale rice farmers alongside the remaining natural wetland for paddy rice growing. Examples of the land use patterns of the study sites are provided in Table 1.1 below.

Table 1.1: Land use categories based on percentage cover of 20 ha area at the study sites in the Mpologoma River wetland, Uganda, July 2011.

Land use	**Mazuba**	**Budumba**	**Kapyani**	**Nsango**
Man made type				
Built up area	0	0.5	1.5	18.1
Subsistence farms	0	8.7	55.3	16.2
Large scale farmland	0	0	0.0	16.2
Subtotal cover	0	9.2	56.8	50.5
Natural type				
Permanent wetland	100	90.6	31.2	18.5
Temporary wetland	0	0	10.2	5.6
Woodland	0	0.2	1.4	21.1
Grassland	0	0	0.5	4.3
Subtotal cover	100	90.8	43.2	49.5
Level of disturbance	Intact wetland	Less disturbed	Moderately disturbed (with small scale farms)	Highly disturbed (Large scale rice scheme)

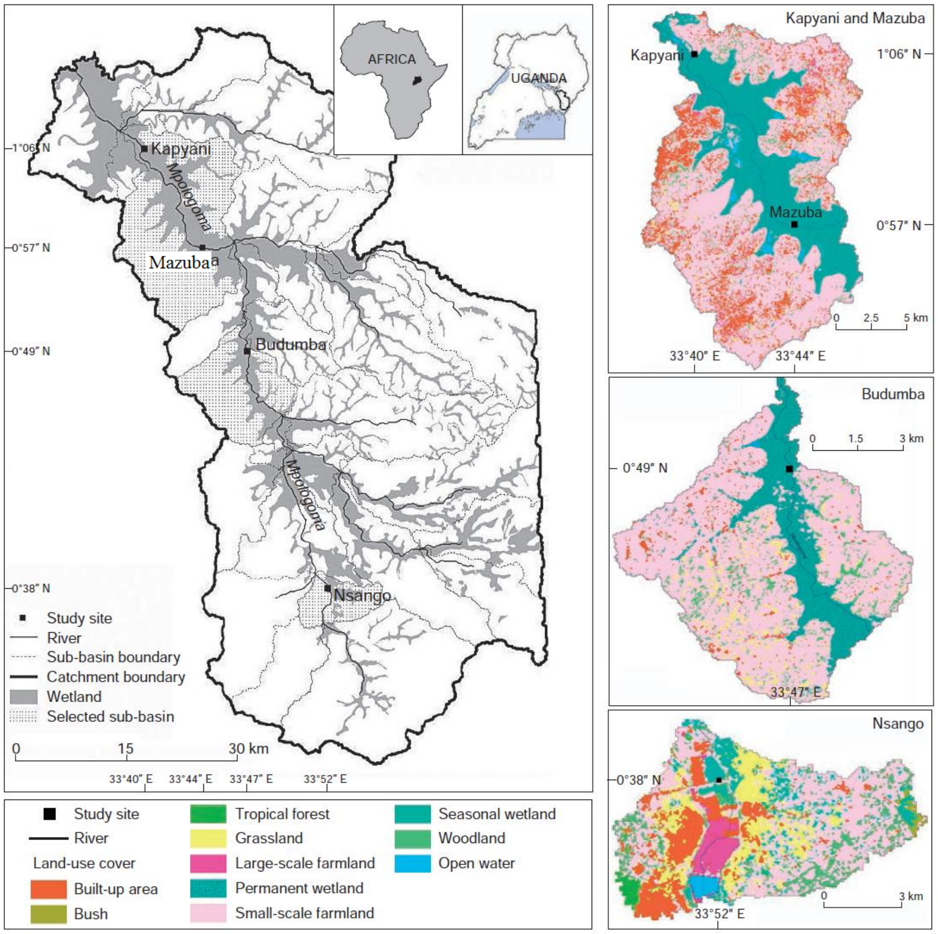

Figure 1.3: Land use cover of three subbasins surrounding the study sites in the Mpologoma river wetland

Plate 1.1: Natural intact wetland at Budumba (a) and less disturbed wetland at Mazuba site (b) in the Mpologoma river wetland

Plate 1.2: Extensive wetland clearing of papyrus for mat making and farming (a) for rice growing (b) when water recedes after flooding at Kapyani site.

Plate 1.3: The Mpologoma river bank left bare during the dry season in (a) and flooded river basin during the rainy season allowing macrophytes to decolonise the area (b) at Kapyani site.

Plate 1.4: The river channel with polluted water coming from Tilda large scale rice scheme (a) and rice out growers in the wetland (b) at Nsango site

1.9 Structure of the thesis

The thesis consists of eight chapters, five of which represent the specific objectives of the study. Chapter one describes the statement of the problem that provided the incentive of the study, objectives of the study, the description of the Mpologoma riverine wetland and the highlights of the differently disturbed study sites. The choice and description of the study sites in chapter one was applied to the subsequent chapters, while the research methods to address each objective were describe in each respective chapter. Chapter two represents an evaluation of the theoretical background of the study focus, showing apparent observations and understanding of the wetland fisheries and land use impacts, *Clarias* species biology and socio economics of the small scale fisheries in relation to the study. Chapters three and four address the ecology of endemic small *Clarias* species in relation to land use in the wetland through the assessment of small *Clarias* habitats, movement patterns and life history parameters at the differently disturbed study sites in the Mpologoma riverine wetland. Chapters five and six represent the variation in production of small *Clarias* species catch with the changing land use in the Mpologoma riverine wetland in 2012 and the prediction for small *Clarias* species catch the last three decades respectively. Chapter seven addresses the human link to the *Clarias* species through a socio-economic survey of the small scale fishery. Lastly, chapter eight gives the major conclusions and recommendations drawn from the whole study.

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CHAPTER TWO:
GENERAL LITERATURE REVIEW

2.1 Introduction

In exploring the impacts of land use change on small *Clarias* species and small scale wetland fishery, many studies on the wetlands fundamental services and land use change impacts on fish species ecology and production were examined. The implicit assumption in the review of these studies was that land use changes negatively affect the wetlands systems and the associated fisheries, and the individual and population of certain fish species, particularly the endemic small *Clarias* species. This chapter provides the theories and concepts of the research topic and enables appreciation and comprehension of the relationships between land use and change and fisheries resource focusing on *Clarias* species. The review is split into six major sections: (i) wetlands fisheries; (ii) wetlands conversion to farmland; (iii) *Clarias* species description, ecology and abundance; (iv) assessment of the impacts of land use change on fish production; (v) socio-economics of small scale fisheries; and (vi) conceptual framework of the study.

2.2 Wetlands fisheries

African wetlands are diverse and include freshwater and salt marshes, mangrove forests, forested freshwater swamps, lactustrine and riverine flood plain wetlands (Chapman et al., 2001; Jordan et al., 2011). The most common wetland type in Uganda are valley bottom papyrus marshes, mostly found bordering rivers and lakes, but there are others such as high altitude bogs, flood plains and swamp forests (Banadda et al., 2009). Wetlands occupy about 13% of the country's total area. The Kyoga Basin has the largest expanse of wetlands in Uganda (Ogutu-Ohwayo et al., 2013). Large portions of these wetlands are dominated by monotypic stands of papyrus that can occur in two distinct functional types: rooted and floating mats consisting of interweaved roots and rhizomes of the papyrus (van Dam et al., 2007). In East Africa, wetlands provide many valuable functions and services such as water quality improvement through nutrient removal, ground water recharge, grazing land, plants biomass for various uses, habitat for fisheries, aquaculture production as well as provision of nutrient rich sediments for agriculture (Kipkemboi et al., 2007; Jordan et al., 2011). They have important hydrological and ecological functions as they retain water and release it slowly, trap silt, provide refugia, and serve as nursery and feeding grounds for fish and other organisms (Chapman et al., 2003; Naigaga et al., 2011). Agriculture may be practiced along the river banks, which are good sites for growing rice, sugarcane and vegetables.

Wetlands in Uganda play an important role as small scale fisheries and in the conservation of fish biodiversity of open waters (Balirwa et al., 2003; Naigaga et al., 2011). Despite the limited diversity of fishes within papyrus swamps and other heavily vegetated wetlands, these habitats contribute to the maintenance of fish faunal structure and diversity. Particularly, rocky and shallow in-shore habitats with fringing macrophyte cover are important refugia for many endangered indigenous fishes such as the cichlids, protecting them from Nile perch predation (Balirwa et al., 2003; Chapman et al., 2003; Naigaga et al., 2011).The heavily vegetated wetlands serve as structural and low-oxygen refugia for fishes that can tolerate such conditions, particularly the catfish and lungfish, and African cyprinid (*Barbus neumayeri*) (Chapman et al., 1999). The wetland fisheries play an important role in rural livelihoods in Uganda through subsistence, commercial and recreational fishing activities (Arthington et al., 2004). In tropical inland fisheries, almost the entire catch is consumed with practically no by-catch (FAO, 2000). The species diversity of wetland fisheries satisfying varied consumption preferences as well as providing 80% of dietary protein and micronutrients to riparian communities (Thilsted and Roos, 1999; Welcomme, 2003). These small-scale fisheries provide nutritional security to remote areas that lack adequate supplies of animal protein and sustain the livelihood of landless fishers who can no longer survive by fishing in depleted rivers and other natural freshwater bodies (Vass et al., 2009). However, due to their contribution to livelihoods, wetlands are facing increasing divergent human demands implying that wetland degradation and food security issues are linked (Nguyen-Khoa et al., 2005).

The increasing human population in Uganda has led to extensive degradation of wetlands by human activities such as habitat modification for agriculture, settlement and waste disposal, among others (Banadda et al., 2009). This leads to the deterioration of the fish habitats and yet, the productivity and diversity of fisheries is closely linked to the structure and functioning of aquatic ecosystems (Nguyen-Khoa et al., 2005). In the past, Uganda's fishing industry had over 300 endemic fish species, but unsustainable fishing practices and deterioration of the aquatic systems has greatly reduced the number of commercial fish species (Reardon and Chapman, 2008). Hydrologically, the Lake Kyoga wetlands are connected to Lake Victoria system. The native fish community in the Lake Victoria and Lake Kyoga wetlands was dominated by haplochromine species, the catfishes (*Clarias gariepinus* and *Bagrus docmak*), two endemic tilapines, cichlids and 38 species of non-cichlids (Goudswaard et al., 2002). After the introduction of the Nile perch (*Lates niloticus*) and *Tilapia* species in open waters and continuous degradation of the aquatic systems, over 50% of the species reported rare in Lake Victoria and Kyoga are now found in wetland refugia (Chapman et al., 2003). However, increased fishing pressure on the wetland species such as *B. docmak, C. gariepinus,* African lungfish (*Protopterus aethiopicus)* and haplochromine cichlids (Balirwa et al., 2003) has led to the decline of wetland fisheries. Wetland degradation could also be decimating the populations of other endemic fish species including the small *Clarias* species.

In order to mitigate the impacts of declining wetland fishery, it is vital to develop an in-depth understanding of the factors and processes that determine aquatic diversity at different spatial scales (Ibanez et al., 2007). Through such knowledge, prediction of the effects of current environmental issues such as global climatic changes, habitat loss and fragmentation effects on the wetlands biodiversity can be achieved. Little is known about the patterns of assemblage composition and distribution within and among riverine fishery in tropical systems under natural conditions (Lewis et al., 2006; Melcher et al., 2011). In temperate systems, the local fish assemblage richness usually increases along the upstream–downstream gradient which is attributed to downstream increase in habitat size, habitat diversity or both (Lewis et al., 2006). The fish richness is measured as a function of stream width, volume, stream discharge, stream order, drainage basin area, stream depth, current velocity and substrate composition. A few studies conducted in tropical systems reveal patterns that generally agree with patterns from temperate regions but are most often spatially limited to a single stream or river (Ibanez et al., 2007). Therefore, there is need to assess ecological changes in wetlands resulting from human interventions.

2.3 Wetlands conversion to farmland

Change in land use from natural vegetation to farmland directly influences wetlands' biological communities, physicochemical properties, channel hydraulics, pool-riffle complexity and substrate composition (Wang et al., 2006). Minimally disturbed systems are at a dynamic equilibrium that typically permits internal adjustment of factors without producing rapid change in structure. The biota in such systems are adapted to dynamic equilibrium conditions and natural disturbance levels (Lipsky, 1992). When anthropogenic disturbances break the dynamic equilibrium among catchment, riparian and stream conditions, fish tend to re-establish new equilibria with their environments. The new equilibria may be generally the degraded physical chemical habitat and changed biological assemblages. The fish may disperse to access remote resources, escape local habitat stressors, colonize adjacent habitats, or migrate to specific habitats that are essential to a specific life stage (Diana et al., 2006). Small scale irrigation schemes where the wet season rice crop is cultivated as a largely rain fed crop and have little land engineering, cause less impacts on fish compared to large scale irrigation schemes (Nguyen-Khoa et al., 2005).

Wetlands are fertile areas and this has attracted many people to grow many crops such as yams, sugarcane, maize, rice and sweet potatoes in them. In Uganda, wetlands particularly in eastern part of the country have been increasingly converted to rice cultivation. The Uganda national records indicate that from 1990 to 2004 the area under rice production increased from 39,000 to 80,000 hectares, with an average of 3000 hectares brought under cultivation annually (Musiime et al., 2005). Large scale irrigated agriculture has been crucial in enhancing food production to feed the globally increasing population. However, this has had substantial impacts on wetlands' ecological processes (Davies et al., 2006). Irrigated agriculture in wetlands alter stream hydrology and geomorphology, and enhance erosion caused by removal of rooted riparian vegetation (Nguyen-Khoa et al., 2005). Changes in macrophytes cover and assemblage structure affects wetland fishery as this compromises its provision of structural complexity for predation avoidance, foraging and reproduction of the fish species (Scarabotti et al., 2011). Rice fields sustain a rich aquatic biodiversity, including unique and threatened fish species (Bambaradeniya and Amerasinghe, 2003). This is attributed to resilience of some fish species to perturbations and other biological attributes (Roger et al., 1991). However, extensive conversion of wetlands into irrigation schemes has negative impacts on fishery since fish are directly removed from wetland systems once they enter into an irrigation system (Baumgartner et al., 2009). When many fish individuals are consistently lost to irrigation diversions on an annual basis, the size and age structure of main-channel fish populations may be skewed towards larger and older fish with stronger swimming abilities. Many fish species cannot survive in irrigation fields for extended periods because of insufficient habitat or poor water quality (King and O'Connor, 2007).

Anthropogenic disturbance influences on aquatic systems have been studied intensively for the last 30 years (Nguyen-Khoa et al., 2005). Several authors have discussed the relative impact of different environmental variables on floodplain fish assemblages in tropical floodplain systems, at temporal and spatial scales of investigation (Arrington et al., 2005; Arrington and Winemiller, 2006). However, there is scarcity of data for most tropical wetlands which precludes accurate prediction of effects of human-induced perturbations on these systems. Indeed, existing models of the structure of riverine fish assemblages are still largely based on patterns observed in temperate rivers (Tejerina-Garro et al., 2005; Ibanez et al., 2007). Traditionally conversion of wetlands into rice fields enhances economic value through increased food productivity and sometimes may have a positive impact on biodiversity, but with expansion and intensification of rice growing, the overall ecological functions of wetlands may be degraded (Nguyen-Khoa et al., 2005).

Fish constitute an integral part of biota in the rice fields adjacent to natural wetlands, especially in the tropics (Fernando, 1996). Fisheries productivity is likely to be maintained as long as ecological connectivity with perennial habitats is sufficient to allow colonization by fish (Bambaradeniya and Amerasinghe, 2003). The different irrigation water management and farming practices within irrigated rice systems may have a greater impact on their fisheries productivity and this needs to be investigated (Nguyen Khoa et al., 2005). Studies on fresh water fish species in the rice schemes in Sri Lanka, Thailand and Philippines by Fernando, 1996 and Halwart et al., 1996 indicate that fish diversity was generally lower than in natural marshlands than rice fields. Fernando (1980) also suggests that the rice field agro-ecosystems are essentially extensions of natural swamps and should reflect the diversity of these habitats. In East Africa, the effects of agriculture on Lake Baringo fishery has been studied, emphasizing the decline of lungfish productivity with increasing agriculture (Aloo, 2002). The robustness of aquatic ecosystems and their biological assemblages determines the fish resilience to variable hydrological conditions and short-term human pressure (Ferreira et al., 2007). The above attributes make the ecology of the particularly neglected small *Clarias* fish species in the wetlands which are linked human–environment systems to be understood for a sustainable and proper management.

2.4 Description, Ecology and abundance of *Clarias* species

2.4.1 Description of *Clarias* species

Clariidae are air breathing catfishes, naturally occurring in wetlands and highly diverse in Africa, where 12 genera with 74 species are known (Teugel, 2003; Offem et al., 2010). They are characterized by an elongate body, four pairs of barbels, and the unique presence of a suprabranchial respiratory organ, formed by arborescent structures derived from the second and fourth gill arches (Greenwood, 1961; Teugels and Adriaens, 2003). Together with the elongated body, a whole set of morphological changes are observed, such as reduction and loss of the adipose fin, fusion of the dorsal, caudal and anal fins, reduction of the pectoral and pelvic fins, reduction of the eyes, reduction of the skull bones and hypertrophy of the jaw muscles (Devaere et al., 2007). The freshwater clariids are one of the 37 catfish families within the order Siluriformes (Sabaj et al. 2004). Although some species are distributed in America, Europe and throughout Southeast Asia, their diversity is greatest in Africa (Teugels 1996; Teugels and Adriaens 2003; Devaere et al., 2007). The endemic *Clarias* species are mostly small, reaching 10 to 30 cm at maturity, and are widespread in African rivers and wetlands (Ngugi et al., 2009). *C. gariepinus*, *C. alluaudi*, *C. werneri*, and *C. liocephalus* are major clariid species within the East African wetlands (Musiba and Nkwengulila, 2006). Among the small Clariids, *C. liocephalus* is a senior synonym of *C. alluaudi* and *C. carsonii* according to Teugels (1986).

2.4.2 Ecology of *Clarias* species

Ecological studies have focused on the distribution and classification of small *Clarias* species in East Africa (e.g. Teugels, 1986; Chapman, 1995) and on *C. liocephalus* feeding behaviour in wetlands of south-western Uganda (e.g. Yatuha et al., 2012). Generally, it has been revealed that the small clariids are mainly stream fish, vary dramatically in size, life traits and habitat use patterns due to spatial and temporal variation along the rivers (Schlosser, 1991). Recent advances in the monitoring of surface waters have shifted from measurement of physicochemical parameters to the use of biological indicators as early warning signals of ecosystem degradation. Fish possess a suite of advantages which have made them to be widely used for measuring a wide range of human impact types on aquatic environments (Barbour et al., 1999). By studying the fish population dynamics using biological metrics and examining their ecological preferences and pollution tolerances, the presence, absence and proportionate abundance of fish can be used to indicate the quality of physical, chemical and biological conditions of aquatic environments in which they live (Raburu and Masese, 2010). Some studies have been done on habitat use and reproductive strategy of large clariids; *C. gariepinus* and *C. anguillaris* (Greenwood, 1974; Offem et al., 2010). Fish life history traits are related to ecosystem processes and ecosystem stability through resistance and resilience (response traits) (Villeger et al., 2010). Therefore, there is a fundamental challenge to establish quantitative links between variation in life history traits of fish species and the land use changes determining the spatial and temporal variations of these traits. The life history traits that are of major concern to many fisheries managers include length and weight measurements which lead to length-weight relationships and fish condition factor. The habitat use, movement pattern and fecundity are essential in evaluating the survival of fish species in the highly changing aquatic systems. This formed the basis on which life history parameters, including length-weight relationships, condition factor and reproduction of small *Clarias* species in the rice growing the Mpologoma wetland wereinvestigated. Each of these life history parameters has unique importance to fisheries science and varies with environmental conditions in different ways. Studies of length, weight, reproduction strategies and feeding habits provide a basis for estimating the production potential of a fishery in any given habitat (Yatuha et al., 2012).

(a) Length–weight relationships

Length–weight relationships and population dynamics of fishes are studied with the major objective of rational management and resource conservation, but are often not available when needed (Laleye, 2006). Similarly, morphological comparisons can be made between populations of the same species or between species. Length–weight data are often used as an indicator of fatness, general well being, gonad development of fish, and are useful for between region comparisons of life histories of a specific species and the state of health of a population (Le Cren, 1951; Wootton, 1990; Ecoutin et al., 2005). Many studies on fisheries are based on statistics expressed either in length or in weight and the length–weight relationships are mainly used to derive the *b* value. The *b* value is an indicator of the physiological condition of the fish and it varies seasonally in response to seasonal variations in environmental condition and changes in the fish wellbeing (Ecoutin et al., 2005). There is little information on length–weight relationships for many species and their relationship with environmental variable and more particularly in relation to small-scale fisheries of Sub-Saharan Africa (Ecoutin et al., 2005). Furthermore, the length-weight relationship (LWR) and the *b* value can be influenced by fishing pressure that excessively crops the adults under unstressed condition (Okogwu, 2011). LWR also change according to fish, sex, maturity, season and even time of day (because of changes in stomach fullness) (Laleye, 2006).

In general and despite the many variations in fish forms between species, *b* is close to 3, indicating that fish grow isometrically but values significantly different from 3 indicate allometric growth (Ecoutin et al., 2005). LWR with *b* values significantly different from 3.0 are often associated with narrow size ranges of the specimens examined; such LWR should be used only within the respective size range (Ayoade and Ikulala, 2007). The estimated *b* value by the non-linear regression analysis of the length-weight relationship of *C. gariepinus* has been significantly below three, which shows that this catfish exhibited allometric growth pattern (Okogwu, 2011). Morphometric relationships between total and standard lengths for 50 fish species in Sub Saharan Africa have been analysed by Layele (2006). These included *C. gariepinus, C. ebriensis, Synodontis schall, S. nigrita, Lates niloticus, Tilapia zillii, Bagrus docmak, Label senegalensis, Barbus macrops, B. chlorotaenia, Oreochromis niloticus* and *Ctenopoma petherici*, among others (Layele, 2006). A declining trend of maximum growth in fishes as compared to their known maximum lengths has been observed resulting from changes in aquatic ecosystem health (Dubey et al., 2012). The LWRs of small endemic *Clarias* species which are also significant to small scale fisheries of eastern African wetlands have not been analysed. Therefore, assessing the length-weight relationship of small clariid species should serve as the background knowledge of these species and a basis for comparison with populations of other aquatic systems that have been subjected to perturbations of various intensities.

(b) Condition factor

The well-being state of the fish can be inferred with a condition factor and it is used for comparing the fatness or well-being of fish (Welcomme, 1979; Froese, 2006). Fish specimen of given a length exhibiting higher weight are said to have a better condition (Ayoade and Ikulala, 2007). Condition is variable and dynamic in individual fish within the same sample. The mean K for the three cichlid species was greater than one, and this showed that these fish species were above average condition within the lake (Ayoade and Ikulala, 2007). The observation that 62%

of the samples examined had condition factor above mean showed that the majority of fish in the population are in excellent condition (Offem, 2010). An average condition factor of each population varies seasonally and yearly in between the sex, developmental stages of the gonad, especially the ovary affect the weight considerably (Welcome, 1979; Farzana and Saira, 2008) Condition factor has been used as an index of growth and feeding intensity (King, 2007). During the rainy season, increased food availability and the lack of any energy consuming processes besides immediate metabolic needs such as locomotion and maintenance result in high K values (Leonardos et al., 2009). Different values of K of a fish indicate also the degree of food sources availability of some species. These relationships are also an important component as they provide important clue on climate and environmental changes on fish ecology (Mahmood et al., 2012).

Condition factor has also been closely linked with reproductive cycle for fishes in other water bodies (Leonardos et al., 2009; Mahmood et al., 2012). Studies have shown that condition factor is highly correlated with GSI (Ayoade and Ikulala, 2007). For example, the mature females of three cichlid species had their maximum values of 'K' during rainy season known for triggering spawning activities in many fish. The accumulation of fats and ripe gonads carried by the mature adult females of *C. gariepinus* attributed higher weight of individual fish and thus the high K values (Offem et al., 2010). However, as the stored energy is consumed during spawning, the condition factor declines. Fishes at periods before reproductive disturbances begin to show a marked departure from the law, and that changes arising from difference of season affect fishes at different sizes (Froese, 2006). The assessment of condition factor is usefull for comparision of life histories of specified fish species between different regions (Laleye, 2006). Therefore, comparison of condition of small clariids at the differently disturbed sites would give an indication on the fish well being in the wetland.

(c) Reproduction strategies of *Clarias* species

These are small fish species expected to have high fecundity which is a survival strategy for living in high variable habitats (Winemiller et al., 2008). Research on other small *Clarais* species has shown that these fish produce high number of eggs. For instance, the fecundity of *C. ulbopunctutus* which also grows to a maximum of 30 cm, ranged from 1974 to 9310 oocytes in river Anambra, Nigeria (Ezenwaji, 1998). Fencudity varies with seasons. A feature of tropical flood river systems having a bearing on reproduction and environmental factors is the alternation of the flood phase with the dry phase (Welcomme 1985, Ezenwaji 1998). During the flood phase, the floodplain is inundated by local rainfall and/or overspill from the river channel, and many fish species breed in the floodplain. At this time, floodplain spawning grounds of clariids generally have abundant and varied food materials and are virtually predator free (Bruton, 1979; Welcomme, 1985), thus providing emerging fish larvae a conducive environment for development and growth. The dry phase is characterized by intensive agricultural and fisheries activities (Ezenwaji, 1998). Therefore, the reproduction strategies of many small *Clarias* species comprise of breeding guilds of the non-guarders and the egg-scatterers which await suitable environmental conditions before spawning. Gonad maturation is associated with increasing water levels, temperature and photoperiod, and very high fecundity (Teugels, 2003). Catfishes rely on rainfall patterns and water quality as triggering factors for spawning migration and breeding in the riverine environment (Rinne and Wanjala, 1983). During the dry seasons, they survive due to their accessory air breathing organs (Bruton, 1979; Clay, 1979). Although some field studies record ripe females and breeding fish, definite spawning sites and the entire breeding habits of small *Clarias species* have not been determined (Greenwood, 1974). Rinne and Wanjala (1983) studied the maturity, fecundity and breeding seasons of the major catfishes in Lake Victoria. The seasonal fluctuations in the weights and fecundity of the fish species suggest a number of interrelated factors such as changes in the behaviour of the fish, fishing activities, rainfall pattern and, recruitment and migration patterns as well as land use changes along rivers (Laleye et al., 2006). With environmental degradation, variations are expected with each life history strategy. Efforts to conserve and propagate these *Clarias* species through fisheries regulation and fish breeding are hindered because of the limited information available on the ecology of these species in African waters (Offem et al., 2010).

Absolute fecundity of clariid catfishes ranges between 5,515 and 650,625 eggs (Gaigher, 1977; Abayomi and Arawomo, 1996; Offem et al., 2010). These authors suggest that most tropical fishes are adapted to breeding at the onset of rains, and the rising flood thus allowing the juveniles to take full advantage of the flooded banks for feeding while protected from predation. Peak season in fecundity of these species which coincides with onset of rains and the rising flood has also been observed by Offem et al. (2010). The fecundity of the catfish ensures a rather tenuous relationship with the total length of the fish (Ezenwaji, 1998). A comparison of total length and fish weight of *C. gariepinus* and *C. ulbopunctutus* in West Africa gives a more accurate relationship with fecundity (Ezenwaji, 1998; Offem et al., 2010). This is in agreement with work done on *C. gariepinus* in South Africa that stated that fecundity increased exponentially with total length (Yalcin et al., 2001). The variation in fecundity is one strategy used to maximize fitness of these species in habitats with strong seasonal variation in environmental quality and food availability (Winemiller et al., 2008).

As a measure of reproductive success of a fish community, reproduction function metrics have not been commonly used in Africa (Raburu and Masese, 2010) owing to lack of information on the reproductive ecology and spawning behaviour of most African fishes. Most of these research works are limited to the reproductive biology of *C. gariepinus* and to date no work has been undertaken on the ecology of *C. anguillaris* in Nigeria (Offem et al., 2010) and other small *Clarias* species in tropical Africa. In this study, the assessment of reproduction of small *Clarias* species is expected to elucidate the potential of the changing wetland habitat to support growth and development of the catfishes.

(d) Habitat use and movement patterns of wetland fishes

Evaluating habitat use by fish is crucial in understanding those factors that influence their distribution and resource use. Habitat selection studies, in general, attempt to determine habitat use in relation to its availability (Austin, 2007; Kadye and Booth, 2013), which in turn depends upon spatial and temporal resource availability (Gillies et al., 2006). Habitat use by fish is known to vary with prey abundance, habitat availability, presence of predators and varying environmental conditions (Kadye and Booth, 2013). Several studies (e.g Gillies et al., 2006; Hansen et al., 2009) have also shown non-proportional use of certain habitats in response to disproportionate availability of influential resources. Within invaded freshwater habitats, information on habitat use is essential as non-native invaders have the potential to influence both resource availability and the distribution of native species (Kadye and Magadza, 2008).

Catfishes are highly mobile and their movements and habitat use within their natural range are known to be driven primarily by foraging behaviour and reproductive biology (Kadye and Booth, 2013). In East Africa, the extensive dense wetlands dominated by papyrus (*Cyperus papyrus*) and *Miscanthidium violaceum* (Chapman et al., 1999) offer conducive habitats for many air breathers (*P. aethiopicus*, *Clarias* spp. and *Ctenopoma muriei*) and also to some water-breathing fishes such as the Haplochromines (Chapman et al., 1999). These large swamps which are characterized by chronically low oxygen conditions may not limit the dispersal of air breathing species such as the small clariids which coexist in wetland habitats (Teugels, 1986). The utilisation and dispersal within wetland habitats is likely to be limited by the spatial and temporal patterns of variation in the land uses. With the fluctuations in the area of available habitat due to either natural or anthropogenic causes like agricultural activities, trade-offs in life history traits play key roles in maintaining this community (De Angelis et al., 2005). As vast areas of wetland are re-flooded each year, opportunistic fish species disperse into and exploit those areas first, while other species appear to dominate more permanently inundated areas of wetland. It has been found that species that fully exploit more stable areas have higher reproductive and (or) survival rates in long hydroperiod areas, and that they are slow to disperse (De Angelis et al., 2005).

Comparison of habitat utilization on a temporal scale in Glen Melville Reservoir, eastern South Africa, showed that the invasive African catfish *Clarias gariepinus* were associated with the river mouth that had rock substrate while few other catfish were in the upper reaches during rainy summer season (Kadye and Booth, 2013). This suggests that shallower habitats are most important for catfish compared to deeper habitats as in Bruton (1979a) assessment of catfish movement. Bruton (1979b) observed that during rainy season, catfish preferred shallow inshore littoral habitats both for breeding and feeding. Within these shallow habitats, individuals display different foraging strategies such as social hunting and surface feeding on floating debris, terrestrial insects, plankton and crustaceans, and organized pack hunting for their preferred fish prey. The permanently flooded wetland habitat could provide the ideal habitat for feeding and spawning for native species such as the small *Clarias* species of the Mpologoma riverine wetland. *C. gariepinus* movement pattern and use of river mouth habitats in the Glen Melville reservoir infer widespread impacts to catfish within the invaded mainstream sections (Kadye and Booth, 2013). The small clariids in Mpologoma wetland could portray similar patterns inferred as the homing behaviour of the catfish, *Clarias gariepinus*.

Localized movements in catfishes have been related to high use of particular habitats where fish would typically exhibit multiple displacements within a small but structured habitat (Daugherty and Sutton, 2005). Habitat use and site fidelity within such defined areas typically follow a diurnal pattern that involves high activity associated with intensive search for prey and low activity in areas of refuge when the catfish are less active (Carol et al., 2007). Movement studies on sharp tooth catfish, nonetheless, indicate both diurnal and nocturnal peaks in response to feeding and risk avoidance behaviours, with its predation impact being high in deep habitats during the day and in shallow areas during the night (Bruton, 1979a; Merron, 1993). Territorial behaviour appears to be common for most catfish as they maintain their home ranges by exhibiting localized movements either within single or multiple localities (Carol et al., 2007). Utilizing defined areas within the invaded habitats shows that catfish impact may be associated with particular habitats, especially those that are likely to be preferred by its potential prey (Kadye and Booth, 2013). In comparison to long-distance movements, short-distance movements define the home range size and utilization distribution densities for catfish. The short distance patterns show that the movements vary from localized relocations on both small and broad spatial scales within single habitats, to localized movements within multiple habitats, which suggest feeding behaviour movements (Daugherty and Sutton, 2005). Hocutt (1989) indicated that local movements were the dominating mode of behaviour in sharp tooth catfish, while Bruton (1979b) suggested that catfish concentrated and intensively searched for prey within a defined area especially where it encounters preferred food sources within lentic habitats. Similar patterns have been inferred for the homing behaviour of the catfish within lotic habitats, such as in the lower Shire River, Malawi (Willoughby and Tweddle, 1978).

In the determination of movement patterns of fish populations, widespread methods such as the use of hydro acoustics, telemetry and microchemistry are used despite their serious biases when their stringent assumptions are not met (Lucas and Baras, 2000). Capture–mark–recapture (CMR) techniques can provide more direct estimates of demographic variables with less bias and can potentially provide good estimates of population abundance and migration repeated observation of individuals (Hojesjo et al., 2007). Some studies have shown that T-anchor tags are generally well retained in the short term (160 days), therefore the method requires a great deal of resources and field time (Lucas and Baras, 2001). The telemetry data should be accurate within 2 metres (Hojesjo et al., 2007). But because migration patterns are inferred from recaptured fish only, and fail to make account of missing fish which may have died, emigrated beyond the limits of sampling area, the method suffers from poor temporal resolution of fish location which generates further underestimation of migration (Hojesjo et al., 2007). Telemetry studies have shown localized home ranges and territoriality in some catfish species such as the flathead catfish (*Pylodictis olivaris*) in the St Josephs River, Michigan (Daugherty and Sutton, 2005), and the non-native catfish (*Silurus glanis*) in the Flix Reservoir, Ebro River (Carol et al., 2007). In tropical floodplain systems, fish may have a very high likelihood of recapture when crowded in small pools during the dry season than when they disperse in the rainy season (Lucas and Baras, 2001). Nevertheless, understanding habitat use and movement patterns of individual *Clarias* species populations is an important aspect of their ecology given the current rate of ecosystem change.

2.4.3 Assessment of the effect of land use change on fish production using modelling

The integrated management and adequate allocation of water resources between different water uses under changing conditions of land use and climate are major challenges which many societies already face or will face during the next decades (Stehr et al., 2008). Land-use change over the years is one of the factors positively correlating with deterioration in water quality of many aquatic systems (Kimwaga et al., 2012). The analysis of land-use and climate change impact on riverine systems' hydrology can be addressed by model applications (Haverkamp et al., 2005). The well-known models that are commonly applied at the basin scale include the Hydrologic Simulation Package Fortran (HSPF; Holtan and Lopez, 1971), the Système Hydrologique Européen (SHE; Abbott et al., 2001), the Soil and Water Assessment Tool (SWAT; Arnold et al., 1998) and the Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS; HEC, 2000). These models, which produce hydrographs as well as water yields and provide possibilities for continuous simulation, can be operated at different time steps, and have varying numbers of input parameters (Stehr et al., 2008). However, the practical applications of these models can be limited by the availability of input data which restricts the choice of models.

Most applications of the above models correspond to case studies from the developed world where data availability may be very different from that typically encountered elsewhere (Stehr et al., 2008). The continuously growing pressures on the African water resources, together with the need to preserve its unique aquatic biodiversity, make it necessary to have a better understanding of aquatic systems hydrology and their sensitivity to climate variability and changes in land use. The SWAT model has been widely used to evaluate effects of land management practices on water, sediment and chemical yields of many aquatic systems (Arnold et al., 1998; Arnold and Fohrer, 2005). It is a process-based and spatially semi-distributed hydrological and water quality model designed to calculate and route water, sediments and contaminants from individual drainage units (sub-basins) throughout a river basin towards its outlet (Arnold et al., 1998; Neitsch et al., 2002). It is a versatile tool that has been used in many parts of the world to predict the impact of management practices on water, sediment and agricultural chemical yields in large complex basins with varying soils, land use and management conditions, over long periods of time (Stehr et al., 2008). The availability of good manuals and the ArcView-based graphical user interface make the SWAT model also attractive to potential end-users for analysing water quality issues (Liu et al., 2008). The model provides a sound description of hydrological processes that can be used to predict the consequences of anthropogenic activities on stream flow, sediment and nutrient transport (Neitsch et al., 2002).

Some studies have been performed regarding the application of SWAT in Uganda and other parts of Africa. Abaho et al. (2009) used an uncalibrated SWAT model to evaluate the impacts of climate change on flow discharge and groundwater recharge in the Sezibwa catchment in Uganda. Ndomba et al. (2010) determined SWAT applicability to a wetland catchment in Rwanda based on daily flow calibration. However, the results showed poor model performance in capturing high flow rates (greater than 3 cms) and peak flows during the calibration period, while significantly under-predicting at the end of the validation period (Mutenyo et al., 2013). Nyeko (2010) used SWAT to evaluate the impact of landuse change on water resources in a large watershed (12,225 km^2) in Uganda. The model was calibrated on a monthly basis; however, the results showed the SWAT model is incapable of capturing peak flows on a daily basis. Another large scale SWAT modeling by Melesse et al. (2008) showed the significant flow reduction (46%) can be expected if rainfall volume is reduced by 20%. Successful SWAT applications in tropical watersheds were reported, although many times model performance on daily time-step was not evaluated (Mutenyo et al., 2013).

The major challenge of using models in many countries is lack of input data. Adequate data for hydrological modelling are difficult to access or not available and the few available rain gauges do not spatially fit the available stream flow gauges (Mekonnen et al., 2009). There are also economic constraints that limit data collection at all locations of the research interest.

However, the importance of building prediction models based on the limited data cannot be over emphasized (Liu et al., 2008). For many parts of the world, including East Africa, limited meteorological data are augmented with available satellite data. Augmentation of the meteorological data for the hydrological modelling is achieved by utilizing estimates derived from remotely sensed data as provided by the Famine Early Warning System (FEWS) which are derived from Meteorsat infrared data and stationary rain gauges generating daily rainfall estimates at a horizontal resolution of 10 km (Mango et al., 2011). Together with the best currently available knowledge for the study area, further improvements in model performance should be sought (Stehr et al., 2008). When using outputs from the model, the limitations inherent in the modelling approach used should be taken into account. To improve model prediction for a shorter time scale, the existing data need to be complemented with the default model components as well as real precipitation data from radars and satellites (Mekonnen et al., 2009).

Protecting and restoring riparian wetlands could be one of the important conservation measures to ameliorate the adverse environmental impacts of agricultural pollutants on water quality. With this regard, it is necessary to quantify the effects of land use changes or climate variability on riparian wetlands by assessing the filtering sediment and associated agricultural pollutants (Liu et al., 2008). Water quality is significantly impacted by a number of land use activities occurring in the catchment (Dabrowski, 2013). Phosphorus is the limiting nutrient in freshwater systems and the most important driver with regards to managing degradation of aquatic systems. Nonpoint source agricultural runoff containing nutrients derived from fertilizer and manure and point source effluent are typically the most important sources of phosphorus pollution in freshwater systems (Hart et al., 2004; Jarvie et al., 2006). In this respect, hydrological and water quality models have been increasingly used to simulate the influence of land use activities on flow and point and nonpoint source pollution in large catchments (Dabrowski, 2013). Proper delineation of the surface and subsurface drainage areas is necessary for estimating upland inputs to riparian wetlands (Liu et al., 2008). SWAT model then simulates nutrient concentrations in the reservoirs, an application that makes it suitable to link nutrient loading with trophic status. However, very limited studies exist on the application of SWAT modelling to simulate nutrient loading in African catchments (Dabrowski, 2013).

In Lake Kyoga basin, wetland has been converted into rice farms. This has affected water quality, fish habitat and wetland fishery productivity. In this regard, advances in the general understanding of the spatio-temporal impacts of land use changes on the wetland hydrology which in turn affects the fishery, is urgently needed. For some African reservoirs, correlations between the fish catch and aquatic system's morphometric parameters such as surface area, volume, mean and maximum depth, and area of watershed, and productivity indicators such as phytoplankton productivity, total phosphorus, nitrogen and chlorophyll a and conductivity concentrations in the water column have been done (e.g. Downing et al., 1990; Lerdburoos et al., 2011). The SWAT model has been successfully applied to simulate hydrology and predict orthophosphate and other water quality parameters in some African countries; including South Africa, Kenya and Ethiopia, among others (Baker and Miller, 2013; Dabrowski, 2013). Correlation analyses provide indications of what can and cannot be predicted using different models and, thus, are an alternative validation approach (Mekonnen et al., 2009). In a study by Downing et al. (1990), fish community production was correlated with the total phosphorus concentration of the water column. Other studies have shown that fish catch has a positive correlation with total phosphorus, dissolved oxygen and orthophosphate phosphorus, and a negative correlation with ammonia-nitrogen and inorganic-nitrogen (Lerdburoos et al., 2011). Potential sustainable fish yield has also been correlated to electrical conductivity and mean depth in terms of morpho-edaphic index (MEI) for the whole fish community in African reservoir fisheries (Welcomme, 1985). Yield of lake fisheries may be approximated using a variety of empirical methods (Pitcher and Bundy, 1995), including correlative relationships with various limnological parameters such as the recently revived morpho-edaphic index (MEI) or primary production (Oglesby et al., 1987; Downing et al., 1990). The ME1 has not been very successful in predicting fish production in African ecosystems (Henderson and Welcomme, 1974). Methods based on primary production may be of more utility for approximate fisheries purposes, even though the approach has also been criticized especially where detailed ecology is the focus (Evans et al., 2005). Total phosphorus is much less expensive to measure than primary production and to reduce underestimation of the fish yield, is used to derive the productivity of particularly benthic feeders (Egertson and Downing, 2004). The relationship between fishery field, fishing effort and water body area and volume explain much of the variability in total catches and is applicable to African inland lakes and reservoirs (MRAG, 1995). Morphometric variables were found to the best predictors of yield, with fishing effort also being important (MRAG, 1995). Therefore, the equation which relates catch per unit effort and water quality parameters would be more appropriate to predict of African inland systems.

2.5 Socio economics of small scale fisheries

Most of the fishers in developing countries are engaged in small-scale fisheries, those that work from shore or from small boats in coastal and inland waters (Neil et al., 2007). These fisheries make important but poorly quantified contributions to national and regional economies, and to the food security and development of many millions of people (UNDP, 2005; Bene et al., 2006; Chuanpagdee and Pauly, 2006). There are no reliable global estimates of the number of people dependent on small scale fisheries, nor reliable assessments of their role in national or regional economies (Bene, 2006). Setting aside problems in definition, the date of the estimates, and the criteria for inclusion, between 20 and 40 million people may participate in small scale fisheries (Neil et al., 2007). If one includes fisheries-associated livelihoods such as marketing and processing as well as children and the elderly in fishing households, more than 200 million people may depend on small scale fisheries (Delgado et al., 2003). However, there is broad consensus that fisheries in the developing world are failing to fulfil their potential as engines of social and economic development (Neil et al., 2007).

There are many features that threaten small-scale fisheries. These range from those within the fishery such as overfishing and excess capacity to those originating outside, and at much larger scales such as distortions in markets and climate change. Fisheries are also adversely affected by the broader political, institutional and economic drivers of global and national economies (Delgado et al., 2003; Cochrane and Doulman, 2005). Competition with other resource users and the indifference and neglect of governments add further layers of vulnerability (Dugan, 2005; Neil et al., 2007). In other fisheries, biophysical influences acting at large spatial scales such as water flows, pollution and climate variability may be the dominant influences, particularly in inland water fisheries (Allan et al., 2005). Not only is there a bewildering diversity of ever-changing small scale fishery with differing ecological features found in divergent social and economic settings but also a large irreducible uncertainty in the processes that govern their future. The attributes of small scale fishers such as operation from dispersed and decentralized localities using small fishing vessels and simple gear fishing activities, have presented significant challenges for sustainability and effective governance (Cochrane et al., 2011). Therefore, there is failure of fisheries management to manage the interface between small scale fisheries and the wider external environment that characterizes the problem (Neil et al., 2007).

The current global crisis in fisheries has provoked great concern to policy makers, fisheries authorities, fishers and other stakeholders (Onyango and Jentoft, 2010). The concern is founded on the reality that these crises threaten ecosystem health, livelihoods and employment and food security, among others (Bavinck et al., 2005; FAO, 2005). However, fisheries policies often evade the hard choices that need to be made to resolve these conflicts (Neil et al., 2007). Tropical fisheries in developing countries rely on diverse ecosystems and their physical attributes influence the role of fishing in riparian livelihoods by shaping the levels of fishing effort and incomes (Hoggarth et al., 1999). The present limnological and biotic changes in Lake Victoria led to the near collapse of the fishery and had a negative impact on the livelihood of the local populations (Onyango and Jentoft, 2010). This means the small-scale fishers' incomes that have often been very low (Cunningham, 1994) will continue reducing. Bene (2004) identified a number of challenges faced by riparian communities such as low standard of living, limited resources, lack of basic needs, security, lack of property entitlement, multiple deprivation, exclusion, inequality and dependency. Around Lake Victoria, poverty has persisted in these fishing communities despite economic opportunities created through the boom in fishing after the introduction and proliferation of Nile perch (*Lates niloticus*, Latidae) that revolutionized the fishery (Kolding et al., 2008). The range of numerical contribution of *Clarias gariepinus* and *C. liocephalus* in the gillnets catches of the Kyoga system is 0.12% to 3.84% and 0.03% to 2.82%, respectively, which has reduced mainly due to habitat changes such as irregular variability in water levels, loss of wetlands and macrophytes, and climatic factors (Ogutu-Ohwayo et al., 2013). Therefore, changes in the socio-economics of communities that are dependent on the Lake Kyoga basin fisheries are expected.

There is sufficient evidence of effective management of sustainable fisheries by small communities in developing countries using traditional methods in the past (e.g. Cochrane et al., 2011). However, these traditional methods have been overwhelmed by a centralized management approach based on natural-science management advice making them less effective than they need to be to ensure sustainability and the supply of fish to societies (Welcomme, 2003; FAO, 2003). This approach has also proven inadequate for effective management of fisheries in general and particularly for small scale fisheries in the developing world (Garcia and Cochrane, 2009). In general, fisheries research and management is shifting from the narrow focus on fish populations and the process of catching them to placing fishing in a broader context that puts more emphasis on interactions among people, power, external disturbance and uncertainty, and wider governance dynamics (Cochrane et al., 2011). Effective management requires a range of perspectives and the inclusion of different actors in the management process, as well as better governance of target communities (FAO, 2006; Garcia and Cochrane, 2009). As small scale fisheries are increasingly vulnerable to this external world, their management with a narrow focus on regulating fish capture is unlikely to be influential in shaping the future. Therefore, investigating the impacts of fishery dynamics on the socio-economics of the marginalised wetlands such as the Mpologoma riverine wetland would fill a knowledge gap on how communities are coping with changes in the fishery. This socio economic perspective would be of great importance towards the formulation of small scale fishery resource management strategies and emphasis on co-management.

2.6 Conceptual Framework

Clarias species ecology and production are affected directly or indirectly by a number of variables ranging from anthropogenic disturbance, hydrology of the wetland, climate and seasonality, exploitation levels and socio-economic factors. Land use change from natural wetland marsh to small scale rice farm or large scale rice farm, has implications on water quality and other habitat attributes such as vegetation structure and function. Individual fish or part of the population face a succession of environmental challenges as they grow, feed and spawn. They become equipped with adaptive plasticity as the phenotype of traits develop in response to the imposed conditions. Small *Clarias* species length, weight, fecundity, gonado somatic index, stomach content and overall production would change either negatively or positively. Even other wetland fish species would be affected hence influencing the overall wetland fishery and socio-economics of the communities at the edge of the wetland.

The postulated wetland disturbance continuum, based on intensities of contiguous land use, was that as the wetland use changes, fish individuals or part of the population's life history biometrics, habitat use, migration and the small scale fishery production will decline.

Anthropogenic disturbance of the wetland compromises the quality of fish habitats and consequently the overall fishery production. The wetland values associated with its integrity are bound to be negatively affected by the increasing wetland disturbance. The relationships between these factors are represented in Figure 2.1. Therefore, the study focused on *Clarias* biometrics, movement patterns, wetland fish species catch and catch per unit effort (CPUE) as the dependent variables affected by independent variables; water quality and vegetation cover. The socio economics parameters were dependent on the wetland production and land use. With proper wetland management, a stable fisheries production will provide a stable environment and social development avenue for local communities living within the wetland vicinity.

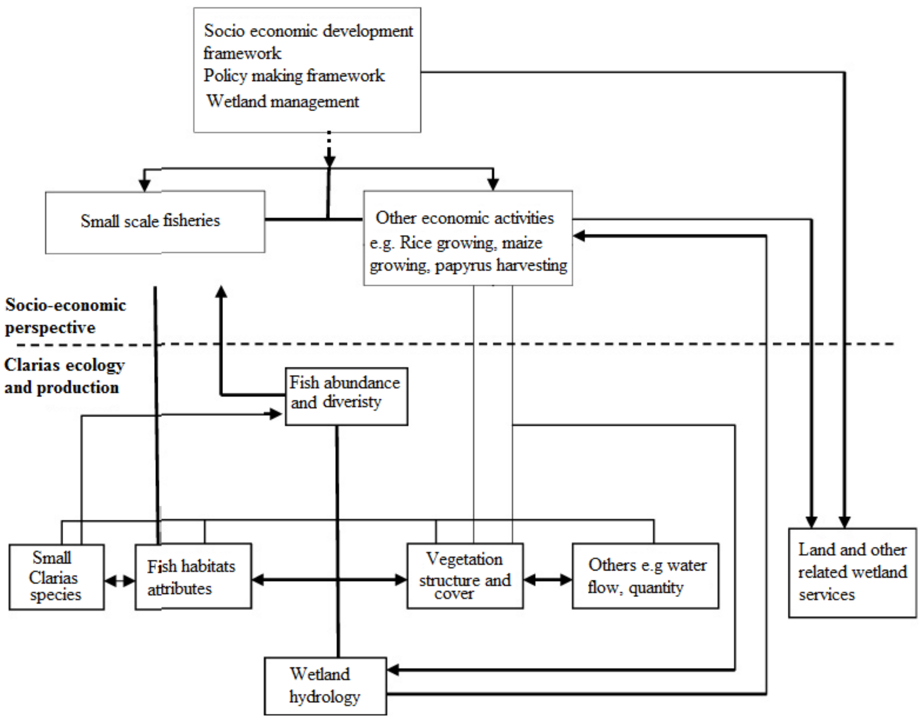

Figure 2.1: Conceptual framework indicating the interrelationships of small *Clarias* fisheries with physical parameters in the Mpologoma riverine wetland

2.7 References

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CHAPTER THREE:

SMALL *CLARIAS* SPECIES LIFE HISTORY BIOMETRICS IN RELATION TO CHANGES IN LAND USE IN MPOLOGOMA WETLAND[1]

Abstract

Degradation of wetlands by land use change affects their ecological integrity and the long-term survival of their fish faunas. Variations in life history parameters of the endemic small *Clarias* species at different wetland sites in relation to land uses changes in the wetland were studied. Water quality, vegetation and small *Clarias* species life history parameters were sampled at the four differently disturbed sites in the wetland. Conductivity was significantly higher at the highly disturbed sites, ranging from 60 to 480 μScm^{-1}. Orthophosphate and total phosphorus were higher at less disturbed sites (Tukey' test, $p < 0.01$). The least disturbed sites were dominated by *Cyperus papyrus* while highly and moderately disturbed sites had a mixture of macrophytes including rice plants. Two small *Clarias* species were identified. *Clarias liocephalus* (Boulenger 1898) was the most abundant (66%) with a mean total length and weight of 16.81 ± 4.03 cm and 33.77 ± 19.63 g respectively. *Clarias alluaudi* (Blgr., 1906) (34%) recorded a mean total length and weight of 17.83 ± 4.49 cm and 39.94 ± 22.99 g respectively. With one way ANOVA and Tukey' HSD test, the weight of *C. liocephalus* was significantly different at the less disturbed Budumba and highly disturbed Nsango ($p = 0.001$). Fecundity of both clariids was significantly higher at the highly disturbed sites than at the less disturbed sites while length at fisrt maturity was lower at the highly disturbed sites than at the less disturbed sites. Length and weight positively correlated with conductivity (rho' = 0.29; $p = 0.001$) and negatively related to total phosphorus (rho'= -0.357; $p = 0.001$). Habitat disturbance due to land use change provided population-level benefits leading to higher values of life history parameters of *Clarias* species at the highly disturbed sites in the wetland.

Key words: *Clarias liocephalus*, *C. alluaudi*, length, weight, condition, fecundity, wetlands disturbance

[1] Publication based on this Chapter:

GA Ssanyu, J Kipkemboi, JM Mathooko, J Balirwa (2014). Response of endemic Clarias species' life history biometrics to land use around the papyrus-dominated Mpologoma riverine wetland, Uganda, African Journal of Aquatic Science, 39(3), 249 - 261, DOI: 10.2989/16085914.2014.946387

3.1 Introduction

Wetland fisheries play an important role in many African countries' commercial and recreational fisheries (Arthington et al., 2004). Wetland catfishes particularly support fisheries in rural subsistence (Ofori-Danson, 1992). In Uganda, River Mpologoma wetland fisheries within the Lake Kyoga basin have always supported livelihoods of communities with limited access to the lake ecosystems. However, the demand to feed a rapidly growing population and effects of climatic vagaries has lead to encroachment of riverine wetland in the basin that used to supplement terrestrial agricultural production. The conversion of marshes into other land uses has been detrimental to the wetland fishery by degrading fish habitats. This has been linked to reduced biotic integrity and extirpation of some fishes (Allan, 2004). Over centuries, most modified ecosystems have recorded loss of biodiversity (Pander and Geist, 2010) and riverine wetland freshwater fishes are the most threatened among all classes of vertebrates worldwide (Collares-Pereira and Cowx, 2004). Indeed the production of large catfish *Clarias gariepinus* in the Lake Kyoga basin has declined from more than 1600 metric tonnes in the 1980s to 1.35 metric tonnes in 2000 (Muhoozi, 2003).

African catfish is not as diverse as that of the America or Asia, but it is largely unique (Golubtsov et al., 2004). *Clarias* species are mostly small, reaching 10 to 30 cm at maturity, widespread in Central, East and South African rivers and wetlands (Ngugi et al., 2009). Studies have been done on the ecology and reproduction of the major catfishes; *C. gariepinus* (Greenwood, 1974) *C. anguillaris* (Boulenger 1911) (Offem et al., 2010) and age, growth and motality of *C. gariepinus* (Okogwu, 2011). However, knowledge of the ecology of the small catfishes *C. alluaudi* and *C. liocephalus* is still limited. Some research has shown that fish assemblage structure is altered by land use such as agriculture but fewer studies have focused on population-level metrics of individual fish species (Paukert and Makinster, 2009), particularly among the African tropical systems (Kadye and Moyo, 2007). Fish population parameters are influenced by spatial variation of habitats within riverine wetland system due to changes in the physical gradients (such as water depth) and other density-independent factors within the system (Pander and Geist, 2010). However some fish are resilient to habitat changes.

The rate of degradation in Mpologoma river wetland may be escalating beyond the resilience of the fish population particularly the small *Clarias* species. This chapter illustrates the response of the life history biometrics of endemic wetland small *Clarias* species exposed to varying land use intensities in the Mpologoma River wetland. Specifically, we focused on the variations of length, weight, fecundity, condition factor and maturity of small *Clarias* species between sites with different levels of disturbance. It was hypothesized that these population parameters of small C*larias* species would vary among the differently disturbed sites along the Mpologoma river wetland. It was also postulated that the less disturbed sites would contrast in land use pattern, water quality and vegetation distribution with the highly disturbed sites along the wetland.

3.2 Materials and methods

The study was carried out at the four sites in the Mpologoma river wetland described in Chapter 1. Prior to the commencement of the field data collection, a site survey was undertaken to characterise, identify the study sites and carry out trial sampling of all parameters. These enabled adequate preparation for fieldwork such as mobilisation of appropriate equipment, identification keys for *Clarias* species and the analysis of reproductive maturity stages, and organising a sampling programme for all sites. Field sampling was done at each of the four sites between January 2012 and August 2013. Based on responses from the local people and observations during the study period, March to May was the long wet season, June to August the short dry season, September to November the short wet season and December to February was the long dry season. The different variables that addressed this study objective were investigated as follows.

3.2.1 General characterisation of the Wetland

a) Characterisation of vegetation cover

Vegetation characteristics of the study sites were investigated using visual estimations and data was collected for dominant macrophytes whose identification was done using taxonomic keys by Katende et al. (1995). Estimates of vegetation abundance of the dominant macrophytes was carried out using DAFOR scale (Garde et al., 2004) at different points along transects at; 0-5 m, 50m and 100 m inside the wetland. The Dafor scale uses score of 5 to + which represent Dorminant, Abundant, Frequent, Occasional and Rare, which was modified by Balirwa (1998), shown in Table 3.1. Species richness at each sites was tested using Shannon

Weiner *H'* index. The vegetation pattern was used to differentiate the differently disturbed sites along the wetland.

Table 3.1: Assessment scale for cover and abundance of the macrophytes after Balirwa (1998)

Score	Descriptor	Label
+	species sparsely present (cover small) < 1% of area	R
1	any number of individuals covering > 1 < 5 % of area	Oc
2	any number of individuals covering 5 - 25 % of area	LF
3	any number of individuals covering 26 - 50 % of area	F
4	any number of individuals covering 51 - 75 % of area	Lab A &
5	any number of individuals covering 76 - 100 % of area	LD & D

b) Physical and chemical characterisation of the wetland water

Water samples were collected from each site using a clean bucket from the upper 20 cm of the water column from the edge of the vegetation (0 - 5 m), mid-river point and within the papyrus dominated emergent macrophyte zone. During each sampling period, three water samples were collected at each point. Conductivity and pH were determined *in-situ* using Hanna pH/Ec/TDS/^{o}C meter and probes. Dissolved oxygen and temperature were determined on-site by Oakton DO 110 meter and probes. Chemical analysis was performed on 0.45 µm membrane filtrate for nitrate nitrogen (NO_3-N) and orthophosphate (Ortho) and unfiltered (TP) samples within 48 hours of collection according to standard procedures (APHA, 1995). The water parameters were used to differentiate the study sites.

3.2.2 Determination of *Clarias* species life history biometrics in the Mpologoma wetland

Fish samples were collected monthly using nine local basket traps baited with dead earthworms. Three traps were set randomly at three different points within the papyrus vegetation of each study site between 06:00 am and 12:00 pm. Identification of *Clarias* species was based on keys by Teugels (1982) which, involved examination of the pectoral spine serrations by a hand lense using a Stereo microscope at X10 magnification. Among these two *Clarias* species, the pectoral spine was serrated on both sides. While the outer side was weakly serrated in both *Clarias* species, the inner side of the pectoral spine had sharp, strong and outward pointing serrations in *C. liocephalus* (Plate 3.1). In *C. alluaudi*, the inside of pectoral spine has blunt weak and slightly inward pointing serrations (Plate 3.2). A number of life history characteristics of the small *Clarias* species from the differently disturbed sites were assessed. These included length, weight, maturity stages, condition factor, fecundity and stomach contents as described below.

a) Length - weight measurements

The total length (TL) and standard length (SL) in centimetres and total weight (W) in grams were measured using a Floy tag meter ruler and SF – 400 Kitchen weighing scale (0.00 g accuracy) of each individual small *Clarias* fish caught respectively. Size frequency histograms were created by calculating the percentage of *Clarias* species of different size classes.

b) Maturity stages and fecundity

Each of small *Clarias* fish sample was dissected to expose the reproductive organs in the field since it is difficult to differentiate males from females among *Clarias* species with observation of outer body parts. Maturity stages was determined based on macroscopic evaluation of gonads with the aid of a hand lens for (Laleye et al., 2006) as described in Table 3.2 below. The mean size at first maturity (L50) was defined as the length at which 50% of the females were at an advanced stage of the first sexual cycle (at least in stage III of the maturity scale). The gonado-somatic index (GSI) was calculated as suggested by NaFIRRI (2007). Fecundity was determined for 30 mature gonads (13.5 cm - 21.7 cm TL, 30 g - 100 g TW; gonadal stages V – VI which had well separated and not spent oocytes) from each site. Absolute fecundity, the probable number of oocytes released at the following spawning, were determined by taking two portions of the ovary (500 fresh eggs ± 50) which were weighed and initially fixed in modified Gilson’s fluid (NaFIRRI, 2007) for about one week until oocytes obtained a free and hard texture. The oocytes were then counted.

3.2.3 Data analysis

All data were analysed using Statistical Package for Social Sciences (SPSS version 10, IBM©). Kolmogorov-Smirnov test was used to test for normality of the water quality parameters and fish population parameters. One-way ANOVA was used to test the differences between mean values of water quality parameters of the different study sites and between seasons. Tukey honestly significance difference (HSD) test ($\alpha = 0.05$) for multiple comparisons among means was carried out whenever a significant *F*-value resulted from the analysis of variance. Principal component analysis (PCA) was used to analyze physico-chemical data association among sites. Loadings of the principal components (PCs) were derived from varimax orthogonal rotation and Kaiser normalization of the second and third PCs. Only those variables which loaded heavily on any of the principal components were considered. To check for relationships between variables and sites, regression relationship scores of the PCs were used.

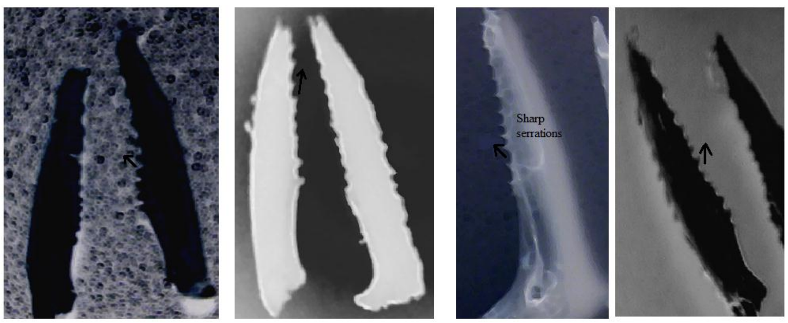


Plate 3.1: Photographs of pectoral spine serration (Mg X10) of *Clarias liocephalus*=

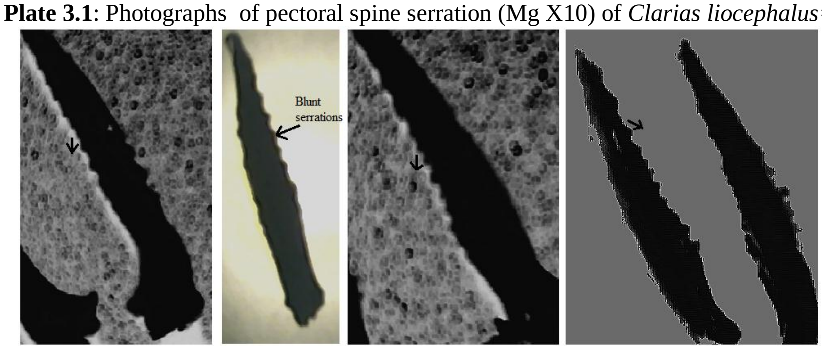


Plate 3.2: Photographs of pectoral spine serrations (Mg. X10) of *Clarias alluaudi*

Comparisons of the mean values of *Clarias* species length and weight between sites was done using one-way ANOVA and LSD post hoc test. Length and weight data collected was used to derive length-weight relationships based on an equation 1 (Ayoade and Ikulala, 2007):

$$\text{Log } W = \text{Log } a + b \text{ Log } TL \quad (3.1)$$

where W is fish weight, TL is fish total length and, a and b are the constants. Analysis of length at 50% maturity for all females and male of both *Clarias* species was done for length classes of 3 cm intervals (i.e. 1-2.99, 3-5.99, 6-8.99, 9-11.99) and scatter plots were done for the percentage of mature individuals against length class. Mean size at first maturity (L50) was determined as suggested by Tweddle and Turner (1977). Relative growth condition factor (Kn, coefficient of condition) was estimated using equation 2 for Fulton's condition factor where W is weight (Kg) and L is standard length (cm) (Wootton, 1998) expressed as:

$$K = (W/L^3) \times 100 \qquad (3.2)$$

Table 3.2: Description of the gonad maturation stages of small Clarias species based on NaFIRRI (2007)

Female	Male
Immature (I) Ovaries very small, indistinguishable macroscopically, fully attached to the connective tissue, eggs are not distinguishable by the naked eye	**Immature (I)** Testes appear as a pair of thin transparent strand, longitudinally along the dorsal wall of the body cavity, sexual products distinguishable by the naked eye
Resting (II) Ovaries small, elongate, paired, with smooth edges and appear pale pink in colour, smooth, cylindrical, eggs not visible macroscopically, only slightly vascularised.	**Early developing (II)** Testes transparent pinkish, narrow and flattened.
Maturation (III) Ovary bigger pinkish or reddish, semi-transparent, pear shaped in section, eggs not visible	**Maturation (III)** Testes semi-transparent pinkish, often vascularised, more flattened in transverse section, no milt visible
Mature/ Resting (IV) Ovary reddish with small opaque yolky ova, clearly visible; elongate	**Mature/ Resting (IV)** Testes opaque, pinkish, well vascularised, firm, triangular in section; slight milt exudes from lumen
Mature/Ripe (V) Ovary yellow-buff, opaque due to presence of large yolky ova clearly visible though superficial membrane, large vessels on surface	**Mature/Ripe (V)** Testes opaque, pinkish, soft, triangular in section, lying in the longitudinal groove and copious milk in node.
Ripe and running (VI) Ova yellow brown in colour, oil globule; slight external pressure causes ripe ova to be extruded from the vent	**Ripe and running (VI)** Similar in appearance to stage V but bigger nodes containing milt, lying in the whole testes
Spent and Resting (VII) Ovaries loose and flabby containing torn follicular tissue rich in blood with few residual stage V ova	**Spent and Resting (VII)** Testes lighter and shrunken n size, residual milt of stage VI seen in deflated nodes

Variation in condition factor at the different sites and among different maturity stage was analysed by Tukey's test. Gonado-somatic index (GSI) was calculated based on equation 3 suggested by Lagler (1971), expressed as:

$$GSI = (\text{Gonad weight (g)}/\text{Total body weight (g)} \times 100 \qquad (3.3)$$

The relationship between fecundity and some morphometric measurements was determined by relating total fecundity (F) to total length (TL), total weight (TW) and constants (a, b) of the fish using equation:

$$F = a \times TLb; F = a \times TWb \qquad (3.4)$$

Fish population parameters were not normally distributed and therefore Spearman's rank correlation was used to test the relationship between these parameters and environmental variables (water quality parameters) and length-weight relationships. Linear regression of log transformed length and weight data and the adjusted R squares and the p values were used to determine the strength of the relationships between length and weight.

3.3 Results

3.3.1 Water quality

The physicochemical parameters showed spatial and temporal variability along the wetland. The values of pH and dissolved oxygen (DO) were lower within the wetland than at the water edge and in the middle of the river (Table 3.3). Dissolved oxygen (DO) within the papyrus vegetation was generally low and ranged between 0.10 mgl^{-1} at highly disturbed site to 4.98 mgl^{-1} at less disturbed site. DO was generally higher during the wet season months (April, May, October and November) with a range of 2.2 to 4.4 mgl^{-1} than in the dry season when it ranged frm 0.6 to 1.8 mgl^{-1} in the mid river section. Conductivity (Ec) ranged from 115 µS/cm at less disturbed Budumba site to 454 µS/cm at the highly disturbed Nsango site. Conductivity at the highly disturbed sites was significantly lower than that of disturbed sites (all at $p < 0.01$) and generally, higher during the dry months (February, July and December) as compared to the wet season months (May and August) (Figure 3.1). Water conductivity, orthophosphate (OPO_4^{3-}) and total phosphorus (TP) concentrations varied significantly among sites with different disturbance (Table 3.4 and Figure 3.2). The pH values ranged from slightly acidic to neutral (6.0 – 7.2). Nitrate-nitrogen levels were very low to undetectable levels at all sites during the wet season while in the dry season, it ranged from 0.01 to 0.12 mgl^{-1} at the less disturbed sites and 0.03 to 0.18 mgl^{-1} at the disturbed sites. Orthophosphate and TP ranged between 0.081 and 1.15 mgl^{-1} and 0.093 to 1.80 mgl^{-1} respectively. Both phosphate levels were lower at the highly disturbed site than at the less disturbed site.

The principal component analysis (PCA) produced three principal components that explained 57.79% of the variance and loaded heavily for variables; conductivity, pH, dissolved oxygen, orthophosphate and total phosphorus (Table 3.5). With the exclusion of water depth and temperature, PCA II accounted for 69.84% of the variance between variables and further removal of total phosphorus and pH, PCA III accounted for 79.58% of the variance. Although other variables significantly correlated with sites, dissolved oxygen, orthophosphate and conductivity were the dominant contributors to variation among the sites along the wetland.

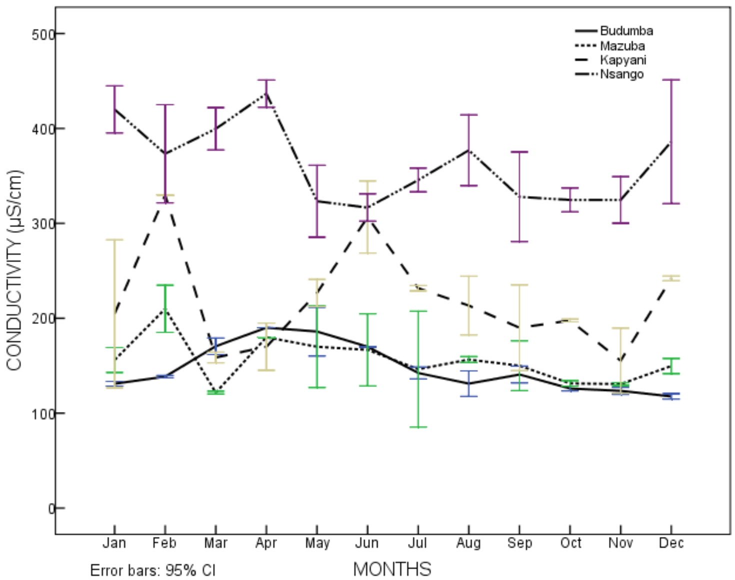


Figure 3.1: The trend of conductivity with time at the different study sites between January and December 2012

Table 3.3: Selected water quality parameters at the three sampling points at each site in the Mpologoma wetland. (values are means, N = 254)

Site	DO (mgl^{-1})	Temp (°C)	Ec (µS/cm)	NO_3^- (μgl^{-1})	OPO_4^{3-} (μgl^{-1})	TP (μgl^{-1})	Depth (m)
Budumba							
5-20m	3.36	25.3	137	0	0.34	1.93	4.7
Mid-river	1.2	23.5	133	0	0.11	0.18	7.2
Within papyrus	0.78	23.2	128	0	1.8	6.75	1.5
Mazuba							
5-20m	3.11	23.5	132	0	0.16	0.26	0.47
Mid-river	1.17	23	132	0	4.65	7.05	4.26
Within papyrus	1.22	23	134	0	0.15	0.23	0.2
Kapyani							
5-20m	1.43	26	222	0	0.18	0.53	2.5
Mid-river	1.38	24.8	177	0	0.23	0.28	7.5
Within papyrus	0.20	24	151	0	0.16	1.15	0.4
Nsango							
5-20m	1.43	25	343	0	0.08	0.2	1.05
Mid-river	1.25	24	374	0	0.18	0.19	1.3
Within papyrus	1.71	25.8	336	0	0.07	0.11	0.35

Table 3.4: Selected water quality parameters measured in *Clarias* habitats (inside the wetland) at the different study sites in the Mpologoma River wetland (January – December 2012) (Values are mean ± S.D., n= 268)

	Budumba	Mazuba	Kapyani	Nsango
DO (mgl^{-1})	1.35 ± 1.03^a	1.98 ± 1.26^a	1.58 ± 0.67^a	0.96 ± 0.76
Temp (°C)	23.75 ± 1.72	24.53 ± 0.81	25.35 ± 1.31	24.18 ± 1.49
Conductivity (µS/cm)	152 ± 32.1^a	161 ± 35.2^a	218 ± 53.1^b	351 ± 55.4^b
OPO_4^{3-} (mgl^{-1})	0.28 ± 0.26^a	0.27 ± 0.23^a	0.13 ± 0.12^b	0.14 ± 0.34^b
TP (mgl^{-1})	0.67 ± 0.44^a	0.62 ± 0.39^a	0.29 ± 0.27^b	0.23 ± 0.19^b
Water depth (m) during the dry season	0.52 ± 0.27	0.45 ± 0.14	0.30 ± 0.15	0.35 ± 0.14

Values in the same row with the same superscript are not significantly different at $p < 0.05$.

Table 3.5: Loadings on the three components and correlation from the PCA of the environmental variables among the study sites in the wetland

Variables	Component Matrix			Correlation	
	PC1	**PC2**	**PC3**	**R^2**	**P-value**
Dissolved oxygen	-.476	-.333	.396	-.289	.000
pH	.515	.340	.402	.299	.000
Temperature	.169	.291	.827	.183	.013
Conductivity	.869	.187	-.142	.798	.000
Orthophosphate	-.390	.618	-.153	-.298	.000
Total phosphorus	-.535	.425	.298	-.350	.000
Water depth	-.027	-.464	.308	.006	.472
Cumulative variance	27.83	43.67	57.79		

3.3.2 Vegetation characterisation

Vegetation patterns portrayed dominance of *Cyperus papyrus* at the least disturbed sites to mixed stands at the highly disturbed sites of the wetland. Fourteen dominant plant families along the Mpologoma River wetland were identified (Table 3.6). Cyperaceae was the most dominant at 0-50 m transect at all sites with abundance percentage of 74% and 73% at the less disturbed sites Budumba and Masuba respectively. While at the highly disturbed Kapyani and Nsango site, Cyperanceae was still dorminant although at a lower percentage of 25 and 30% respectively. Other families that followed in abundance were Poaceae, Convolvulaceae and Compositae at all sites. Within Cyperaceae, *Cyperus papyrus* was the dominant species. Within the Poaceae family, *Leersia hexadra* (45 – 80 %) and *Vossia cuspidate* (25 – 50%) were dominant at all sites. While among the Convolvulaceae, Impomoea species were dominant. In terms of species rishness using Shannon-Weiner index, the highly disturbed Nsango site had 8.4, a value higher than the rest of the sites. Disturbed Kapynai had 4.9, less disturbed sites Budumba and Mazuba had 4.1 and 2.9 species richness respectively. All sites were dominated by *Cyperus papyrus* beyond 50 m from the wetland edge. The moderately disturbed Kapyani and highly disturbed Nsango sites had a higher cover of *Polygonum* sp., *Leersia hexandra*, *Vossia cuspidata*, rice and maize crops at the 0 – 50 m transect. There were also differences at the open water transest. The highly disturbed Nsango site recorded a high cover of *Eicchornia crassipes*, *Hygrophla auriculata* and *Lemna* sp. at the open water transect while the least disturbed sites recorded higher percentage cover of *Nymphaea* sp. and *Pistia stratiotes*.

Table 3.6: Percentage cover of the dominant plant taxa at the different disturbed sites in the wetland in 2012

Sites		Budumba		Mazuba		Kapyani		Nsango	
Transect	Family	Dominant plant species	% cover	Dominant plant species	% cover	Dominant plant species	% cover	Dominant plant species	% cover
0-50 m	Amaranthaceae	*Amaranthus bybridus*	2						
	Compositae	*Malananthera scandens*	2	*Vernonia sp*	5				
		Vernonia sp	2						
	Convolvulaceae			*Ipomoea aquatica*	5			*Ipomoea rubescens*	5
								Ipomoea cairica	5
	Cyperaceae	*Cyperus papyrus*	64	*Cyperus papyrus*	73	*Cyperus papyrus*	25	*Cyperus papyrus*	30
		Cyperus dives	10						
	Fabaceae	*Tamarindus indica*	5						
	Mimosaceae	*Mimosa pigra*	4					*Mimosa pigra*	5
	Palmae	*Phoenix reclinata*	1	*Phoenix reclinata*	2			*Phoenix reclinata*	5
	Polygonaceae	*Polygonum senegalense*	4			*Polygonum senegalense*	15		
	Poaceae	*Leersia hexadra*	4	*Vossia cuspidata*	5	*Vossia cuspidata*	15	*Oryza sativa*	15
								Leersia hexandra	10
				Panicum maximum	5	*Oryza sativa*	20	*Echinochloa pyramidalis*	10
						Zea mays	25	*Vossia cuspidata*	10
	Pteridaceae	*Pteris* sp	2						

	Verbenaceae			*Lantana trifolia*	5				
	Tihaceaa							*Truimfetta* sp	5
100 m	Cyperaceae	*Cyperus papyrus*	100	*Cyperus papyrus*	100	*Cyperus papyrus*	20	*Cyperus papyrus*	20
	Poaceae					*Oryza sativa*	80	*Oryza sativa*	80
Open water	Araceae	*Pistia stratiotes*	10	*Pistia stratiotes*	10				
	Ceratophylaceae	*Ceratophyllum demersum*	15			*Ehydra fluctuans*	60	*Hygrophila auriculata*	20
	Nyphaeaceae	*Nymphaea* sp	55	*Nymphaea* sp	50	*Polygonum senegalense*	40		
	Pontedariaceae							*Eichhornia crassipes*	50
	Poaceae	*Leersia hexadra*	30	*Vossia cuspidata*	40				
	Lemnaceae							*Lemna* sp.	30

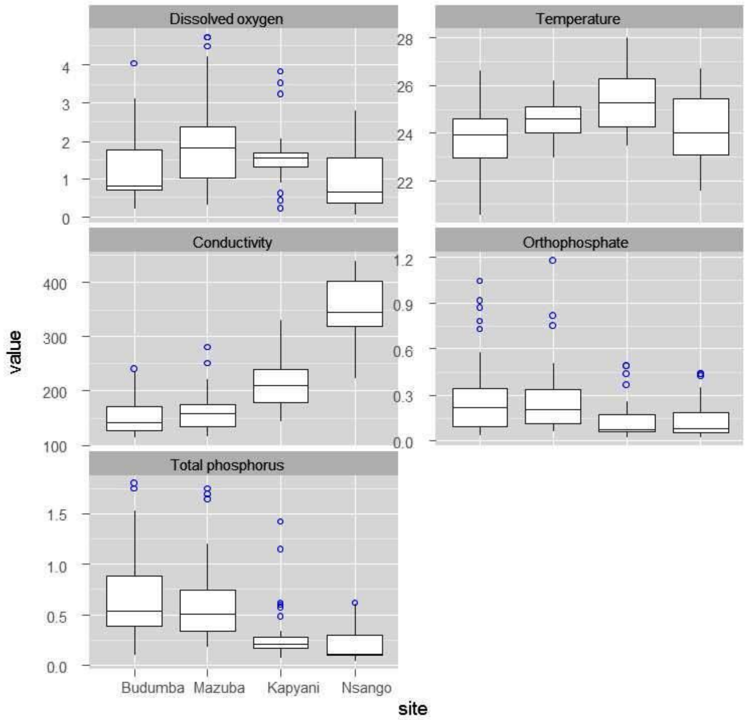


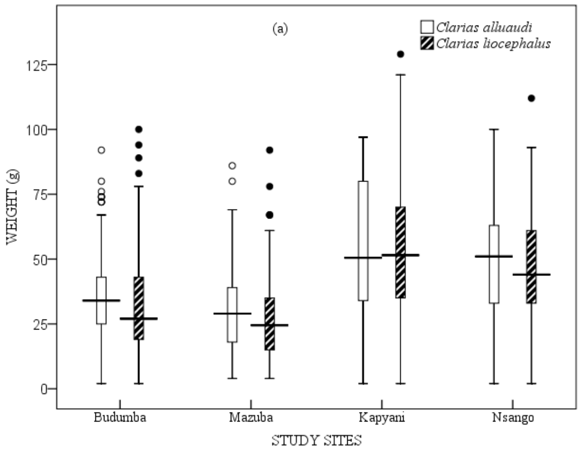
Figure 3.2: Selected water quality parameters; dissolved oxygen (mgl^{-1}), temperature (^{o}C), conductivity (µS/cm), orthophosphate (µgl^{-1}) and total phosphorus (µgl^{-1}) within papyrus section at the different study sites from January to December 2012 (values are median and interquartile range)

3.3.3 Small *Clarias* species life history parameters

a) Length-weight relationships

The 1086 *Clarias* specimens collected comprised of 2 species (*C. liocephalus* - 66% and *C. alluaudi* - 34%). There were variations in their population parameters between sites. Higher length and weight values were recorded for both species at the highly disturbed sites compared to the less disturbed sites (Figure 3.3). At less disturbed sites (Budumba and Mazuba), the mean weight of immature (stage I to III) and mature (stage IV to VII) female *C. alluaudi* and *C. liocephalus* were 12.25 ± 2.06 g and 36.25 ± 1.07 g, and 8.5 ± 3.87 and 38.0 ± 0.66 g respectively. At the highly disturbed sites (Kapyani and Nsango), the mean weight of immature and mature female *C. alluaudi* and *C. liocephalus* were 13.0 ± 1.76 g and 58.61 ± 0.18 g, and 13.11 ± 0.89 g and 55.36 ± 0.22 g respectively. *C. alluaudi* at Budumba and

Mazuba (less disturbed) were significantly smaller than those at Kapyani and Nsango (highly disturbed sites) all p = 0.041. *C. liocephalus* were significantly smaller at Mazuba than those at Kapyani (p = 0.023) and smaller at Mazuba than those at Nsango (p = 0.001).



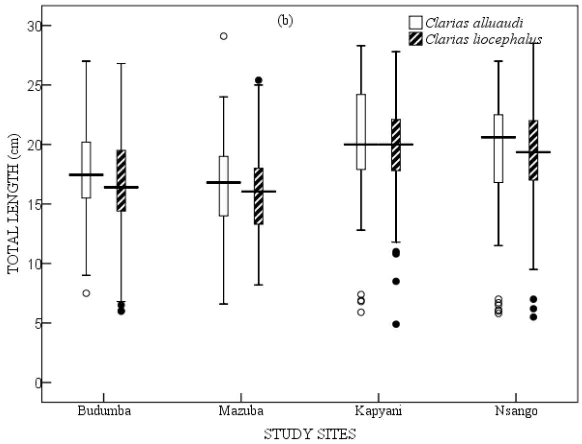


Figure 3.3: The weight (a) and total length (b) of both *Clarias* species within Mpologoma wetland from September 2011 to August 2012 (values are median and interquartile range)

The frequency distribution of *C. liocephalus* total length in relation to a 15 cm mark at the different sites showed that highly disturbed sites had more fish individuals greater than 15 cm than those of less disturbed sites (Figure 3.4). 15 cm was the average age at first maturity for both clariids in the wetland. Length-weight relationships (LWR) were significantly strong

(Table 3.7; $p < 0.05$) for both *Clarias* species at all sites as indicated by correlation coefficients (many adjusted R^2 were greater than 0.85). Exponent b values were generally lower than the expected value for an ideal fish (3.0); the fish exhibited negative allometric growth pattern.

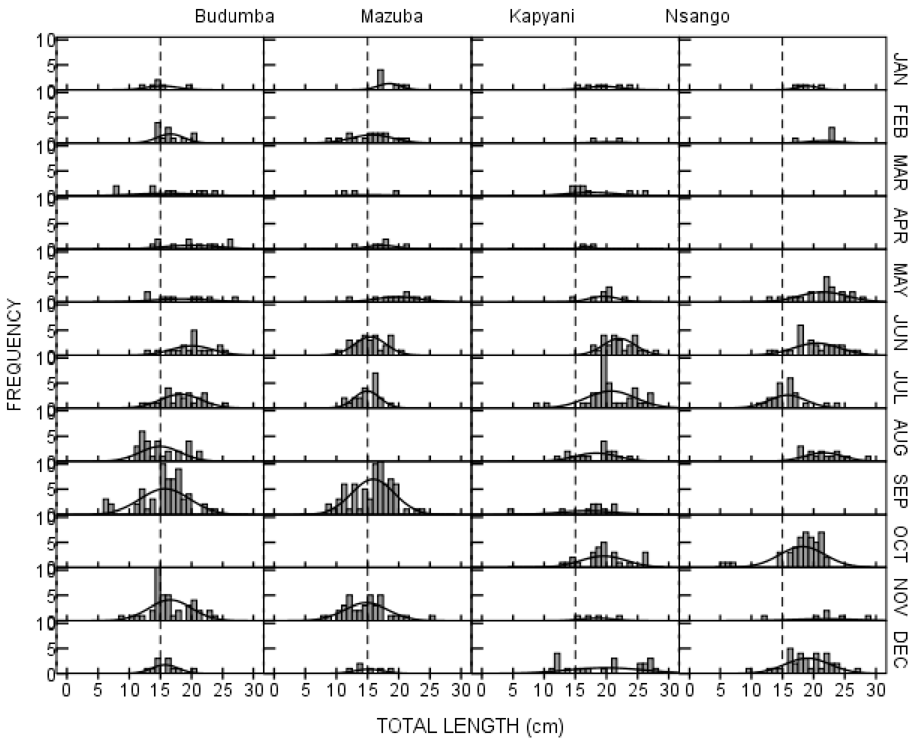


Figure 3.4: Percentage frequency distribution of *Clarias liocephalus'* total length in relation to a 15 cm mark at the different sites within the wetland in 2012

Table 3.7: Descriptive statistics and length-weight relationship for the *Clarias* species at the different sites in the Mpologoma river wetland in 2012

			Length (cm)	Weight (g)		W=aL^b		
Clarias alluaudi	Sex	n	Min-max	Min-max	A	b	r^2	SE (b)
Budumba	♀	49	11.0-23.0	7.00-73.00	-2.09	2.90	0.88	0.16
	♂	56	7.5-24.4	2.0-80.0	-2.25	3.02	0.93	0.01
Mazuba	♀	56	6.6-23.5	6-25.5	-1.28	2.25	0.92	0.09
	♂	42	8.5-29.1	6.0-25.5	-0.93	2.64	0.83	0.14
Kapyani	♀	33	6.0-25.5	2.0-80.0	-2.09	2.91	0.97	0.09
	♂	29	5.9-26.6	2.0-94.0	-1.94	2.76	0.98	0.08
Nsango	♀	50	5.8-27.0	2.0-93.0	-1.56	2.50	0.72	0.61
	♂	53	6.0-27.0	4.0-93.0	-1.50	2.44	0.91	0.11
Clarias liocephalus	♀	96	6.0-24.0	2.0-78.0	-1.95	2.81	0.98	0.05
Budumba	♂	129	8.0-26.8	3.0-100.0	-1.63	2.51	0.89	0.10
Mazuba	♀	115	8.5-24.0	4.0-78.0	-1.81	2.65	0.88	0.12
	♂	108	8.2-25.4	7.0-92.0	-1.55	2.46	0.92	0.08
Kapyani	♀	69	4.9-26.6	2.0-92.0	-1.49	2.45	0.93	0.11
	♂	62	5.0-26.2	3.0-109.0	-2.08	2.89	0.89	0.18
Nsango	♀	75	5.0-25.0	8.0-68.0	-1.64	2.56	0.76	0.24
	♂	61	6.0-28.5	5.0-112.0	-1.56	2.48	0.95	0.10

n: sample size SE (b): standard error of the slope b

a and b: parameters of the relationship r: adjusted R squared

b) Condition Factor (K)

Condition was variable within individual fish population, between sexes and maturity stages and, also varied seasonally and among sites. The coefficient of condition (K) was low during the dry months (January and August) and high during the wet months (May and November). At Budumba K values ranged from 0.49 to 1.42, while at highly disturbed Nsango, they were higher ranging from 0.53 to 1.91 (Figure 3.5). Using Bonferroni test, K values of immature fish at Nsango site (disturbed) were significantly lower than those of Budumba site (less disturbed). While among mature *C. liocephalus* K values were higher at the highly disturbed Nsango site. With Spearman's rank correlation, *Clarias* species' total length and weight were positively related to conductivity. Though weak relationships, conductivity was positively correlated with *C. alluaudi* weight at rho' = 0.215 (p = 0.001) and related to its total length at rho' = 0.238 (p = 0.001). Conductivity was also related to weight of *C. liocephalus* at rho' = 0.266 (p = 0.023) and its length at rho' = 0.238 (p=0.01).

Negative correlation was realized between both species biometrics and nutrients. Weight of *C. alluaudi* was related to orthophosphate at rho' = - 0.324 (p = 0.001).

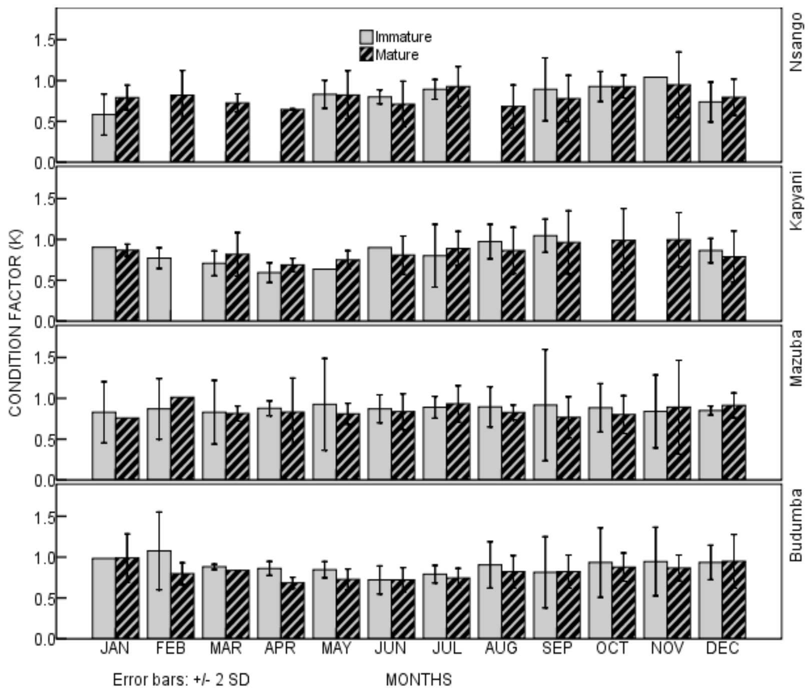


Figure 3.5: The body condition of mature and immature *Clarias liocephalus* in Mpologoma river wetland from January to December 2012 (Values are Mean ± S.E., n = 194)

c) Maturity stages

Maturity analysis showed that 50% and 75.9% of *Clarias alluaudi* females were mature at the 15-17.99 cm and 18-20.99 cm total length classes respectively. While 60.5 % and 86.1% of *C. liocephalus* females were mature at the above length classes. 38.5% and 74% of *C. alluaudi* males were mature at the above two length classes, while 33.8% and 86.4% of *C. liocephalus* males were mature at the two length classes respectively. *C. liocephalus* female and males mature earlier than those of *C. alluaudi*. Although, there was no significant difference between the lengths at 50% maturity (L_{50}) of both species, there were differences among the differently disturbed sites (Figure 3.6). The L_{50} for both *Clarias* species females was low at the highly disturbed sites Nsango and Kapyani (12.8 cm and 15.5

cm respectively) and high at the less disturbed sites Budumba and Mazuba with 16.5 and 18.0 cm respectively. It was also observed that the L_{50} for female *C. liocephalus* was low are highly disturbed sites (i.e. cm, Kapyani - 15.0 cm and Nsango - 16.5 cm compared to Budumba - 18.0 cm, Mazuba – 18.0 cm).

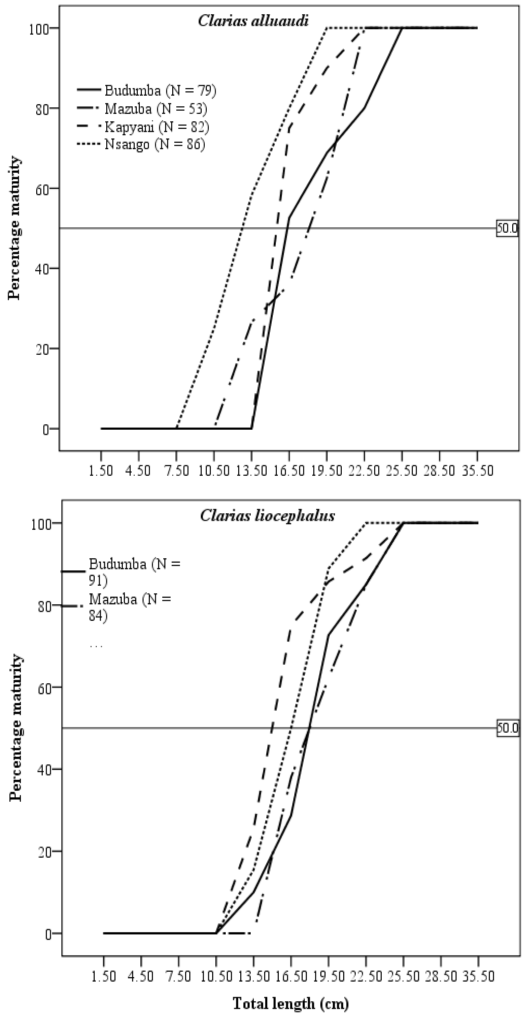


Figure 3.6: Length at 50% maturity of female fish of both *Clarias* species in the Mpologoma riverine wetland in 2012

d) Fecundity

Fecundity ranged from 198 to 3650 eggs (mean of 1522 ± 1140 eggs) and 130 to 6726 eggs (mean of 2447 ± 3725 eggs) in *C. alluaudi* and *C. liocephalus* respectively. Fecundity was higher at Kapyani and Nsango (disturbed sites) for both species (Table 3.8). Fish with high total length and weight recorded the highest fecundity. Correlation between fecundity and total length of both species revealed a significant but weak relationship (rho' = 0.436 at p = 0.001; n = 139). A relatively stronger relation between fecundity and length of *C. alluaudi* was realized (rho' = 0.532 at p = 0.001; n = 70). While a weak relationship between fecundity and length of *C. liocephalus* was realized (rho' = 0.321 at p = 0.001; n = 89; Figure 3.7). Gonado Somatic Index (GSI) ranged from 0.91 to 34.28 for both species (Figure 3.8). It also varied considerably with time, giving two peaks during the rainy months of October to November and April to June. In October the highest mean GSI of 17.54 ± 7.90 for *C. liocephalus* and 12.93 ± 5.49 for *C. alluaudi* was observed. Low mean values of GSI of 9.39 ± 8.05 and 7.35 ± 4.04 for *C. alluaudi* and *C. liocephalus* respectively were observed between April and June.

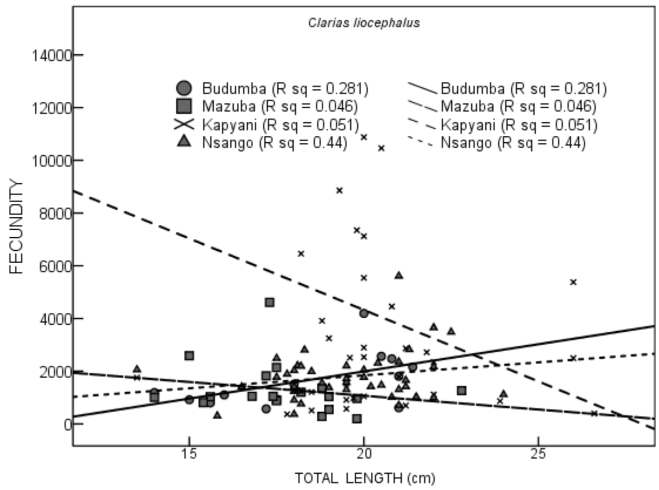


Figure 3.7: Relationship between fecundity and total length for both *Clarias* species collected in the Mpologoma River wetland (January to December 2012)

Table 3.8: The total length and fecundity of *Clarias* species in the Mpologoma river wetland (values are mean ± S.D, n= 1086)

		Clarias alluaudi			***Clarias liocephalus***	
	n	Total length (cm)	Fecundity	n	Total length (cm)	Fecundity
Budumba	21	18.95±2.08	703.08±331.01[a]	19	17.77±2.07	1192.20±723.60[a]
Mazuba	28	17.01±2.46	897.32±434.57[a]	23	17.98±2.53	963.86±393.83[a]
Kapyani	31	20.48±2.21	1803.60±1366.90[b]	35	20.87±2.53	1522.30±897.50[b]
Nsango	37	19.14±2.64	1784.20±941.97[b]	43	19.39±1.72	1630.20±606.40[b]

n is sample size, values in the same column with the same superscript are not significantly different ($P < 0.05$)

GSI also varied among the different sites with disturbed sites recording higher GSI than less disturbed sites (Figure 3.9). *C. liocephalus* GSI ranged from 7.7 to 17.28 at less disturbed Budumba site and 2.6 to 31.07 at highly disturbed Kapyani site. While *C. alluaudi* GSI ranged from 0.9 to 24.27 at less disturbed Budumba site and 3.58 to 34.27 at highly disturbed Kapyani site.

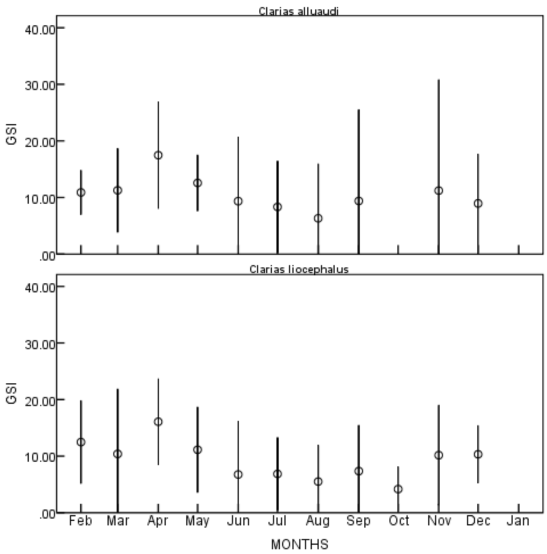


Figure 3.8: The trend of Gonado Somatic Index of both *Clarias* species in the Mpologoma riverine wetland from January to December 2012 (values are mean ± S.D)

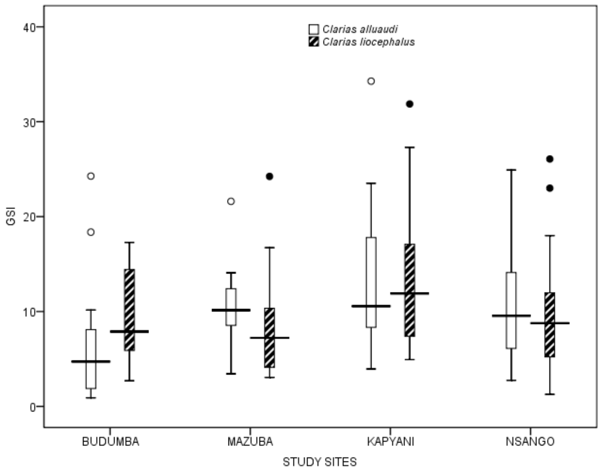


Figure 3.9: Gonado Somatic Index of both *Clarias* species at the differently disturbed sites in Mpologoma river wetland from January to December 2012 (values are median and interqaurtile range)

3.4 Discussion

3.4.1 Wetland site characteristics

Site characteristics influenced biometric features of clariid species. The length, weight and reproductive characteristics of *Clarias* species within the Mpologoma riverine wetland varied with the level of disturbance of the sites. This was attributed to the differences in impacts of land use changes on fish habitats. Variations among fish habitats within aquatic systems have direct implications for fish communities (Paukert and Makinster, 2009). Human activities, particularly farming in wetlands, affect water and substrate characteristics, setting off a complex cascade of changes (Allan, 2004) such as changes in water quality and vegetation characteristics (Urska-Kuhar et al., 2007). This explains the variations in the vegetation characteristics and water quality among the differently disturbed sites along the Mpologoma wetland. Changes in plant community structure from monotypic to polytypic species composition lead to an overall increase in resource availability (Raghubanshi and Tripathi, 2009) and high diversity of habitats with complex food webs (van Dam et al., 2007). A combination of soft tissue and highly decomposable plant materials and low phosphorus result in high abundance of benthic invertebrates (Hansson et al., 2005). This could have contributed to better nourishment for the *Clarias* fish at the highly disturbed sites and hence relatively large sized and heavier fish individuals than those of less disturbed sites. Although benthic invertebrate abundance was not investigated in this study, the disturbance at the sites could have favoured high abundance of invertebrates. Comparing with other studies, flathead catfish (*Pylodictis olivaris*) faster growth in disturbed areas (agricultural areas) was attributed to greater prey availability in silt and detrital substrates, and water with high conductivity and low phosphorus levels compared to the undisturbed sites (Paukert and Makinster, 2009).

Wetlands influenced by agricultural activity often have higher levels of conductance and have been associated with the high sediments from the agriculturally-disturbed wetland basins (Chipps et al., 2006). The high sediments from cultivation within the Mpologoma wetland increased remineralisation in the water column leading to high relatively conductivity. The result on conductivity was comparable to those of earlier studies. In the fingerponds in Kusa wetland along Lake Victoria, high conductivity was recorded during the dry season and this was attributed to the increased ionic concentration as the pond water volume decreased with evaporation during the dry season (Kipkemboi, 2006). In the Mpologoma wetland, higher conductivity was recorded during the dry at all site than during the wet season which was also attributed to high evapo-transpiration that increases ionic concentration in the water.

The Intermediate Disturbance Hypothesis (IDH) suggests that species diversities are moderate in stable ecosystems, highest in intermediate and low in severely degraded ecosystems (Connell, 1978). The results on dominant macrophytes species at highly disturbed Kapyani site were consistent with the hypothesis. The site was recorded with the higher species richness index of the macrophytes than the less disturbed sites and the highly disturbed Nsango site. The site was highly disturbed with small scale rice and maize farms which would be abandoned during the flooding regime. This favored regrowth of natural wetland vegetation and the existence moderate disturbance of the wetland. Such intermediate levels of disturbance permit more heterogeneous habitat patches to exist which support a wide range of species (Barrett et al., 2010).

3.4.2 Small *Clarias* species length-weight relationship and condition factor

The exponent coefficients (*b*) in the LWR for both *Clarias* species were within the given range (around 3) for fishes that maintain a constant body shape with increase in length and weight (Lagler et al., 1977). However all *b* values were lower than 3, therefore both *Clarias* species exhibited an allometric growth pattern, similar to growth patterns of fish species from other tropical systems (Laleye, 2006), other *Clarias* species (Ayoade and

Ikulala, 2007) and *C. anguillaris* (Offem et al., 2010). The *b* value is affected by ecological factors such as temperature, food supply, spawning conditions, sex, age, fishing time and pressure (Kalayci et al., 2007) and water quality (Okogwu, 2011). Disturbed sites recorded lower *b* values than less disturbed site, which meant that the fish body length increased fast than weight gain, indicating physiological stress at the disturbed sites. Body condition varied among maturity stages and sexes in *Clarias* species. Immature fish of both species at all sites had higher coefficients of condition than mature fish. This was attributed to differences in energy allocation, even in the absence of information on potential ecological differences between immature and mature individuals (Vasquez et al., 2009). Immature fishes mainly allocate their ingested energy to growth and maintenance whereas part of this energy is allocated to gonad production in adults (Wootton, 1998).

During the rainy season, condition factor was higher at the highly disturbed site than at the less disturbed sites which, was a strange result. Weight has a relationship to condition factor. The results showed that the clariids had a higher weight than those at the less disturbed sites. Also the female clariids at the Nsango site had more oocytes in their gonads compared to other site, resulting in higher weight values and higher condition factor. There were also other factors that contributed to the results. Environmental factors such as temperature and food availability and quality are of great importance in explaining the trends in body condition (Armstrong and Witthames, 2011). *C. gareipinus* was recorded with higher condition during the rainy season (Offem et al., 2010). During the rainy season, the flood released nutrients, leading to rapid growth of vegetation and increased availability of fish prey items for such as young shoots and leaves, and a variety of macro-invertebrates (Offem et al., 2010). It also has been reported that prey availability increases in habitats with high silt and detrital substrates, and water with high conductivity (Paukert and Makinster, 2009). The conditions of high nutrients and conductivity due to the effluent from the large scale rice scheme upstream of Nsango site could have led to higher abundance of the clarrid prey. Because the nutrition status reflected is by the fish body condition (Armstrong and Witthames, 2011), higher condition factor of clariids at the highly disturbed Nsango site compared to less disturbed sites could be explained the high abundance of the clarrids prey.

3.2.3 The clariids maturity

Fish size at first maturity has often been used to evaluate population responses to environmental stresses, either natural (temperature and predation) or anthropogenic (pollution and fishing) (Chuwen et al., 2011). In this study, the catfish from the highly disturbed sites matured faster than those of the less disturbed site. Natural selection for rapidly maturing individuals is one strategy employed by fish to reproduce before habitats deteriorate further (Marshall and Browman, 2007), which could explain early maturity at the highly disturbed sites. Some studies relate changes in size to changes in fish population density (Chuwen et al., 2011) and that density-dependent phenotypic expressions occur when there is strong competition for a limited supply of food or other essential resources. Competition for resources was ruled out as a major factor that determines clariids' population characteristics for this vast Mpologoma wetland which was assumed to have a high availability of food items. Stressful conditions triggered by environmental conditions and deteriorating water quality (lower oxygen and pH) could have prompted the fish to mature earlier at the highly disturbed sites than at the less disturbed ones. The observed modifications in life-history traits have two interacting origins: genetic and phenotypic plasticity changes (Vasque et al., 2009). In this study, phenotypic adaptation could explain the variations in *Clarias* species maturity and fecundity along the wetland while the generally high fecundity of all individuals is a genetic adaptation of these small fish species.

3.4.4 Small *Clarias* species reproductive strategy

Upstream water flows, feeding the mainstream river essential in maintaining the seasonal flood pulse that is largely responsible for the system's high productivity, influencing many fish species' reproductive cycles (Neil et al., 2007). Breeding peaks of *Clarias* species were recorded during high rainfall and did not vary with levels of disturbance. This was in agreement with many studies on fresh water fish species that recorded GSI peaks during periods of intense sunshine and rainfall (Gómez-Márquez et al., 2008). A combination of physical, chemical and biological factors, such as changes in water level, pH, temperature, clarity and flow velocity, flooding of marginal plants, associated chemical changes and access to suitable spawning sites, are some of the proximate factors responsible for triggering the spawning of catfish (Yalcin et al., 2001). These changes were evident during the rainy months (May and October) during which the small *Clarias* species fishes recorded high GSI values. Generally the high number of eggs could be explained by survival strategy employed by small fish in all tropical region, particularly in streams that experience frequent hydrological disturbances (Winemiller et al., 2008). The high number of eggs is comparable to the fecundity of *C. ulbopunctutus* which also grows to a maximum of 30 cm, ranged from 1974 to 9310 oocytes in river Anambra, Nigeria (Ezenwaji, 1998). The *Clarias* species exhibited more of a total (Hardie et al., 2007) and periodic spawning strategy associated with high fecundity and synchronized spawning period (Winemiller, 1989). Total spawners, which spawn either in one event or over a short time period, respond to large-scale environmental variation by increasing fecundity in order to increase survival in the deteriorating fish habitats and this could explain the higher fecundity of *Clarias* species at disturbed sites.

This study suggests that land use changes within the wetland positively affected the life history biometrics of these *Clarias* species through variations in habitat attributes, particularly the water quality variables. The low correlation coefficients of the regression between water quality and fish biometric were due to the noise effects of other factors such as basin hydrology and water inflow / outflow through the different sites in the wetland. Habitat disturbance due to agricultural activities within the wetland led to habitat heterogeneity, which provided population-level benefits within the species enhancing variations in length, weight and fecundity of the *Clarias* fish populations in the wetland. The resilience of these small *Clarias* species to perturbation was also an important reason as to why their life history biometrics responded that way to land use changes. Although in this study the *Clarias* species seemed resilient to wetland degradation, there is a need to assess the range of land use changes that could lead to a shift in the wetland's ecological role that could disrupt the resilience of these *Clarias* species, so as to formulate an appropriate wetland management strategy.

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CHAPTER FOUR:

VARIATION IN SMALL *CLARIAS* SPECIES' HABITAT ATTRIBUTES AND MOVEMENT PATTERNS IN RELATION TO LAND USE IN MPOLOGOMA RIVERINE WETLAND, EASTERN UGANDA

Abstract

Clariids are relatively resilient to pollution even though their habitat use and movement patterns could be affected by land use activities in wetlands. This study's objective was to assess the habitat use and movement patterns of small *Clarias* species at the different sites in relation to land use in the wetland. Data on fish habitat physico-chemical characteristics were collected from the differently disturbed study sites. The small *Clarias* movement patterns were monitored by use of mark and recapture method with external Floy type tags. Invertebrate survey and fish stomach content analysis were carried out to assess the *Clarias* food items. More information on the movement and habitat use was generated from a structured questionnaire survey among the fishermen in the wetland. Water quality parameters varied among sites with conductivity significantly higher at the highly disturbed sites (ANOVA, Tukey's test $p < 0.05$) while dissolved oxygen lower at the highly disturbed sites than the less disturbed sites ($p = 0.027$). Invertebrates varied among sites with higher chironomid larvae at the highly disturbed sites than at the less disturbed sites. The occurrence percentage of food items in the fish stomachs varied among sites; more plant materials (53%) and oligochaetes (88.6%) in the small *Clarias* fish stomachs at less disturbed sites while 52% insect and 21% chironomid larvae in fish stomachs at the highly disturbed site. The small clariids habitats were shallow water pools of about 0.5 m deep, dark areas, high plant cover and slowly flowing water. 76.5% of the fishermen concurred that these small fish make movement and 30.8 % of the fishermen attributed the fish movement to reduction in water level. Although floy tag recovery rate was low, a downstream movement during the dry season was exhibited by the tagged fish at all sites. These results were attributed to the species' life history strategy, adaptation to change in environmental variables and avoidance of predators in deep waters. There is need for further investigation on the movement patterns of small *Clarias* species using the radio telemetry for comparison and derivation of more generalized and conclusive view.

Key words: small *Clarias*, mark-recapture, Floy type tags, habitat use, riverine wetland

4.1 Introduction

Catfishes are highly mobile fish. Their movements and habitat use within their natural range have been reported to be driven primarily by foraging behaviour and reproductive biology (Kadye and Booth, 2013). Factors that determine movements and habitat use in most fish species include changes in temperature, water quality, food availability and suitable spawning areas (Zimmer et al., 2010). Movements of riverine fish species are further influenced by habitat conditions such as vegetation, substrate, water depth and water velocity (Kadye and Booth, 2013). These microhabitat variables are influenced by stream gradient, stream size and human activities which ultimately influence fish communities (Kadye and Moyo, 2007). Despite the limited diversity of fishes within papyrus swamps and other heavily vegetated wetlands, the microhabitats maintain large populations of endemic wetland fish species including clariid catfishes (Chapman et al., 1999). Changes in wetland use may alter vegetation structure and other environmental conditions affecting the fish movements and their habitat use. Agricultural activities in wetlands alter hydrologic flows and dynamics of the flood pulse, undermining the ecological integrity of systems and changing the hydraulic connectivity between habitats (Kingsford et al., 2006; Conallin et al., 2010). Fish habitat use and movement patterns are disrupted and yet their movements have often been regarded as an adaptive behaviour for increasing growth, survival, reproductive success and consequently productivity of the fishery (Koed et al., 2006).

The longitudinal movement and habitat use of several large catfish species have been studied in large lakes and rivers. Migration behavior of catfish (*Ictalurus punctatus*), flathead catfish (*Pylodictis olivaris*) and *C. gariepinus* have been studied within their natural range (Siegwarth and Johnson, 1994; Daugherty and Sutton, 2005; Kadye and Booth, 2013). However, little information is available for disturbed habitats and the lateral movements within wetlands (Mitamura et al., 2008; Conallin et al., 2010; Kadye and Booth, 2013). The small scale Mpologoma riverine wetland fishery depends heavily on the endemic small *Clarias* species for subsistence and bait for *C. gariepinus* and *Protopterus aethiopicus* fishing. This wetland, which is part of the Lake Kyoga basin, has been altered by land use changes associated with agricultural activities (Annon, 2004). Over 7000 hectares of wetlands are converted into rice farms to cater for the high population growth rate of 4.7 % in eastern districts of Uganda, (Musiime et al., 2005; MAAIF, 2009). Apparently, the production of catfish (*C. gariepinus*) in Lake Kyoga basin has reduced from more than 1600 metric tonnes in the 1980s to 1.35 metric tonnes in 2000 (Muhoozi, 2003). Conversion of natural wetland to agricultural land use often results in habitat fragmentation and degradation.

Wetland conversion is one of the widespread anthropogenic contributors to loss of fish species in many wetlands (Hugueny et al., 2011). Disturbance of fish habitats by the human activities can trigger changes in their life history strategies, dispersing them to remote areas to escape local habitat stressors and disrupt movements to specific habitats that are essential to a specific life stage (Diana et al., 2006).

This chapter describes the assessment of the variation in habitat attributes and movement patterns of small *Clarias* species at the different sites in the Mpologoma riverine wetland. It was hypothesized that habitat attributes and movement patterns of small *Clarias* species would vary between wetland sites with different levels of disturbance. The wetland water quality, vegetation pattern, macro-invertebrates and small *Clarias* species stomach content and movement patterns would be different at the differently disturbed sites within the wetland. Knowledge of the clariid habitat use and movement will contribute to the understanding of the impact of wetland use change on the wetland fishery in the era of escalating wetland degradation in rural areas in Uganda.

4.2 Materials and Methods

Four differently disturbed sites in the Mpologoma riverine wetland part of Lake Kyoga basin were identified for the study as described in Chapter 1. The sites were: Mazuba which represented an intact wetland site, Budumba was the least disturbed site, Kapyani was the moderately disturbed site with small scale rice farm in the wetland and Nsango was the highly disturbed site receiving discharge from the Tilder large scale rice scheme. Physico-chemical parameters were determined and used to assess the small *Clarias* fish habitats attributes at all the sites. Stomach content analysis and macro-invertebrates survey were done for some of the fish caught to assess the food composition so as to infer their habitat use. Small *Clarias* fish species were trapped, tagged and released to assess their movement patterns at each site in the wetland.

4.2.1 Determination of physico-chemical parameters

Determining habitat physical characteristics such as water depth, dissolved oxygen, conductivity, nitrogen and phosphorus concentrations, substrate and the dominant vegetation was done from January to December 2012. Water depth was measured at three different points using a deep stick within wetland nearby the fish trapping points once every month at each site. Water samples were also collected at three different points nearby fish trapping areas for water quality assessment. Conductivity and pH were determined *in-situ* with a Hanna pH/Ec/TDS/^oC HI 9813-6 meter and probe. Dissolved oxygen and temperature were determined on site by Oakton DO 110 meter and probe. Chemical analysis of alkalinity, NO_3-N, SRP and TP was done according to standard procedures (APHA, 1995) in the laboratory. Macrophyte cover and substrate characteristics survey in the nearby the small *Clarias* species trapping sites were done using proportional additive assessment where the proportions of area was estimated and summed up to 100 percent. In this case, a habitat area of 100 m^2 was assigned the following attributes: depth – 50% 0 – 1 m, 50% 1-2 m; substrate - 25% gravel, 50% sand, and 25% silt; and cover – 30% submergent and 70% no cover basing on Habitat Suitability Matrix (HSM) method (Minns et al., 2001).

4.2.2 Wetland Invertebrate community survey

Macro-invertebrates were sampled during a single visit to each study site in the dry and wet season months (January and May respectively) of 2012. Macro-invertebrates were collected from macrophyte beds in each wetland using funnel traps designed for use in littoral habitats (Whiteside, 1974). Each sampler consisted of a plastic funnel (30-cm diameter) attached to a plastic plate, with mesh net of 0.5 mm. After removing the fish traps, a stick was used to dislodge the macro-invertebrates from the substrate and water column and collected with the funnel nearby the trapping area. The whole sample was washed into a bucket, stirred and sieved again with 0.5 mm mesh sieve. Macro invertebrates retained were handpicked with forceps and preserved with 70% alcohol in vials for identification. Macro invertebrates were considered as those organisms recognisable with the naked eye, excluding copepods, cladocerans and ostracods. All invertebrates were identified to the lowest taxon (genus) as much as possible using available identification keys (Day et al., 2003; De Moor et al., 2003). Notable exceptions were chironomids (family) because chironomidae has more than 30 genera and unidentifiable immature individuals are usaully collected. The number of macro invertebrate individuals per sample was expressed as their relative abundance as shown in equation 4.1 according to Batzer et al., (2001).

$$R.A = (n \times 100)/N \; (p_i \times 100) \qquad (4.1)$$

where n is the number of individuals of one taxon; N the total number of individuals in the sampling site; p_i the proportion of the ith species.

4.2.3 Fish gut content analysis

In order to determine the variations in food needs of the small clariids at the differently disturbed sites, fish stomach content analysis was also done. Fish samples of small clariids were collected monthly using nine locally made basket traps baited with dead earthworms. Three traps were set randomly at three different points within the papyrus of each study site between 06:00 am and 12:00 pm. Each fish specimen was immediately sacrificed and its stomach contents were placed into separate vials and preserved with 40% alcohol. The degree of stomach fullness rates were recorded ranging from 0 (empty), 1 (quarter-full), 2 (hall-full), 3 (three quarter-full) and 4 (full stomach) as described by NaFIRRI (2007). Gut contents were then taken to the laboratory for analysis. In the laboratory, they were emptied into separate petri dishes and the prey items identified into different groups. The food items were quantified using the volumetric method where percentage volume contribution of each food item is visually assessed relative to all of the food items present in the gut. This was multiplied by the percentage fullness of the stomach. The importance of each food type between samples was then determined using the total number of points for each food type expressed as a percentage of the maximum number of points for a particular sample. The importance of each food item relative to other food items in any one sample was determined using the number of points of a food item expressed as a percentage.

4.2.4 Tracking small *Clarias* fish movement

The movement patterns were monitored by using external Floy tags. Trapping and tagging for recapture was done for all sites and during all seasons between August 2012 and August 2013 to determine spatial and seasonal aspects of small *Clarias* species movement behaviour. Fish to be marked by tagging were collected using five basket experimental fishing traps at the four differently disturbed sites. Live fish in good physical condition were selected immediately after capture. They were placed in bucket containing cool water collected from the wetland. Individual fish specimen was picked for total length and weight determination and thereafter a floy tag inserted quickly (Plate 4.1). A floy tag was inserted through the fish's dorsal musculature passing between the anterior dorsal fin rays. Tagged fish were then placed in a bucket with freshly collected wetland water until they recover their balance, breathing and swimming movements, after which they were released into the wetland from one selected point for the whole tagging exercise. Only those fish that showed a good reaction to the tagging were released. At each site, fish for tagging were randomly selected and tagged with differently coloured tags from those used at other sites. All tagging was performed on-site, at the margins of the wetland to avoid mortality caused by the stress of transportation. The tagging was based on procedures described by Mlewa et al. (2005). Tagged fish were released close to the landing point of every site. The recovery of the released tagged fish was made through the fishery based on a cash reward and recording the location of the fishing activity (Hoggarth et al., 1999). Local fishermen were engaged in retrieval of recaptured tagged fish. Prior to the tagging exercise, an awareness creation was done through public meetings, posters, handouts and verbal announcements to fishermen indicating that for any caught tagged fish, the mean distance moved, direction from the release point (upstream or downstream) and home ranges of individual fish should be noted and reported to the researcher. Each tag returned by fishermen was recorded for its site and the indicators of fish movements including distance in metres at which the tagged fish was recaptured, direction from release point (downstream or up upstream of the river) and time in number of days after release were noted.

More information on the movement patterns and habitat use was generated from structured questionnaire distributed among the fishermen at every site to evaluate the small *Clarias* species movements and habitat attributes. During the fishing season, questionnaires were randomly distributed to fishermen, enquiring on the characteristics of the suitable fishing sites and breeding sites for small clariids, best and worst fishing season, small *Clarias* fish species' movement patterns and the possible reasons for the fish movement.

4.2.5 Data analysis

All data were analysed using the Statistical Package for Social Sciences (SPSS version 16, IBM ©). One-way ANOVA followed by Tukey's Honestly Significant Difference (HSD) test was used when a significant F value was obtained to discriminate between the mean values of water quality parameters amongst the different study sites. Principal component analysis (PCA) was used to analyze association between physico-chemical parameters among sites with varied levels of disturbance. Loadings of the principal components (PCs) were derived from varimax orthogonal rotation and Kaiser normalization of the second and third PCs. Only those variables which loaded heavily on any of the principal components were considered. To check for relationships between variables and sites, regression correlation scores of the PCs were used. The number of macro invertebrates per sample was expressed as their relative abundance for each site.

The stomach fullness index of fish was determined to evaluate the feeding pattern of the small *Clarias* species at the differently disturbed sites. Occurrence percentage (F) was estimated using the formula indicated below as proposed by Stobberup et al., 2009.

$$F = (N_{ei} / N_t) \times 100 \qquad (4.2)$$

where N_{ei} = number of stomachs containing a type of prey i and N_t = total number of non-empty stomachs examined. The prey items were identified to family level and the relative proportion of each to stomach fullness was calculated according to Hyslop (1980). Stomach content data were combined into key prey groups for subsequent analysis: detritus, chironomids, molluscs, insects (larvae, pupal and adult stages of terrestrial insects), crustaceans (copepods and ostracods) oligochateas (all worms) and higher plant material.

The total number of tags recaptured was used to calculate the percentage tag return of the 202 released tagged fish in both the wet and dry season of 2012. The distances moved by the tagged fish were estimated in relation to 100 m of a football pitch. Frequencies and percentages of responses of the socio-economic data on *Clarias* movement patterns were calculated. Cross tabulations with the Chi square test were used to test the association dependency among variables and between variables and study sites.

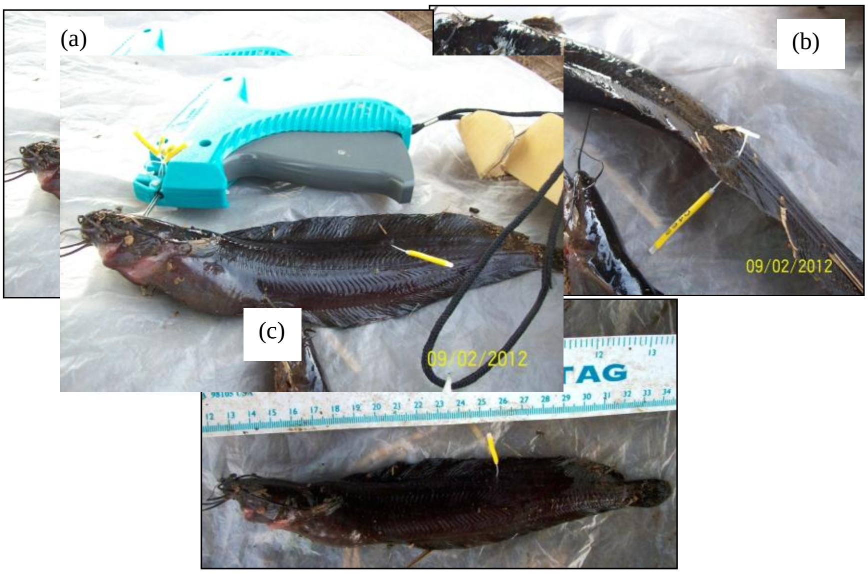

Plate 4.1: The floy tagging gun (a), small *Clarias* species tagged with a numbered tag that was used for tracking the fish (b) and a mature size of small *Clarias* species in the Mpologoma wetland (c)

4.3 Results

4.3.1 Small *Clarias* fish habitat preference

Small *Clarias* fish were mainly found within the wetland and shallow ends of the river channel at all sites. Variations in suitable fishing areas were observed between seasons. During the rainy seasons, the fish were caught deep inside the wetland vegetation while during the dry season more small fish were caught in shallow areas near the river channel. There were differences in the phosphorus concentration, electrical conductivity, substrate characteristics and plant cover along the wetland (Table 4.1). Water conductivity was as low as 115 µS/cm at the least disturbed Budumba site and as high as 454 µS/cm at the highly disturbed Nsango site. Conductivity was significantly higher at the highly disturbed Nsango site than at the other sites (ANOVA, Tukey's HSD test $p < 0.05$). It was also higher during the dry season than in the wet season at the highly disturbed Kapyani and Nsango site ($p < 0.05$). Dissolved oxygen was lower at the highly disturbed sites than at the less disturbed sites ($p = 0.027$) in the wetland. The dissolved oxygen (DO) within the papyrus was lower at the highly disturbed Nsango site (0.76 ± 0.66 mgl^{-1}) compared to that of least disturbed Budumba site (1.76 ± 1.35 mgl^{-1}). Conductivity increased while dissolved oxygen and orthophosphate decreased in dry season at all sites in the wetland. Nitrate concentration was very low at all sites ranging from 0 to 0.043 mgl^{-1}. Total phosphorus was also lower at the highly disturbed sites than the less disturbed site. The principal component analysis (PCA) produced three principal components that explained 57.79% of the variance, loaded heavily for the variables; conductivity, pH, dissolved oxygen, orthophosphate and total phosphorus. With the exclusion of water depth and temperature, PCA II explained 69.84% of the variance. Although other variables significantly correlated with the sites, dissolved oxygen, orthophosphate and conductivity were the dominant contributors to variation among the sites along the wetland.

The plant taxa were dominated by Cyperaceae, followed by Poaceae, Convolvulaceae and Compositae at all the sites, while a few plant taxa were unique to particular sites. The moderately disturbed Kapyani and highly disturbed Nsango sites had a higher cover of *Polygonum* sp., *Leersia hexandra* and *Vossia cuspidata*. Rice and maize crops were common at these two sites. *Eichhornia crassipes* was only recorded at highly disturbed Nsango site. While the least disturbed sites Budumba and Mazuba had *Nymphaea* sp and *Ceratophyllum demersum*, they were dominated by *Cyperus papyrus.* The hand feeling of highly disturbed sites substrate was recorded as much smoother feel of roating plant materials of grasses. The hand feeling of least disturbed sites substrate had a much more coarse materials with large pieces of roating plant materials particularly papyrus remains than the highly disturbed sites.

Table 4.1: Small *Clarias* fish habitat metric characteristics and substrate description at the different study sites in the Mpologoma wetland during the wet season in 2012 (values are mean ± S.D., n = 256)

Habitat characteristics	Budumba	Mazuba	Kapyani	Nsango
Water depth (m)	0.52 ± 0.27	0.35 ± 0.14	0.30 ± 0.15	0.35 ± 0.14
Dissolved oxygen (mgl^{-1})	1.29 ± 1.32	1.76 ± 1.35^{a}	1.36 ± 0.37	0.76 ± 0.66^{a}
Temperature (ºC)	24.85 ± 1.11	25.03 ± 1.13	25.73 ± 1.47	24.76 ± 1.40
Conductivity (µS/cm)	160 ± 27^{a}	180 ± 54^{b}	186 ± 67^{c}	$357 \pm 97^{a,b,c}$
OPO_4^{3-} (mgl^{-1})	$0.49 \pm 0.39^{a,b}$	0.26 ± 0.32	0.16 ± 0.15^{a}	0.16 ± 0.15^{b}
TP (mgl^{-1})	$0.69 \pm 0.54^{a,b}$	0.66 ± 0.59	0.30 ± 0.29^{a}	0.23 ± 0.19^{b}
Description of sediments/substrate	Very dark, no sand or gritty feeling, a lot of decomposing plant materials (particularly of papyrus remains)	Dark brown, little soil (silt and clay), little gritty feeling, decomposing plant material (particularly of papyrus and grass remains)	Very dark, with sand and some gravel, more gritty feeling, a lot of decomposing soft plant material (particularly of grass, herbaceous plants and papyrus)	Very dark, little sand or gritty feeling, a lot of decomposing plant materials (particularly of grass, herbaceous plants and papyrus remains)

Values in the same column with the same superscript were not significantly different (Tukey's test; $P < 0.05$)

4.3.2 Wetland macroinvertebrate community composition

Fourteen invertebrate taxa were identified at the study sites in the wetland (Table 4.2). Oligochaetes, insects' larvae and gastropods were the dominant groups which also showed differences among the different sites. Oligochaetes had a higher percentage occurrence at the least disturbed site (Mazuba) than at the moderate and highly disturbed (Kapyani and Nsango) sites. On the other hand, insects' larvae and gastropods were higher at the disturbed sites than at the least disturbed sites. Particularly, chironomid larvae had a higher percentage at the Kapyani and Nsango sites than at the least disturbed Mazuba site. Other taxa were rare but present at all the sites. At highly disturbed sites and during the dry month of January, chironomid larvae were the most abundant items while during the wet month of May oligochaetes were the most abundant prey items. During both seasons at the less disturbed sites, the major food items found in the fish stomach was predominantly oligochaetes, insect larvae and plant material. Small fish and other shallow water adult insects were consumed more during the wet season month.

Table 4.2: Percentage occurrence of macroinvertebrates in the substrate at the different wetland sitesin November 2012 (values represent percentage contribution of each taxa to the total number)

Class		**Budumba**	**Mazuba**	**Kapyani**	**Nsango**
Oligochaeta	*Limnodrilus* sp	49.93	58.24	23.01	37.76
Hirudinea	*Haempis* sp	6.13	4.40	4.87	2.49
	Glossiphonia sp	1.65	-	-	-
Chironomidae	*Chironomus* sp. larvae	24.10	15.38	32.30	28.22
Diptera	*Culicodes* sp larvae	-	-	2.65	-
	Chaoborus sp. larvae	2.48	-	-	-
Ephemeroptera	*Afronurus* sp. larvae	3.31	4.40	0.88	-
Orthoptera	*Glyllotalpa* sp.	0.83	-	1.33	-
	Gyrinus sp. larvae	1.65	-	0.88	-
Odonata	*Idomacromia* sp. larvae	1.65	6.59	1.33	0.83
Hemiptera	*Lethocerus* sp	0.83	-	0.88	0.41
Gastropoda	*Physa* sp	5.79	6.59	29.65	20.33
	Helisoma sp	1.65	-	1.33	1.24
Bivalvia	*Lucinoma* sp	4.40	0.88	8.71	4.40
	Total	100	100	100	100

4.3.3 Fish gut content

Of the 738 fish stomachs examined, 15.3% (113) were full, 26.0% (191) were partially full and 58.3% (434) were empty. Eight food items comprising of aquatic flora and fauna were dominant with varying occurrence percentage in the fish guts at the different sites (Table 4.3). Oligochaetes were the most dominant prey at all sites with a range of occurrence percentage of 47.7 to 96.8 % and mean fullness index of 6.0 because it was mainly used as bait for trapping the small *Clarias* species. Molluscs and fish prey were rare (low occurrence percentage). Based on the percentage of relative importance, chironomids scored higher percentage compared to other food items at the highly disturbed sites. While insects and small fish scored higher percentages at the less disturbed sites than those consumed at the highly disturbed sites (Figure 4.1). With one way ANOVA, the occurrence percentages of insects and chironomids were significantly different between sites (F = 3.45 and 3.08; P = 0.025 and 0.043 respectively. After the LSD post hoc test, the occurrence of insects was significantly different between Budumba and Kapyani (P = 0.012) and between Mazuba and Nsango (P = 0.036). The occurrence of chironomids was significantly different between highly disturbed Nsango and less disturbed sites Budumba and Mazuba (P = 0.021 and 0.021 respectively). There were no marked seasonal differences in the clariids' stomach content at the less disturbed sites. At the highly disrtubed Kapyani and Nsango sites, unidentified plant seeds were observed in the fish guts during the rainy season. With respect to change in diet among the small *Clarias* species by comparing food items in between immature and mature clariids, generally all size groups consumed most of the prey categories. However, small fish were also consumed by the mature small *Clarias* species more at less disturbed Mazuba site than in the other sites as indicated by the amount of unidentified fish remains with a percentage occurrence of 20.5%. While fish prey was totally absent in the immature classes of the clariids in the wetland. There were no significant differences between prey items in the different seasons among the *Clarias* species in the wetland.

Table 4.3: Occurrence percentage (Op) of different food items in the stomachs of small *Clarias* species in the Mpologoma riverine wetland, January to December 2012

Food items	Budumba	Mazuba	Kapyani	Nsango
Detritus	32.3	20.5	45.5	22.7
Fish	3.2	20.5	6.1	6.8
Insect	27.5	6.8	12.1	52.3
Chironomids	8.1	13.6	21.2	20.5
Oligochates	96.8	88.6	71.2	47.7
Vascular plant material	53.2	54.5	31.8	31.8
Molluscs	3.2	9.1	3.0	4.5
Crustaceans	3.2	0.0	4.5	6.8

4.3.4 Small clariids movement patterns in the wetland

A total of 253 fish with a total length range of 12.0 to 24.32 cm were tagged and released between January and December 2012 along the wetland (Table 4.4). Of these 15 tagged fish (6.32%) were recaptured within about one month after release (Table 4.5). During the dry season months, all recaptured fish at the sites were found downstream as far as 120 m. Although, few recoveries of marked fish were made during the wet season months, more fish were recaptured upstream than those caught downstream. Therefore, fish move upstream during rainy season and downstream during the dry season. The distances moved by the tagged fish ranged between 20 m to 150 m downstream and there were no significant differences between distances moved by the targeted fish at the differently disturbed sites. The water depth within the wetland varied with seasons. At all site the water depth was high inside the wetland particularly at Budumba and Kapyani with mean depth of 1.54 m and 0.84 m respectively. During the dry season water depth was low at all sites within the wetland, particularly at the highly disturbed Nsango site with as low as 0.21 m.

Supplementary information on the movement and habitat use of the *Clarias* was derived from indigenous knowledge of the community members based on the structured questionnaire survey (Table 4.6). Of the 124 respondents interviewed, 76% agreed that small *Clarias* species move and 30% believed these fish moved with changes in water level. The majority of fishermen (76.5%) could identify best fishing sites for small *Clarias* species and 58.5% of fishermen mentioned ideal areas are those with water depth range of 0.5 to 1.0 m, slowly flowing water, dense and mixed vegetation cover of different emergent macrophytes. They also revealed that such areas should have underneath rotting vegetation particularly grasses and other herbs. In addition, 46% of all respondents indicated that the ideal habitat substrate should be predominantly clay.

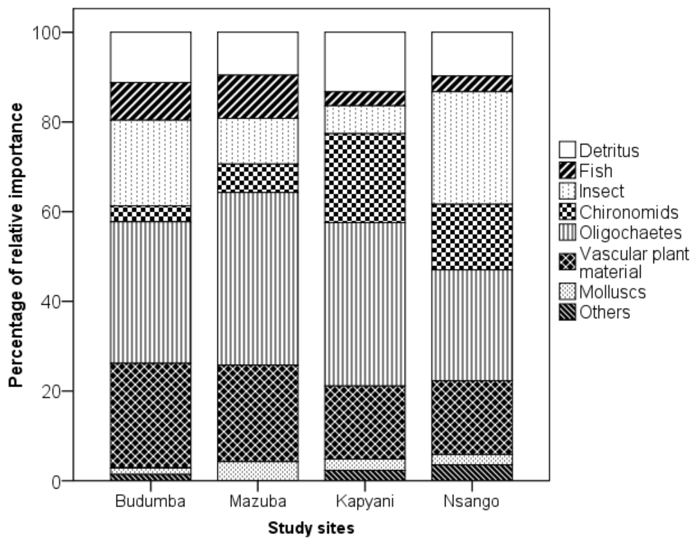

Figure 4.1. Relative importance of food items in the guts of small *Clarias* species at the different sites in the wetland

Table 4.4: Number of small *Clarias* fish species, mean length and weight of the released tagged fish at the different sites in the wetland

Site	n	Mean Total length (cm)	Mean Weight (g)
Budumba	64	15.78 ± 3.76	28.14 ± 17.39
Mazuba	47	18.02 ± 4.15	34.69 ± 18.12
Kapyani	56	18.16 ± 3.22	33.84 ± 20.21
Nsango	35	19.17 ± 5.15	44.78 ± 22.35

Table 4.5: Floy tags recovery, direction of movement of tagged fish and mean water depth within the wetland at the different study sites along the wetland (August 2012 to July 2013)

Site	Release Date	Tag No.	Downstream	Upstream	Days at recapture	Water depth (m)
	Dry season					
Budumba	Jan-12	495	20 m		3 day	0.57
Budumba	Feb-12	473	70 m		10 days	0.45
Budumba	Mar-12	482	50 m		4 days	0.51
Budumba	Jul-12	551	120 m		8 days	0.48
Budumba	Jul-12	567	80 m		15 days	0.48
Mazuba	Jan-12	76	20 m		3 days	0.34
Mazuba	Feb-12	91	18 m		5 days	0.25
Kapyani	Feb-12	450	110 m		5 days	0.34
Kapyani	Feb-12	446	50 m		10 days	0.34
Kapyani	Feb-12	442	90 m		21 days	0.34
	Wet season					
Kapyani	Apr-12	423	150 m		25 days	0.51
Kapyani	May-12	417		80 m	11 days	1.53
Kapyani	Aug-12	403	120 m		14 days	0.84
Nsango	May-12	295		10 m	5 days	0.53
Nsango	May 12	283		30 m	6 days	0.76

Table 4.6: Summary of responses based on community members interviewed at the different study sites indicating the level of indigenous knowledge on small *Clarias* species movement and habitat preference in the Mpologoma riverine wetland

	Budumba (n = 46)	**Mazuba** (n = 27)	**Kapyani** (n = 49)	**Nsango** (n= 29)	**Overall** (n = 151)
Knowledge of Catfish movement					
Yes	80.4	89.7	51.0	100	76.5
No	10.9	0	16.3	0	8.5
Not applicable	8.7	10.3	32.7	0	15.0
Knowledge of the fish moving season upstream/downstream					
Wet season	39.1	27.6	24.5	58.6	35.9
Dry season	47.8	37.9	22.4	24.1	34.7
Not applicable	13.0	34.5	49.0	17.2	29.4
Main reasons for moving					
Low water	37.3	20.0	52.8	3.4	30.8
High water	11.6	24.0	8.3	17.2	14.3
Following water	20.9	20.0	30.6	20.7	23.3
Limited food items	7.0	8.0	8.3	44.8	15.8
Spawning time	23.3	28.0	0	13.8	1.5
Knowledge of small Clarias fish habitats					
Yes	84.8	75.9	55.1	100	76.5
No	0	0	4.1	0	1.3
Don't know	15.2	24.1	40.8	0	22.2
Best fishing areas for small Clarias fish species					
Water level					
Less than 0. 5m	0	0	8.5	20.7	6.8
0.5 to 1 m	60.5	50	48.9	79.3	58.5
Above 1 m	11.6	17.9	0	0	6.8
Don't know	27.9	32.1	42.6	0	27.9
Substrate characteristics					
Stony	2.7	0	0	19.0	4.3
Sandy	0	3.8	12.9	0	4.3
Clay soft	64.9	53.8	38.7	33.3	49.6
Don't know	32.4	42.3	48.4	47.6	41.7
Small Clarias species Catch (Individuals per trap per day)					
Low	9 ± 4	9 ± 3	10 ± 4	14 ± 3	10 ± 4
Peak time	30 ± 2	44 ± 3	36 ± 2	51 ± 3	39 ± 3

4.4 Discussion

4.4.1 Wetland fish habitats

Wetland fish habitats vary with the ecological heterogeneity of the limnological characteristics and biota of any aquatic ecosystem (Onyango and Jentoft, 2010). In the Mpologoma wetland, fish habitat attributes; water level, vegetation cover, substrate composition and invertebrate community varied among sites with different land uses. Land uses such as agricultural activities affect water and sediment inputs, destabilize the existing habitat attributes and set off a complex cascade of changes (Allan, 2004). High conductivity and low dissolved oxygen at the highly disturbed sites were attributed to the effects of wetland perturbation by agricultural activities (Kuhar et al., 2007; Ssanyu et al., 2014). The low dissolved oxygen caused by low redox reactions, resulted in lower orthophosphate at the highly disturbed sites than at the less disturbed sites. Agricultural activities regulate river flow which has undermined the ecological integrity of many of the many rivers, changing the dynamics of the flood pulse and altering patterns of hydraulic connectivity between habitats (Kingsford et al., 2006). There are corresponding ecological changes in river and floodplain environments, and in the flora and fauna. There is an invasion of wetland biota, a loss of some habitat specialists and an increase in the abundance of habitat generalists, proliferation of alien plants and animals and perennial inundation has reduced the 'pulse' of wetland productivity associated with disturbance of the wetland (Conallin et al., 2010). This explains the variations in dominant macrophytes at the wetland edge and along the lagoon at the different sites within the wetland. Agriculture related disturbances in wetlands encourage growth of a mixture of plants including opportunistic herbaceous species (Raghubanshi and Tripathi, 2009). The majority of these plants have low fiber content which decompose more easily than the tough papyrus plant at the less disturbed areas. Vegetation cover affected the composition of substrates and therefore the presence of herbaceous plants could explain the occurrence of fine plant materials in the substrates of highly disturbed sites. The undifferentiated alluvium of the Mpologoma catchment deposits as the parent rock/materials leads to soils with black and grey sandy clays in the substrates (Anon, 2004), observed at all the sites. However, substrates of highly disturbed Nsango had a gritty feeling of sand which could attributed to influence by deposition of recently weathered soils typical of upstream areas. While at the less disturbed sites, Budumba and Mazuba, substrates had a non gritty feeling of clay associated with increased deposition of silt and clay particle due to low water current. On the other hand, Kapyani substrates had a gritty feeling of sand attributed to the high water flow which reduces settling of small soil particles content, leaving more large particles to settle in the wetland sustrate.

Water depth within the wetland did not vary significantly among the three upstream sites as it did at downstream, Kapyani site. This was attributed to differences in rainfall and temperature regimes and the cumulative increase in water depth downstream of the river. The occurrence of the long rains (March to May), the short rains (September to November) and the high rainfall variability explains the progressively drier climate from east to west in the Lake Kyoga basin (WREM, 2008). In addition to the increasing farming activities within the wetland, Kapyani site was potentially vulnerable to both droughts and floods. The site behaved more like a seasonal floodplain wetland with a water depth varying between very low and very high values. Therefore, climate variability and wetland clearing for rice growing were very important drivers that determined the water depth and vegetation patterns at the highly disturbed Kapyani site. On the other hand, conversion of natural wetland to large scale rice scheme affected the water quality of fish habitats at highly disturbed Nsango site. The use of agricultural fertilizers for intensive rice production accounted for the higher conductivity and lower dissolved oxygen observed in Nsango than the other sites. The water from highly fertilized and mechanised Tilder rice scheme drained into the Nsango study site impacting water quality. The site's low dissolved oxygen was attributed to high redox reactions of high organic matter in the inflowing water. The characteristics of water released from the rice fields had an effect on the vegetation pattern at the Nsango site. The probable high essential nutrients for plant growth resulting from the fertiliser application in the rice fields at Nsango boosted the growth of water hyacinth associated with high nutrient waters. On the other hand, the small scale rice and maize farms cultivated right to the river bank could have led to the high levels of electrical conductivity recorded at highly disturbed Kapyani. The limited use of fertiliser at Kapyani compared to that used at Tilder rice scheme near Nsango site partly led to less biotic activity and low organic matter. This explains the higher dissolved oxygen and less conductivity recorded at moderately disturbed Kapyani site than at highly disturbed Nsango site.

4.4.2 The clariids' habitats and feeding habits

Both *C. liocephalus* and *C. alluaudi* were primarily found in shallow water within the emergent vegetation zones of the wetland. The water level within the wetland where fish traps were placed did not vary much between the differently disturbed sites. On average, the water depth was a half metre indicating that the small *Clarias* fish preferred shallow pools at all sites in the wetland. The fishermen confirmed that small catfish catch was higher in vegetated shallow waters during both rainy and dry seasons. Other studies such as Kadye and Booth (2013) have also demonstrated that catfish prefer shallow inshore littoral habitats for both feeding and breeding. Despite the same water depth, the macro invertebrates varied among sites in the wetland. At highly disturbed sites and during the dry months of January to March, chironomid larvae were the most abundant items while during the wet months of April, May and October, oligochaetes were the most abundant prey item. Changes in riparian vegetation composition due human activities, together with modification of stream morphology, decreased habitat diversity, affected water quality and consequently altered the invertebrate composition of streams (Kuhar et al., 2007). The Intermediate Disturbance Hypothesis (IDH) suggests that species diversities are moderate in stable ecosystems, highest in intermediate and low in severely degraded ecosystems (Connell, 1978). The comparison of macroinvertebrates results at hihgly disturbed Kapyani site with less disturbed Mazuba and highly disturbed Nsango site was consistent with the hypothesis. The combination of small scale farming activities and abandonment of farms during the flooding regime at Kapyani site offered the intermediate disturbance conditions, leading to high number and abundance of macroinvertebrates at the site.

The principal food item for the small *Clarias* species was insect larvae which were also found abundant in the substrates at all the sites. A large portion of the stomach content was plant material and detritus which was swallowed accidentally as the fish ate the macro invertabrates. Prey items for the small *Clarias* fish could have varied with changes in their abundance which is dependent on the prevailing ecological conditions in the wetland. But also individual fish displayed opportunist foraging strategy by hunting in the substrate for earthworm and chironomids and surface feeding on floating debris and small fish depending on the availability of the prey (Kadye and Booth, 2013). Small fish and other swallow water adult insects were consumed more during the wet season months. Unidentified plant seeds washed from the adjacent gardens into the stream during floods could explain their occurrence in fish stomachs of both small *Clarias* species at the highly disturbed Kapyani site particularly in the rainy season. This implied that small clariids changed their feeding behaviour from omnivorous at the highly disturbed sites to opportunistic feeding at the less disturbed sites as response to variability of food items in the wetland.

According to Bruton (1979), catfishes are generally known to be benthic feeders. However, this study revealed that small *Clarias* species depend on a wide range of prey, hence the omnivorous feeding habit like other clariids such as *C. gariepinus* and *C.*

anguillaris (Offem et al., 2009; Alhassan et al., 2011). The presence of detritus in their stomachs further confirms these species' primarily benthophagic feeding habit. Naturally, *C. liocephalus* is an opportunistic feeder, consuming food depending on availability rather than preference (Yatuha et al., 2012). The relatively high frequency of empty stomachs among sampled fish was attributed to the general nocturnal feeding behaviour in catfishes (Bruton, 1979a). All in all, the abundance of plant material and detritus among other food materials in the stomachs of both *Clarias* species defined their ecological role. The conversion of resources at the base of the food chain into food for higher trophic levels is a common phenomenon of wetland fish species (Bruton and Jackson, 1983).

4.4.3 Small *Clarias* species movement patterns in the wetland

Small *Clarias* fish species exhibited downstream and upstream movement in the wetland based on the results from the experimental tagging and indigenous knowledge from local fishermen. Fish movement is an adaptive strategy involving shifting of part or all of a population in time between discrete sites but not necessarily involving predictability or synchronicity in time, since inter individual variation is a fundamental component of populations (Vokoun and Rabeni, 2005). The seasonal upstream and downstream movement exhibited by small *Clarias* species, is a common habit of riverine species in search for suitable habitats (Vokoun and Rabeni, 2005). While the water level in the river channel rose during the wet season, the small *Clarias* species moved upstream towards inundated vegetation zones to avoid the large-fast swimming predators (*Protopterus* sp and *C. gariepinus*) in the deep waters downstream. Fish movements are some of the strategies by which individual fish may easily and quickly adjust to variations in local habitat changes (Saraniemi et al., 2008; Zimmer et al., 2010). Water depth decreases upstream during the dry season forcing these fish to move downstream looking for suitable foraging habitats. The modified channel morphology permitted the fish to move further downstream which was demonstrated by the longer distance moved by small *Clarias* fish at the highly disturbed Kapyani site than at the other sites. The intact natural vegetation at the less disturbed Budumba and Mazuba site provided hydraulic resistance to water flow, enabling fish to forage laterally near the release point which explained the fish recapture at a few metres near the release point at these sites. Therefore, variation in the human induced wetland disturbance affected the small *Clarias* species movements in the wetland.

Many studies of other catfish species migrations have associated the fish movements to spawning and foraging behavior triggered by changes in water quality (Siegwarth and

Johnson, 1994). From the gonado somatic index analysis, these small *Clarias* species spawn at the beginning of the rainy season (April to May and October to November) (Ssanyu et al., 2014). Therefore, the clariids start moving upstream looking for suitable spawning site with clear flowing water in the rainy season. In the dry season, water level reduced upstream, water quality declined in the shallow areas which necessitated the small catfish to move downstream. The observation was similar to that of flat head catfish migration in three streams in the North America during a rainy season, followed by downstream movement back into the river in a dry season (Siegwarth and Johnson, 1994). During the dry season, reduction in water level led to restrictions in catfish movement and fragmentation of the fish population by habitat discontinuity created by alternation of dry areas and shallow pools within the wetland. This also explains the downward movements and the higher chances of recovering the tagged fish that was observed in the dry season.

The recovery rate of tagged fish in the present study was low (about 6%). This was comparable to other similar studies which had only 1% recovery (Hay and McKinnell, 2002). Some studies have shown that T-anchor tags are generally well retained in the short term (160 days) and accurate within 2 metres (Hojesjo et al., 2007). Most of the tags recovered in this study were got with a shorter time. The release and non recaptured tagged fish may have died or emigrated beyond the limits of sampling area. The method suffers from poor temporal resolution of fish location which generates further underestimation of migration (Carol et al., 2007). Therefore, there could have been underestimation of the movement patterns of the small clariid in the wetland due to low number of tagged fish and recovery efficiency. According to Knouft and Spotila (2002), mark and re-capture studies under-estimate movements of tagged individuals due to the low recapture rates and other ineffiencies of the method. Movement that occurs within a site cannot be accurately quantified unless recapturing at adjacent sites is avoided to prevent overlaps (Knouft and Spotila, 2002). In this study, the sites were more than 10 km apart from each other and therefore overlaps were negligible. The lateral distances between recapture and release locations were used to determine distance moved by fish. Under-estimations in fish movement studies can also be reduced when re-sampling is done in a large area of stream using contiguous re-capture method (Knouft and Spotila, 2002). Another short-coming of this telemetry study was that relatively few catfish could be monitored relative to the population size and duration of monitoring was constrained by seasonal abundance of small catfish along the wetland.

Based on the observations from the Mpologoma wetland, it can be concluded that small *Clarias* species' habitat attributes varied among sites which, was attributed to the effects of wetland land use changes. The clariids fed oppounistically on the available prey items in their habitats. The prey items varied among the different sites due to the differences in the prevailing water conditions at the sites. They fed more on chironomids at the highly disturbed site and others at the less disturbed sites. The fish moved within the wetland downsteam and upstream depending on the season in search for suitable swallow water for feeding, prey avoidance and spawning. The movement patterns did not vary among sites particularly because of the limited efficiency of the telemetry method used in the study. A combination and comparison of telemetry and radio telemetry techniques, as well as correcting the problems in the experimental design associated with the mark recapture technique, would be useful for understanding the movements of small *Clarias* species.

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CHAPTER FIVE:

SMALL SCALE WETLAND FISHERY PRODUCTION IN RELATION TO LAND USE RELATED DISTURBANCE IN THE MPOLOGOMA RIVER WETLAND[2]

Abstract

In densely populated areas in eastern Uganda where livelihoods demands create immense pressure on environmental resources, small scale wetland fisheries may be affected by changes in land use for agriculture practices. This study was carried out to investigate the variation of fish catch at the different wetland sites in relation to land use in the Mpologoma riverine marsh. Water quality and wetland fish species catch data were collected using standard procedures for water sampling and fish gill net sampling in addition to local fishermen's landings at the four differently disturbed sites. Conductivity and orthophosphate values significantly differed between sites and explained 72.03% of the variance among sites in the principle component analysis. Seven fish taxa dominated the wetland fishery. Catches of the large sized fish species catch, *Clarias gariepinus* (Burchell, 1815) and *Protopterus aethiopicus* (Heckel, 1851) (range of 0.45 to 38kg/day and 0.25 to 20kg/day respectively), were higher at the less disturbed sites than at the highly disturbed sites, and accounted for over 91.5% of total wetland catch. *Tilapia zillii* (Garvais, 1848) and *Oreochromis leucostictus* (Trewavas, 1933) catch were also higher at the less disturbed sites (ANOVA and Tukey's test, all $p < 0.05$) while *Haplochromis* sp, *Clarias liocephalus* and *C. alluaudi* catch did not vary among sites. Conductivity and orthophosphate significantly and negatively correlated with the two large fish species' catch (rho' = 0.50 and 0.34, both at $p < 0.05$). These parameters did not correlate with small *Clarias* fish species catch. Land use changes negatively influenced the water quality which negatively affected the fish life history strategies of the large fish species. However, the small fish species appear to have been resilient to wetland disturbance. Therefore there is need to control land use changes to secure good quality water that will enhance high fish production of the Mpologoma riverine wetland small scale fishery.

Key words: Papyrus wetland, small scale fishery, catch, disturbance

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[2]Publication from this chapter:

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5.1 Introduction

Small-scale fisheries play a significant role in human and socio-economic development (Vass et al., 2009). They are an entry point for poverty reduction through their role in generating revenues, creating employment and their contribution to food security (Heck et al., 2007; Bene et al., 2010). Wetland fisheries constitute majority of small scale fisheries which often provide a safety valve for people who cannot access other sources of livelihood (Bene, 2004). These small scale wetland fisheries provide nutritional security in remote areas that lack adequate supplies of animal protein and sustain livelihood of landless fishers who can no longer survive by fishing in depleted freshwater bodies (Vass et al., 2009). However, although wetlands provide habitat for 40% of all fish species (Arthington et al., 2004), 20% of their biota are amongst the most threatened components of global biodiversity (Smith et al., 2005). This is largely due to human induced environmental degradation in wetlands and in the adjacent landscapes. The demand for increased food production to cater for the rising human population and large numbers of undernourished people in the developing countries, have led to widespread conversion of wetlands into agriculture (Okechi, 2004). Besides, climate change is likely to have a profound impact on land management practices leading to more changes in land use decisions (Verburg et al., 2011). Consequently, land requirements, reclamation potential and general environmental management will be adversely affected (Carvalho et al., 2004).

Many African wetlands are open to fishing by anyone (open access) or subject to exclusive communal or individual use rights (Garaway et al., 2006; Martin et al., 2011). Often, wetlands under exclusive access arrangements are exploited less intensely and maintain higher standing stocks of fish than open access wetlands (Lorenzen et al., 1998). With increasing population demands, the open access wetlands may also be subjected to intensive exploitation of both water and fisheries resources (Garaway et al., 2006). Lake Kyoga basin has the largest expanse of wetland in Uganda. However, between 1994 and 2008 the area of wetlands in the Kyoga lake basin declined by 48.5% from 2615 to 1346 km^2 and much of this loss was accounted for by the large commercial rice schemes and numerous small-scale rice farms (Ogutu-Ohwayo et al., 2013). Research has shown reduction in the large wetland fish species, *Clarias gariepinus* and *Protopterus aethiopicus* in the Lake Kyoga basin (Muhoozi, 2003). *C. gariepinus* catch reduced from more than 1600 metric tonnes in the 1980s to 1.35 metric tonnes in 2000 (Muhoozi, 2003).

Understanding the effects of land use changes on the fisheries is essential for the proper management of exploited wetlands (Rientjes et al., 2011). Although there are a few existing land use change on fisheries models based on observed patterns in temperate areas, scarcity of data for most tropical riverine wetlands limits proper management of human-induced impacts on these resources (Ibanez et al., 2007). Small scale Mpologoma riverine wetland fishery which is part of Lake Kyoga basin, supports local communities with no access to open lake fisheries with cheap fish supply. However, its wetland area is under intensive exploitation for agriculture to feed the increasing population in this region (Musiime et al., 2005). This chapter describes the assessment of the dynamics of the Mpologoma wetland small scale fishery in relation to land use change. It was hypothesized that the wetland fish species catch and water quality would vary at the different sites with the different land uses in the wetland. The role of land use change through varying levels of wetland disturbance in relation to water quality parameters, fish species composition and their catch was quantified.

5.2 Materials and Methods

5.2.1 Study sites

The research was carried out at four wetland sites with different levels of disturbance in the Mpologoma riverine wetland in the Lake Kyoga basin. Budumba and Mazuba sites were minimally disturbed with small farms at the edge of the wetland. Kapyani site was highly disturbed with small scale rice and maize farms inside the wetland, using low implement agriculture and rain-fed lowland systems. Nsango site was highly disturbed with a large scale rice scheme which uses artificial fertilisers, rain fed lowland and irrigation systems in the wetland. The water quality parameters, wetland fish species composition and abundance in terms of catch and catch per unit effort were investigated.

5.2.2 Wetland water quality characterisation

To characterise water quality of the wetland sites with different land uses, three water samples were collected from different points (within the wetland, middle of lagoon and edge of the lagoon) at each of the four sites. Conductivity and pH were determined in-situ with a Hanna pH/Ec/TDS/ºC meter and probe. Dissolved oxygen and temperature were determined *in-situ* by Oakton DO 110 meter. Chemical analysis was performed on 0.45 µm membrane filtrate for alkalinity, nitrate-nitrogen and orthophosphate concentration, and unfiltered samples for total phosphorus within 48 hours of collection according to standard procedures (APHA, 1995).

5.2.3 Fish data collection

Fish samples from the gill net fishing, basket trapping within the wetland and local fishermen daily landing were used to determine the wetland fish species composition and fishery production. Experimental fish sampling was done with gill nets hanged in the lagoons and traps placed inside the emergent vegetation in the wetland. Gill nets of 2, 2.5 and 3 cm mesh sizes were set in parallel in the lagoon. Ten local basket traps (Plate 5.1) were randomly deployed to catch fish inside the flooded vegetation zone of the wetland. All the fishing gear were set at around 7:00 hours and retrieved before 14:00 hours. This was done to reduce loss of fishing gear to the local fishermen during overnight fishing. On landing, fish samples were counted, their total length and weight measured, and records of the gear and effort used were recorded at every site. Some fish were preserved in 40% ethanol and retained for identification using various identification keys (Greenwood, 1974; Witte and van Densen, 1994). To cater for the seasonal changes in fishery, each site was sampled once a month for 12 months between September 2011 and August 2012.

More data on wetland fish species and catch was collected from fishermen landings at each site for every sampling day. The local fishermen distributed their fishing effort throughout the study site to ensure random sampling of a large portion of the study site. At each site, fishermen had their own institutional arrangements which regulated the number of fishermen per landing site and where to fish. Therefore, the decision of about where and how to fish was left to the fishermen. The local fishermen dominantly used gill nets (2.5 cm and 3.0 cm mesh sizes) of about 45 m by 1.5 m deep, fishing lines with varying number of hooks and local basket traps (0.4 by 0.4 by 0.3 m, on average) to catch fish. Fishing lines consisted of a weight (approximately 2 kg) with varying number of baited hooks mainly set to catch *Protopterus* sp and *C. gariepinus* within the wetland. Bait materials included pieces of small fish species such as small *Clarias* species, *Tilapia* species, frogs, insects and earthworms. Most fishing gear were set at 18:00 hours and retrieved at 9:00 hours to prepare for the markets. Data on captured species brought to the major landing beaches at each site by fishermen were recorded including fish taxa, fish counts, total length (Tl, in centimetres), weight (Wt, in grams), type of gear and effort used. The total length and weight were measured using a floy tag fish measuring tape and weighing scale with 0.1 gramme accuracy. The whole counting and measuring was done as quickly as possible after the fishermen returned with their catch. For small species such as small *Clarias* species, *Haplochromis*, *Tilapia* and *Barbus* species, random sub samples were taken to measure total lengths but their total number in the catch recorded. For large species such as *C. gariepinus* and *Protopterus* sp groups of similar sizes were counted and sub sampled for measuring their total length and weight to get as much data as possible in the limited time allowed by the fishermen.

Plate 5.1: Local basket trap compared to the minnow trap with one inlet and one outlet way (a). The outlet filled of the trap with plant materials to hold the trapped fish (b).

5.2.4 Data analysis

Fish data were summarised into the species composition, catch and catch per unit effort (CPUE) for spatial and temporal variation along the wetland. The fishermen usually fished only once a day and therefore species catch was considered as total species catch in kilogram per day. Since the fishery was a multispecies type and uses non-selective fishing gear, for gill nets and fishing traps, CPUE was calculated by dividing the catch in grammes of the most dominant fish species caught by the individual gear and by the number of hours the method was deployed. Most gillnets were set for less than 5 hours and most fishermen had only one net, therefore the units of CPUE of gill nets derived from the mean sizes of gillnets and fishing hours used along the wetland. The majority of the fishermen used locally made basket traps of similar sizes and shape. Therefore, the units of CPUE of traps was derived from number of traps and hours used per fisherman. CPUE of lines with hooks was calculated by dividing the catch in grammes of most dominant fish species considering the mean number of hooks per fisherman and the hours spent fishing. Most fishermen used to set line hooks from 6:00 pm to 6:00 am. Therefore, 12 hours were used in the calculation of the hooks CPUE. Due to differences in mean number of hooks per sites, the hooks' CPUE was standardized to 100 hooks per hour. Fish species diversity was calculated using Shannon Wiener's index (H') of diversity (Thiebaut 2006) in the equation

$$H' = - \sum p_i \ln(p_i), \qquad (5.1)$$

where p_i is the relative abundance of individual fish species.

Statistical analysis on fish data was performed using SPSS version 16 (IBM ©). All the wetland fish species catch and CPUE were treated as separate dependent variables. Data was log transformed since it was not normally distributed (Kolmogorov-Simonov test ($p = 0.00$) and skewness of 4.523). One-way ANOVA followed by Tukey's HSD post hoc test was used to test differences in species CPUE, catch and fish length between sites. Using R-statistic software (*R version* 3.0.2; R Development Core Team 2008), Non-Metric Multi Dimensional Scaling (NMDS) was used to measure community dissimilarities between study sites in the wetland. The relationship between study sites with different land uses and water quality parameters was evaluated using NMDS to ordinate the similarity between sites. Water quality parameters were further fitted to the ordination as vectors to identify the parameters that significantly differentiate the study sites. Stepwise multiple linear regressions with forward selection of variables were used to analyze the relationship between fish catch and the water quality parameters which discriminated the different study sites in the wetland.

5.3 Results

5.3.1 Fish species composition and catch

Data on a total of 5137 fish specimens were collected from all study sites over the sampling period. Of the eight fish taxa identified, six fish taxa dominated the wetland fish community. *C. gariepinus, C. liocephalus, C. alluaudi, P. aethiopicus*, *Oreochromis leucostictus, Tilapia zillii* and several *Haplochromis* species were dominant at all sites along the wetland. Other fish taxa found were *Barbus* sp and *Synodontis afrofischeri*. *Synodontis afrofischeri* was observed only at highly disturbed Kapyani site. The number of species per site ranged from seven at the highly disturbed sites to nine at the less disturbed sites. The mean Shannon Wiener index of diversity was 5.4 ± 1.2 per site and did not significantly vary among sites. During the wet season months, a higher number of species was recorded than during the dry season months. For instance, the species richness index of 4.94 and 4.81 were realized in January and February, while 6.77 and 6.69 were realized in September and October respectively at less disturbed Nsango site.

Wetland fishery production was estimated to be 57 kg per ha per year. The mean catch at less disturbed Budumba site (29.03 ± 9.66 Kgday^{-1}) was high compared to that of highly disturbed Nsango site (2.07 ± 1.62 Kgday^{-1}, Table 5.1). The number of fishermen ranged from 12 at the highly disturbed Nsango site to 27 at the less disturbed Budumba site. Three fishing gear types (gill nets, line hooks and basket traps) were dominantly used at all sites in the wetland. Many fishermen used line hooks with a range of 13 hooks at the highly disturbed Nsango site to over 119 hooks at the less disturbed Budumba site. At the less disturbed Budumba and Mazuba sites, the fishermen had a high number of hooks to catch within the intact wetland. Traps and gill nets were used mainly used catch small fish and *Tilapia* species at all sites. During the rainy season, gillnets with 3.0 cm mesh size harvested more fish than other fishing gears. Hooks were dominantly used during the dry season. More than 50% of the total landings were done by the hooks. The gill nets with 3.0 cm mesh size were the second most important, followed by the gill nets with 2.5 cm mesh size and traps. The catch from hooks and traps did not vary significantly between seasons ($p > 0.05$, Figure 5.1). But among sites, the number of hooks were significantly higher at the less disturbed Budumba site than at the highly disturbed Nsango site ($p = 0.023$). The catch varied among the dominant fishing gears used. Significantly higher catch was realized by the use of line hooks than all other fishing gears ($p = 0.001$). The mean catch from line hooks' of 11.42 ± 6.94 Kg/day was observed in the wet season and 14.86 ± 9.56 Kg/day was observed during the dry season which, was higher compared to 3.29 ± 3.11 and 4.86 ± 4.39 Kg/day of gill nets used in the wet and dry seasons respectively.

Table 5.1: Number of fishermen, fishing gear type per fisherman and boats at one major landing site of the differently disturbed sites in the Mpologoma river wetland between September 2011 and August 2012 (values are mean ± S.D)

	Budumba	**Mazuba**	**Kapyani**	**Nsango**
Number of fishermen	22 ± 5	22 ± 4	30 ± 9	17 ± 5
Number of hooks per fisherman	85 ± 34	50 ± 35	64 ± 41	30 ± 17
Number of gill nets per fisherman	1	1	1	1
Number of traps per fisherman	8 ± 3	6 ± 3	5 ± 2	7 ± 3
Number of boats per site	16 ± 4	17 ± 2	13 ± 2	7 ± 2
Catch ($Kgday^{-1}$)	29.03 ± 9.66	21.28 ± 10.46	24.10 ± 11.70	2.07 ± 1.62

There were temporal and spatial differences in the catch of individual fish species within the wetland. Relatively large catches were observed in the dry season than in the wet season and more at the less disturbed sites than at the highly disturbed sites. *C. gariepinus* and *P. aethiopicus* dominated the fishery by catch weight with a range of 1.43 kg per day at the highly disturbed site to 21.41 kg per day at the less disturbed site and 0.99 to 18.42 kg per day, respectively (Table 5.2). Fish catch at Nsango was significantly lower than that of other sites (Tukey's HSD test, $p < 0.05$). Higher catch of both *C. gariepinus* and *P. aethiopicus* species was recorded during the dry months (January, February, July and August, Figure 5.2). Significantly higher catch of both species was recorded at the less disturbed sites (Budumba and Mazuba) than at the highly disturbed site (Nsango) at $p < 0.001$ (Tukey's HSD test). The disturbed Kapyani site recorded relatively high *C. gariepinus* catch almost the whole sampling period. The catch of small *C. liocephalus* and *C. alluaudi* was higher at the highly disturbed site than at the less disturbed sites (Figure 5.3).

The mean CPUE for the major commercial fish species varied with fishing gear, season and study site. The CPUE for *C. gariepinus* and *Protopterus* sp were higher with the use of hooks than that of other fishing gear, during the wet season and at the highly disturbed Nsango site (Table 5.3). At the less disturbed Budumba site, mean CPUE for *C. gariepinus* was higher (1.31 Kg100hooks^{-1}hr^{-1}) in the dry season as compared to 0.90 Kg 100hooks^{-1}hr^{-1} recorded during the wet season. CPUE for the two large fish species at highly disturbed Nsango site was significantly different from that of the other sites ($p < 0.05$). However, the highly disturbed Kapyani site CPUE (4.50 Kg 100hooks^{-1}hr^{-1}) was higher than the other highly disturbed Nsango site (1.20 100hooks^{-1}hr^{-1}) in the dry season. The CPUE for *C. gariepinus* and *Protopterus* sp. showed an increasing trend during the dry months (Figure 5.2). The CPUE of small fish species (*C. alluaudi*, *C. liocephalus*, *Haplochromis* spp and *Barbus* sp) did not vary significantly between season and sites (Figure 5.4; $p > 0.05$).

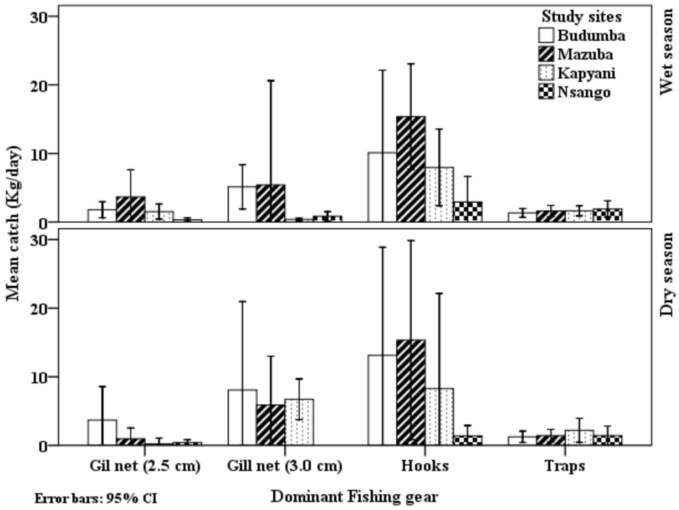

Figure 5.1: The catch of major fishing gear at the four sites in the Mpologoma wetland between September 2011 and August 2012 (values are mean ± S.E)

Table 5.2: The catch of major fish species at the differently disturbed sites in the Mpologoma river wetland from September 2011 to August 2012 (values are mean catch ± S.D in Kg/day)

Fish species	n	Budumba	Mazuba	Kapyani	Nsango
Oreochromis leucostictus (Trewavas, 1933)	565	1.56 ± 1.07^a	1.13 ± 1.51^a	0.61 ± 0.41^a	0.29 ± 0.15^b
Tilapia zilli (Garvais, 1848)	703	1.92 ± 1.28^b	0.86 ± 0.58^a	0.93 ± 1.14^a	0.32 ± 0.18^c
Haplochromis spp	1115	0.26 ± 0.25^a	0.19 ± 0.09^a	0.33 ± 0.42^a	0.19 ± 0.13^a
Clarias liocephalus (Boulenger 1902)	788	0.50 ± 0.32^a	0.42 ± 0.21^a	0.66 ± 0.70^a	0.75 ± 0.52^a
Clarias alluaudi (Boulenger, 1906)	419	0.37 ± 0.24^a	0.30 ± 0.25^a	0.27 ± 0.19^a	0.42 ± 0.36^a
Clarias gariepinus (Burchell, 1815)	1062	14.64 ± 6.77^a	11.28 ± 8.39^a	15.88 ± 6.56^b	3.05 ± 1.62^c
Protopterus aethiopicus (Heckel, 1851)	598	13.38 ± 5.04^a	9.72 ± 4.78^a	6.47 ± 3.09^a	2.25 ± 1.46^b

Values in the same row with the same superscript are not significantly different ($p < 0.05$)

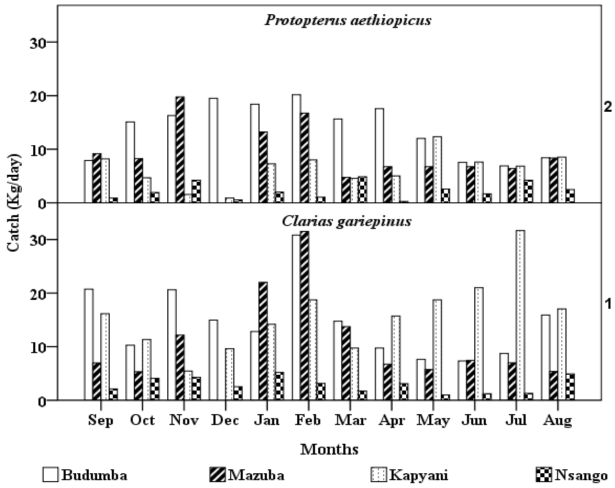

Figure 5.2: The mean catch of the big fish species in the Mpologoma wetland fishery between September 2011 and August 2012

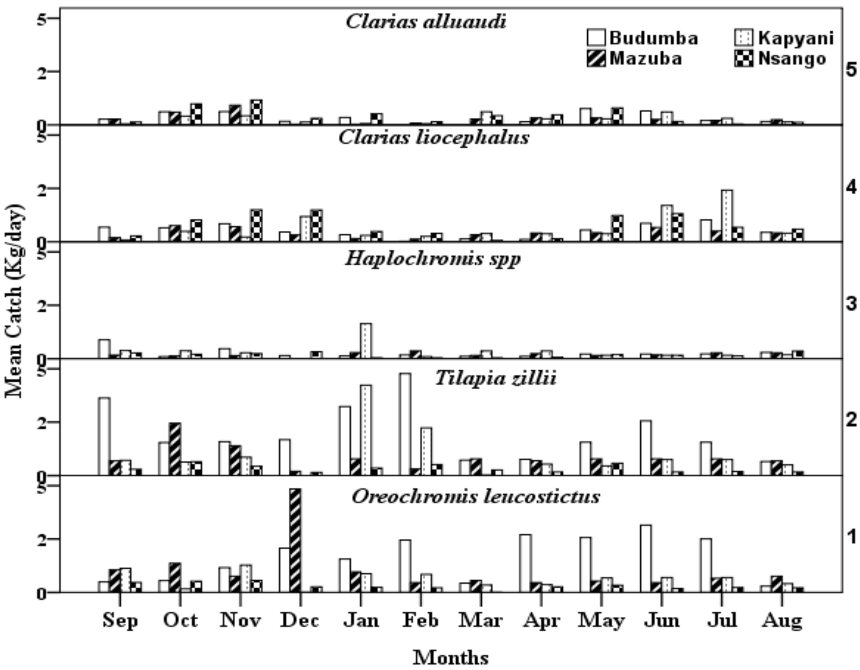

Figure 5.3: Mean fish catch of the small fish species at diferent sites in the Mpologoma riverine wetland between September 2011 and August 2012

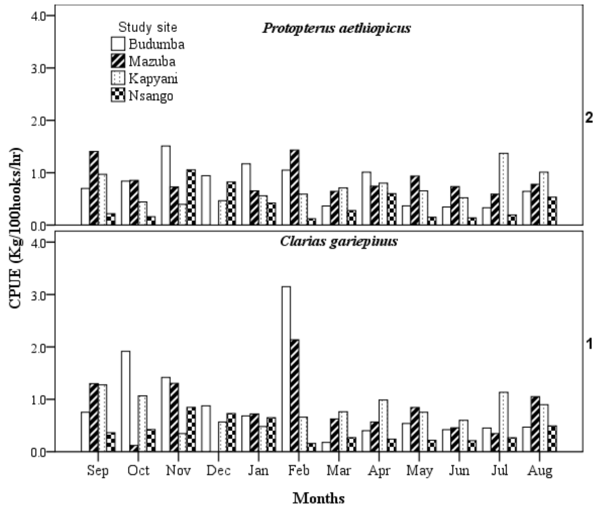

Figure 5.4: Monthly catch per unit effort (CPUE) of the large fish species at the differently disturbed sites in the Mpologoma wetland between September 2011 and August 2012 (values are means)

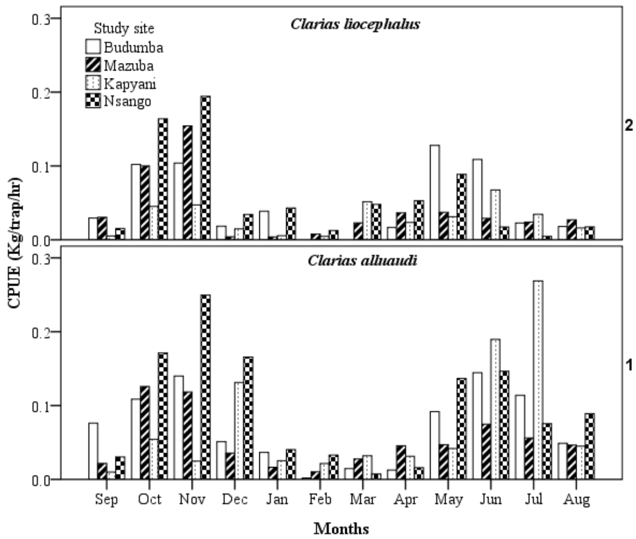

Figure 5.5: Monthly catch per unit effort (CPUE) of the small *Clarias* species at the differently disturbed sites along the Mpologoma wetland between September 2011 and August 2012 (values are means)

Table 5.3: Catch per unit effort (CPUE) for the major commercial fish species at the differently disturbed sites in the Mpologoma wetland and seasons between September 2011 and August 2012 (values are means)

			Dry season				**Wet season**			
Gear type	**Species**	**Units of CPUE**	**Budumba**	**Mazuba**	**Kapyani**	**Nsango**	**Budumba**	**Mazuba**	**Kapyani**	**Nsango**
GN 2.5	*Haplochromis* spp	Kg 45m^{-1}hr^{-1}	0.03	0.00	0.00	0.10	0.13	0.04	0.01	0.12
	C. gariepinus	Kg 45m^{-1}hr^{-1}	0.20	0.00	0.53	0.08		0.92	0.20	
	Protopterus sp	Kg 45m-1hr-1	0.40	0.00				0.29		
	Small *Clarias* spp	Kg 45m^{-1}hr^{-1}			0.45					
	Tilapia spp	Kg 45m^{-1}hr^{-1}	0.85	0.22	0.59	0.23	0.45	0.54	0.20	0.15
GN 3.0	*C. gariepinus*	Kg 45m^{-1}hr^{-1}	0.35	0.40	1.60		0.46	0.49	0.20	0.36
	Haplochromis spp	Kg 45m^{-1}hr^{-1}					0.07			
	Protopterus sp	Kg 45m^{-1}hr^{-1}	0.52	0.57	0.90		0.38	0.20	0.06	
	Tilapia spp	Kg 45m^{-1}hr^{-1}	0.13	0.14			0.46	0.17		0.47
Hooks	*C. gariepinus*	Kg 100hooks^{-1}hr^{-1}`	1.31	1.10	4.50	1.20	0.90	1.85	0.76	1.20
	Protopterus sp	Kg 100hooks^{-1}hr^{-1}`	0.86	1.05	1.28	0.54	1.32	1.88	0.81	1.09
	Small *Clarias* spp	Kg 100hooks^{-1}hr^{-1}`	0.16	0.20	0.33	0.27	0.15	0.16	0.11	0.26
Traps	*Barbus* sp	Kg trap^{-1}hr^{-1}	0.04	0.02		0.09		0.02		0.03
	C. gariepinus	Kg trap^{-1}hr^{-1}	0.04	0.06	0.11	0.06	0.09	-	0.11	0.08
	Haplochromis spp	Kg trap^{-1}hr^{-1}	0.01	0.04	0.09	0.23	0.03	0.14	0.05	0.07
	Protopterus sp	Kg trap^{-1}hr^{-1}	0.05	0.12	0.12	0.05	0.06	0.12	0.12	0.07
	Small *Clarias* spp	Kg trap^{-1}hr^{-1}	0.16	0.11	0.18	0.19	0.20	0.15	0.15	0.24

5.3.2 Wetland fish species size

There were variations in the total length of *C. gariepinus* and *P. aethiopicus* in the wetland with a range of 12 to 135 cm and 16 to 151 cm respectively. The mean total length of *C. gariepinus* at the less disturbed sites, Budumba and Mazuba, was 47.27 ± 20.47 cm and 45.32 ± 16.76 cm respectively. While at the highly disturbed sites (Kapyani and Nsango) the mean total length of *C. gariepinus* was 41.19 ± 21.85 cm and 27.33 ± 10.98 cm respectively. Larger fish individuals of both species were caught during the wet season (April, May and October). The mean total length of these two species was significantly lower at highly disturbed Nsango site than that of the less disturbed sites ($p < 0.01$; Figure 5.6). The less disturbed sites had larger fish even among the *Oreochromis* and *Tilapia* species than the highly disturbed sites. However, the small fish species behaved differently. *C. liocephalus* total length ranged from 6.0 to 26.4 cm at Budumba and from 9.5 to 28.5 cm at Nsango. *C. alluaudi* total length was higher during the dry months of the year than that of *C. liocephalus*. During the rainy season, both small *Clarias* length increased to closely similar means.

Table 5.4: Water quality parameters of fish habitats (inside the emergent vegetation in the wetland) at the different study sites in the Mpologoma River wetland (September 2011 – August 2012; values are means ± S.D)

	Budumba	Mazuba	Kapyani	Nsango
DO (mgl^{-1})	1.35 ± 1.03^a	1.98 ± 1.26^a	1.58 ± 0.67^a	0.96 ± 0.76^b
Temp (°C)	23.75 ± 1.72	24.53 ± 0.81	25.35 ± 1.31	24.18 ± 1.49
Conductivity (µS/cm)	152 ± 32.1^a	161 ± 35.2^a	218 ± 53.1^b	351 ± 55.4^b
OPO_4^{3-} (mgl^{-1})	0.28 ± 0.26^a	0.27 ± 0.23^a	0.13 ± 0.12^b	0.14 ± 0.34^b
TP (mgl^{-1})	0.67 ± 0.44^a	0.62 ± 0.39^a	0.29 ± 0.27^b	0.23 ± 0.19^b
Water depth (m) during the dry season	0.52 ± 0.27	0.45 ± 0.14	0.30 ± 0.15	0.35 ± 0.14

Values in the same row with the same superscript are not significantly different.

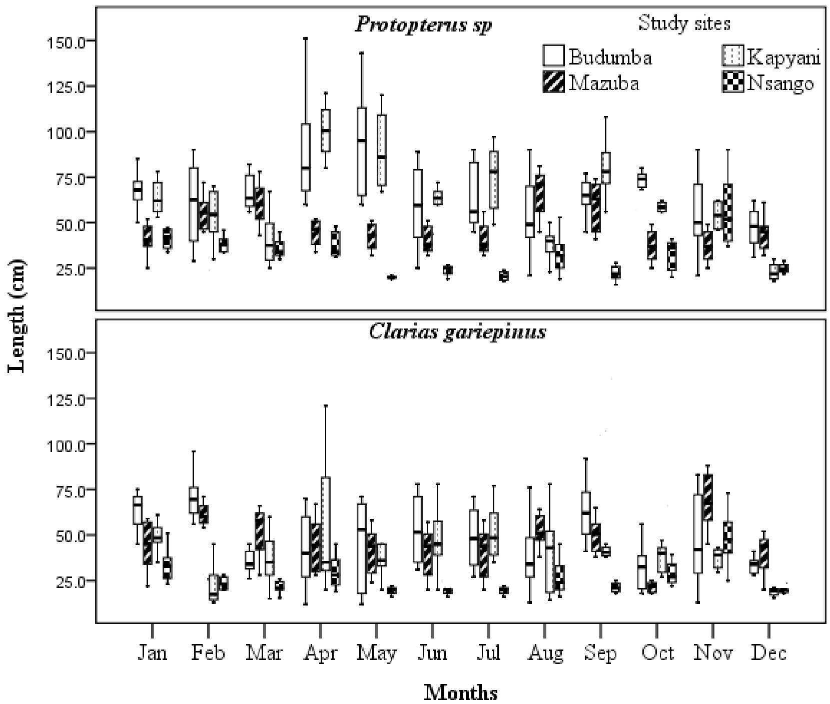

Figure 5.6: The total length of the large fish species caught at the differently disturbed sites in the Mpologoma river wetland between September 2011 and August 2012 (values are median and the interquatile range, cm)

Table 5.5: Environmental vector fitting of the NMDS analysis of the water quality parameters of the different study sites

Water quality parameters	**NMDS1**	**NMDS2**	**r^2**	**Pr(>r)**
Dissolved oxygen	-0.95645	-0.29191	0.0150	0.316
Temperature	-0.15069	-0.98858	0.0651	0.07 *
Conductivity	0.41252	-0.91095	0.4269	0.001 ***
Orthophosphate	-0.99996	0.00869	0.7077	0.001 ***
Total phosphorus	-0.93377	0.35788	0.8128	0.001 ***

Significant codes: 0 '***' 0.001 '**' 0.01 '*' P values based on 999 permutations.

5.3.3 Environmental data

The concentration of water quality parameters varied in space and time along the wetland (Table 5.4). Conductivity ranged from 115 µS/cm at less disturbed Budumba site to 454 µS/cm at the highly disturbed Nsango site. Conductivity at the less disturbed sites was significantly lower than that of disturbed sites and it was higher during the dry months than the wet months. Nitrate concentration were very low to undetectable levels at all sites during the wet season while in the dry season, it ranged from 0.01 to 0.12 mgl^{-1} at the less disturbed sites, and 0.03 to 0.18 mgl^{-1} and 0.093 to 1.15 mgl^{-1} at highly disturded Kapyani and Nsango sites respectively. From the NMDS analysis, the resulting ordination was two dimensional with final stress of 17.7 at $p < 0.05$ indicating that obtaining a lower stress with random data was unlikely. The less disturbed Budumba and Mazuba sites were very similar as the distance between their circles was close to zero. The highly disturbed Nsango site associated with a large scale rice scheme was different from that of the less disturbed sites as the distance between their circles was larger than zero (Figure 5.7). The vector analysis showed that conductivity, orthophosphate and total phosphorus were significantly important in differentiating the study sites all at r^2 of 0.43, 0.71 and 0.81 respectively, all at $P < 0.001$ (Table 5.5). There was a significant relationship between fish catch and water quality parameters. A strong spearman rank correlation, rho' = 0.501 and 0.348 ($p < 0.05$), between *C. gariepinus* catch with conductivity and orthophosphate respectively was realised. *P. aethiopicus* catch was significantly correlating with conductivity, orthophosphate and total phosphorus (rho' = 0.510, 0.465 and 0.441, $p < 0.01$ respectively). With stepwise multivariate linear regression, *P. aethiopicus* catch was significantly related to conductivity and orthophosphate ($R^2 = 0.544$; $p < 0.01$; catch = -13.214 – 0.023 conductivity + 16.69 orthophosphate). No significant relation was realized between water parameters and the small fish species catch and CPUE.

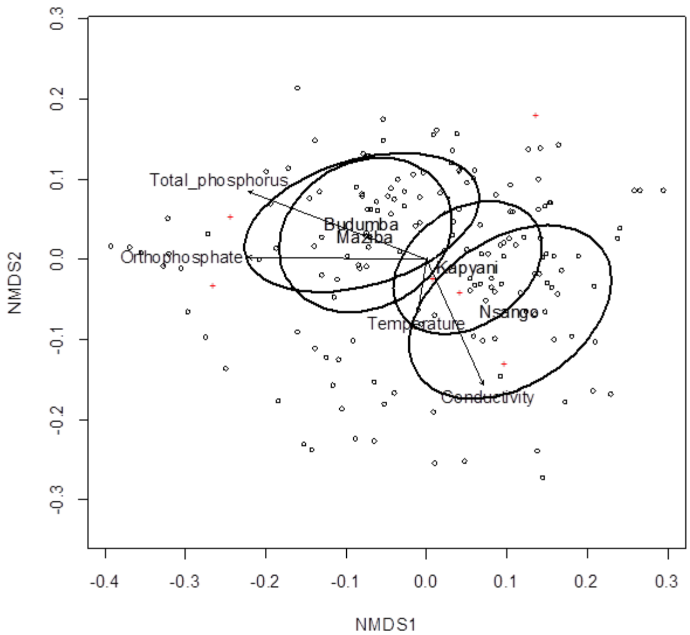

Figure 5.7: Non-metric multidimensional scaling plot of study sites in the Mpologoma river wetland. Visually fit ellipses were drawn around sites that had significantly similar levels of the water quality parameters.

5.4 Discussion

5.4.1 Wetland fish species composition

The Mpologoma wetland is a critical refuge for a subset of Lake Kyoga fish species given the high number of similar fish species recorded in the wetland compared to those reported in the Lake. *C. gariepinus, P. aethiopicus, O. leucostictus* and *Tilapia* spp which are important Lake Kyoga fish species (Ogutu-Ohwayo et al., 2013) were also recorded in the wetland. High diversity and similarity in fish species was largely attributed to the nearby fresh waters which were once connected by heavy floods or drainage free of barriers that enabled dispersal of fish species (Olden et al., 2010). Even as the level of fish habitat disturbance increase in the wetland, there was a general similarity in fish species community which could have been attributed to some fish species being relatively tolerant to pollution. The tolerant species include *Oreochromis* species (Raburu and Masese, 2010), *P aethiopicus, C. gariepinus* and *C. alluaudi* (Timmerman and Chapman, 2004). Normally reduction in species richness and abundance is expected along an aquatic system degradation gradient (Raburu and Masese, 2010). Indeed at the highly disturbed Nsango site, the abundance of *P aethiopicus* and *C. gariepinus* was lower than in the other sites. During the relatively poor water quality periods (high conductivity and low dissolved oxygen), particularly in the dry months, Nsango site had the lowest number of fish species compared to the other sites.

5.4.2 Small scale wetland fishery production

The Mpologoma wetland production estimate was in the order of magnitude of African floodplain production. Lightly exploited floodplain river systems in Africa produce about 40 - 60 kg ha^{1} yr^{1} of fish (Welcomme, 1985), while highly exploited tropical floodplains production has been estimated at 110 - 160 kg ha^{1} yr^{1} of fish (Bayley, 1988). The dynamics of floodplain inundation has been hypothesised to enhance high fisheries yields in many tropical rivers throughout the world (Montana et al., 2011). The seasonally expanded aquatic floodplain habitats serve as nurseries for juveniles, foraging areas and refuge for many fish species, sustaining diverse and high fish populations in riverine wetland systems (Ibanez et al., 2007). The estimated high Mpologoma wetland production was also attributed to the high exploitation rate as a result of high number of fishermen and high fish effort observed particularly at the less disturbed sites. High exploitation rates are common phenomenon in open-access resource. However, this has a consequence of fish resource decline as the fishing efforts continue to increase (Paterson and Chapman, 2009).

There is a complex relationship between catch (fish abundance) and effort as function of fishermen's behaviour where by fishermen's individuality and personal goals are important factors determining the degree of exploitation of a resource (Lopes, 2011). The variation of fishermen's behaviour could explain observed variation in catch at the different sites in Mpologoma wetland. On average, the fishermen spent almost the same time span fishing both in wet and dry season, therefore the differences in CPUE resulted from the variation in fish abundance with time at the sites. Despite the few to no full time fishermen at all sites, the fishers were able to access distant less exploited areas with abundant fish resources particularly at the less disturbed sites leading to high catch. The fishing gears used also contributed to the variation in the catch and CPUE. The record of high number of hooks per fisherman at the less disturbed sites indicated the importance of this gear to achieving high catch and CPUE. The reliability of fishing gear as an index of fish density depends on fish activity, gear selectivity, avoidance and the morphology of the fishes (Olin et al., 2010). This explained the application of various fishing gear that enabled exploitation of the various fish species at the different sites, during different seasons in the wetland.

5.4.3 Wetland fish species catch in relation to land use

Fish species abundance is influenced by physical and chemical composition of water (Randle and Chapman, 2004), habitat size and diversity (Budy et al., 2008), and water flow patterns into the wetland (Vorwerk et al., 2009). The differences in wetland fish species abundance and catch were governed primarily by water quality variation among sites, given the strong negative correlation between catch and conductivity at the sites. This agreed with earlier studies on floodplain fisheries which highlighted dissolved oxygen, conductivity, pH and water depth as major determinant factors to fish abundance (Louca et al., 2009). Fish species richness increased with lower conductivity and increasing water depth (Louca et al., 2009). This explains high wetland fish species presence at the less disturbed Budumba site which had deeper waters and low conducitivity. High conductivity and low dissolved oxygen were associated to increase disturbance in the wetland. This result compared with the high conductivity and low dissolved oxygen levels reported in the highly studied polluted Nakivubo wetland in Uganda (Kansiime et al., 2007). Wetland disturbance could have impacted on the evapotranspiration rate leading to increased salts in the water which, has a pronounced impact such as high conductivity and alterations of vegetation species in wetland systems (Louca et al., 2009). Sustained increase in conductivity compounded by high sedimentation levels lead to negative implications on the fish ecology (Chapman et al., 2003). Lungfish (*P aethiopicus*) catch has declined in the past few decades due to the combined impact of overexploitation and large-scale conversion of wetlands to agricultural land (Goudswaard et al., 2002). Such species with preferences for lower conductivities and high dissolved oxygen disappear from the wetland once these conditions persist (Goudswaard et al., 2002; Louca et al., 2009). This explains the low *C. gariepinus* and *P aethiopicus* abundance and high *C. liocephalus* and *C. alluaudi* abundance at highly disturbed Nsango where those harsh conditions were observed.

Higher fish species composition and abundance was recorded at the downstream disturbed Kapyani site and this was attributed to a number of factors. The interaction between the river and lake hydrology which modifies the fish habitats with modified vegetation and deeper waters (Cooper et al., 2007) allowed more fish to coexist, both wetland and open water dwelling species, despite the level of disturbance. The other reason could have been the increase in accessibility to the fishing areas due to wetland clearance at the Kapyani site. Furthermore, the site is permanently connected to the nearby satellite lakes Nakuwa and Lemwa. During the flooding regime, the small scale farms at the site were abandoned, allowing opportunistic wetland fish species and macrophytes to re-establish themselves. Therefore, there could have been fish habitat recovery from disturbance during the flooding season which is associated with increased food resources, with consequent high fish abundance (Morris et al., 2007; Vorwerk et al., 2009). Furthermore, wet season rice crop when cultivated as a largely rain fed crop and have little land engineering, causes less impacts on water quality and later on the fish life history parameters (Nguyen-Khao et al., 2005). Thus, the high fish catch recorded at the Kapyani site.

Tropical riverine fish abundance and biological production are dependent on both wet and dry season aquatic habitat (Martin et al., 2011). The temporal variation in fish species size particularly among the large sized fish was attributed to the changes in water level within the wetland that increased the catching efficiency of the fishermen. Fish have adapted to the hydrological seasonality of tropical floodplains by moving into flooded areas during the high water season and returning to permanent wetlands in the dry season (Martin et al., 2011). In the dry season when the water level was low, wetland fish were easily caught due to the limited escape routes. One the other hand, large sized fish which more aggressive were less easily caught during the high water level/rainy season than during the dry season when they get trapped in shallow water areas in the wetland. The temporal variation in the wetland fish species' abundance and catch along the wetland could also be attributed to their reproductive traits and predator avoidance habits. Low abundance of all *Clarias* species at the beginning of the rainy season along the wetland was due to their breeding cycles (Offem et al., 2010). *T. zillii* spawn at the end of the dry season (El-Sayed and Moharram, 2007) and this could explain their low abundance during the dry season in the wetland. *Oreochromis* spp spawn anytime but higher abundances are observed during the rainy season (Melcher et al., 2012). Variation of small fish species abundance which breed throughout the year could be attributed to avoidance of predators such as *P aethiopicus* and *C. gariepinus* in clear water. High abundance of haplochromines in highly polluted areas is due to their behaviour of non-avoidance of predators in turbid waters while their low abundance in less polluted areas is due to predator avoidance in clearer waters (Ogutu-Ohwayo, 1990).

Availability of abundant food during the rainy season is also an important factor responsible for the temporal variation in the wetland fish (Offem et al., 2010). Rainy conditions lead to higher detritus and softer decomposing plant materials, whilst low phosphorus favoured high abundance of benthic invertebrates (Hansson et al., 2005) which are important food for mainly the small fish species. Disruptions in the food base caused by alterations in water quality, particularly at the highly disturbed sites, have been found to lead to higher percentage of omnivores (generalists) and a decrease in the proportions of insectivores and carnivores (Morris et al., 2007). *C. gariepinus* which is predatory (Raburu and Masese, 2010) was less abundant than *C. liocephalus*, an opportunistic feeder at the highly degraded sites. Thus, feeding and reproductive strategies are among the divergent life-history characteristics that make these riverine fish species respond to annual flood pulse and short-term environmental disturbances in different ways (Winemiller, 2005; Montaña et al., 2007).

The relationship between land use and small scale fishery production was realized through the negative relation between *C. gariepinus* and *P. aethiopicus* catch and conductivity and a positive relation with orthophosphate both of which were important in discriminating the sites with different land uses. The results should be of interest to wetland resource managers because land use changes in the wetland have the potential to drastically affect the water quality, negatively impacting the production of large commercial fish species of such a small scale fishery. There is need to local government to make immediate management strategies that would regulate the land use change rate which may have potentially irreversible effects to both small and large fish species that sustain the Mpologoma riverine wetland small scale fishery.

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CHAPTER SIX:

SMALL *CLARIAS* FISH POTENTIAL RELATIVE ABUNDANCE IN RELATION TO LAND USE CHANGES IN THE MPOLOGOMA RIVER BASIN

Abstract

Rice growing plays a siginificant role in the livelihood of the poor riparian people along the Mpologoma riverine wetland. However, there are drawbacks in terms of its effects on water quality and other fish habitat attributes which could affect wetland fishery, particularly endemic *Clarias* species. The aim of this study was to predict the trend of *Clarias* species catch with increased wetland conversion to farmland over the years in the Mpologoma riverine wetland through SWAT modelling. The model assessed the variation in land use and water quality in the Mpologoma River Basin with time. The simulated water quality values based on land use characteristics were used to predict small *Clarias* species' catch per unit effort using a fish yield prediction model for benthic fish species. There was a 16.3% decrease in agricultural land area to built-up areas and bushland and a 7.1 % decrease in wetland hectarage to agricultural land and built-up areas from 1986 to 2013. However, the accuracy of SWAT model was low based on the river flow rate as indicated by Nash-Sutcliffe coefficient (NSE) of 0.35 and r^2 of 0.61, it simulated ample water parameters. The pre-ditermined conductivity, SWAT simulated total phosphorus and depth values were incorporated into the fish prediction model. The fish model predicted better the small *Clarias* species catch per unit effort (CPUE) at Kapyani; the observed and predicted CPUE were significantly similar (NSE = 0.62; p = 0.67 for equality of means test). There was subsequent increase in predicted CPUE from 516 to 1114 g/trap/night at the highly disturbed site between 1986 and 2012. The high CPUE was driven by the high nutrient content which increased with the changing wetland cover to other land uses, particularly to agricultural land use. There is need to modify the models to predict better values so that the future trend of land use change in the Mpologoma wetland, its effects on small *Clarias* species CPUE and sustainability can be assessed, owing to understanding the human induced dynamics on wetland fishery production.

Key words: SWAT model, land use, CPUE model, small *Clarias*, wetland

6.1 Introduction

The high population growth rate in Uganda has contributed to the increased number of people who are food insecure from 12 million in 1992 to 17.7 million in 2007 (MAAIF, 2010). The introduction of many rice varieties brought about a rice green revolution in sub-Saharan Africa and indeed farmers were enthusiastic to adopt a number of them in areas of Uganda where rice is not a traditional crop (Miyamoto et al., 2012). Wetlands are intensively targeted for this agricultural expansion because of their fertile soils and abundant water supply especially during the dry season (Madebwe and Madebwe, 2005). Rice growing expansion in eastern Uganda has led to an increase of the area under rice production from 39,000 in 1990 to 80,000 hectares in 2004 (Musiime et al., 2005). Such irrigated agriculture accounts for a large share of freshwater use by humans and is widely regarded as a major cause of degradation of freshwater ecosystems and the associated fisheries (Nguyen Khoa, 2005). Irrigation developments impact on the aquatic systems' productivity and diversity has been mainly through modifications of the hydrologic, and habitat connectivity by canals, in-filling and drainage of wetlands in irrigated areas, and pollution of drainage water (Madebwe and Madebwe, 2005).

Wetlands freshwater fisheries are particularly impacted through changes in catchment water quality and hydrologic dynamics (Nguyen Khoa, 2005). The runoff from different types of land use may be enriched with different kinds of contaminants; sediments, phosphorus, and nitrogen loads (Lutz, 2004). Irrigation schemes create reservoirs for storage of wet season river flows for dry season irrigation, thus tend to attenuate natural flow patterns through drainage returns and seepage (Bunn and Arthington, 2003). Aquatic systems' chemical properties, channel hydraulics, and the associated biological communities are shaped by many landscape factors that operate at a variety of spatial and temporal scales (Wang et al., 2006). Land use change influences river deliveries of water, nutrients, minerals and sediments and determines regimes for flow, sediment inputs, nutrient levels, and water temperatures (Moerke and Lamberti, 2006). These influences are exacerbated by the catchment characteristics of climate, elevation, vegetative cover, land use, soil permeability, landscape slope, topography, and overall superficial geology (Wang et al., 2006). Several water quality models have been developed for analyzing various environmental problems for specific scales as documented in extensive literature reviews (e.g. Borah et al., 2006; Srivastava et al., 2007). One of the most widely used of these models is the Soil and Water Assessment Tool (SWAT), a watershed-scale water quality model (Arnold and Fohrer, 2005, Gassman et al., 2007). SWAT has been successfully applied worldwide to simulate observed hydrologic and pollutant losses across a wide range of watershed scales and environmental conditions, and for numerous land use and other scenario studies (Gassman et al., 2007).

The conversion of natural intact wetland into other land uses in Mpologoma catchment may impact wetland water quality which also affects the *Clarias* species production. This chapter presents the prediction of the water quality and small *Clarias* fish yield trends with increasing land use change in the Mpologoma wetland. It was argued that a common modelling framework, in which numerical models associated with each hypothesis have been stated, would provide the basis to evaluate and compare small *Clarias* catch in the wetland. It was hypothesized that water quality would change in response to land use cover change over time and that fish productivity could be determined from morphometric measures of mean water depth, conductivity and nutrients. Some recent multivariate models that predict yields of single species fisheries are based on alkalinity, algal biomass (chlorophyll *a*), habitat size, benthos standing crop, fish body size, fishing effort, mean depth, phytoplankton productivity, dissolved solids, nitrogen and phosphorus concentration as important predictors of fisheries production (Hayes and Anthony, 1964; Downing et al., 1990; Egertson and Downing, 2004). Consequently, it was further hypothesized that the predicted water quality at the different land use scenarios would result in varying *Clarias* species catch in the Mpologoma riverine wetland. The fish yield predictions would enhance the understanding of impact of large scale land use change on the wetland fisheries resources.

6.2 Materials and methods

6.2.1 Study area

This study was carried out in the Mpologoma River sub-catchment found within the Lake Kyoga basin (1º12’ N Latitude and 34º40’ E Longitude) in Uganda. The river discharges over 610 million m^3 of water annually into Lake Kyoga. The sub-catchment has a vast permanent swamp, extending up to 102 km east of Lake Kyoga, and exists as a network of small vegetated valleys in a slightly undulating landscape fed by 38 sub-catchments. The climate is tropical with rainfall ranging from 1470 mm to 2300 mm and temperature ranging from 16 ºC to 32 ºC. The swamp is dominated by papyrus (C*yperus papyrus*), hippo grass (*Vossia cuspidata*) and reeds (*Phragmites*). There is also a diverse assemblage of species of other aquatic grasses and herbaceous vegetation with some trees in the less deeply inundated areas of the seasonal floodplains (Katende, 2004).

The region has a population growth rate of 4.3 % per annum resulting to over 284 persons per square km (UBOS, 2010). With the increasing population, there are changes in the major human activities within the wetland; from ancient times small scale fishery to other livelihoods in the wetland such as growing crops and livestock grazing. The upstream areas of the wetland are characterised by large scale rice schemes of over 3,000 hectares of the wetland. The mid-stream areas are associated with intact natural wetland vegetation with small vegetable gardens at the edge of the wetland. The downstream section is dominated by moderately disturbed area with small scale rice and maize farms of 2 – 6 acres inside the wetland, using low implement agriculture and rain-fed lowland systems (MAAIF, 2010). During the wet season and heavy flooding, the wetland is abandoned and natural vegetation re-generate.

6.2.2 Water quality model parameterisation

The Soil and Water Assessment Tool (SWAT) was used to predict the impact of land management practices on water flow and water quality parameters in the complex Mpologoma catchment with varying soils, land use and management conditions. The main parameters of the model included climate, hydrology, erosion, soil temperature, plant nutrients, agricultural chemical inputs, land management and channel routing according to Arnold et al. (1998). Conceptually, SWAT divided the catchment into 25 sub-watersheds (Figure 6.1). Each sub-watershed was connected through a stream channel and further divided into hydrologic response unit (HRU). HRU was a unique combination of a soil and a vegetation type in a sub-watershed, and SWAT simulated hydrology, vegetation growth and management practices at the HRU level.

Model set-up

The model used was part of the climate variability study in the Lake Kyoga basin (Kigobe 2009). The model set-up involved five steps: (1) data preparation, (2) sub basin discretization, (3) HRU definition, (4) parameter sensitivity analysis and, (5) calibration and validation. Arc SWAT required three basic files for delineating the catchment into sub-basins and HRUs: a digital elevation model (DEM), a soil map, and a land use/land cover (LULC) map. In this study, a 90 m spatial resolution shuttle radar topographic mission (SRTM) DEM was used (Rabus et al., 2003). Elevation in the study area varied between 1042 and 4182 m, with a mean of 1197.99 ± 269.62 m. The soil map at scale of 1:2 000 000 was obtained from the Soil Terrain Database of Eastern Africa (SOTER), FAO (2002). The harmonized world soil database was used to update the soil properties of the obtained soil map from Uganda National Biomass Center. The basin consisted of 23 % loamy sands (LS), 8.9 % sand (S), 46.2 % sandy loam (SL), 18.4 % sandy clay loams (SCL) and 16.5 % clay soils (C), 1.4 % clay loams (CL), 8.4% pits (PITS) and 0.03 % water (WA) I as indicated in Figure 6.1. During the model development, 25 sub-basins were delineated and 25 HRUs were generated for the whole basin for the same period based on the dominant land use/cover, soil type and elevation. The discrepancy in the number of HRUs in the three periods was due to land-use distribution being more homogenous during the second period (1990 – 1998). Land use map was obtained from the Uganda National Biomass data base 2008. Rainfall data was derived from remotely sensed data as provided by the Famine Early Warning System (FEWS) daily rainfall for the region. These data were augmented by using three local rainfall gauges (Soroti, Tororo and Pallisa) within the Mpologoma catchment.

Model calibration and validation

Daily hydrological model runs were made using an existing/calibrated SWAT model for the Mpologoma basin (Kigobe 2009). Before beginning model calibration, a sensitivity analysis was performed using the SWAT in-built sensitivity analysis tool. Ten most sensitive parameters were then used for calibration (Table 6.1). Model performance was evaluated using the Nash and Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970) and the coefficient of determination (R^2). The model was calibrated using data from 1965–1975 and validated for the period between 1997 and 2006. As the earlier period is more natural, with fewer anthropogenic influences, it was assumed that the calibration parameters based on the earlier runs better represent the physical characteristics of the catchment. The model outputs were, however, compared with measured data from both time periods. As the main scope of the study was to determine the water quality of the out flowing water and land-use change in the catchment, modelling groundwater intrusion was not considered a part of the analysis.

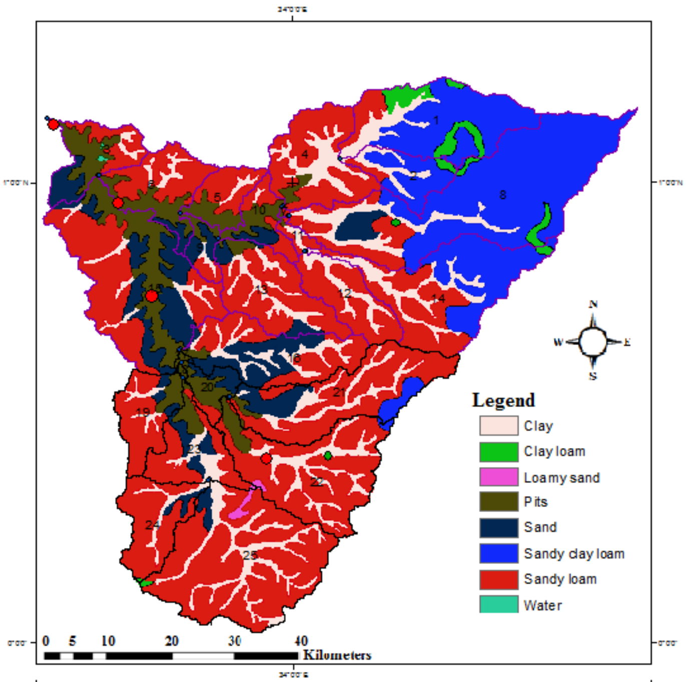

Figure 6.1: Soil types of the Mpologoma river basin from the soil and terrain database for eastern Africa (FAO, 2002)

6.2.3 Evaluating land use changes

A supervised signature extraction with the maximum likelihood algorithm was employed to classify the Landsat Thematic Mapper images following the basic principles of the USGS land use/land cover classification system (LULCCS) with ArcGIS (version 10.1). Both statistical and graphical analyses of feature selection were conducted, and bands 2 (green), 3 (red), and 4 (near infrared) were considered to be the most effective approach in discriminating each class and thus used for classification. Training site data was done by the on-screen selection of polygonal training method. The accuracy of the three classified maps was checked with a stratified random sampling method, by which 50 points were selected for each land use and land cover category. The reference data was collected from field survey or from existing land use and cover maps that had been field-checked. The overall accuracy was derived from the number of correctly classified pixels divided by the total number of ground control points used for validation. In performing land use and land cover change detection, a cross-tabulation detection method was employed to produce a change matrix. Quantitative areal data of the overall land use and land cover changes as well as gains and losses in each category between 1986 and 2013 were compiled. The change matrix gives the knowledge of the main types of changes (directions) in the study area. In order to analyze the nature, rate, and location of land use and land cover changes, a set of 'gains' and 'losses' images for each category was also produced. These 'change' images were overlaid with an image of the Mpologoma river basin boundary, which was constructed in a vector GIS environment and converted into a raster format with the resolution of 30 metres. This GIS overlay was intended to find land use and land cover change information within the Mpologoma river basin.

Table 6.1: The most sensitive parameters used in the calibration using the SWAT model

Parameter	Description	Min	Max
CN2	Initial SCS Runoff Curve number for Wetting Condition-2	-0.5	0.3
surlag-bsn	Surface Runoff Lag Time	0.20	0.90
CH-k2	Channel Effective Hydraulic Conductivity	70.0	150.0
GWQMN	Threshold Depth for Shallow Aquifer for flow	50.0	150.0
ALPHA_BF	The Base Flow Alpha Factor	0.20	10.0
canmx	Maximum Canopy Storage	0.10	5.00
SOL_AWC	Soil Available Water Capacity	-0.20	0.20
rchrg_dp	Deep Aquifer Percolation Factor	0.10	0.40
GW_REVAP	Ground Water "Revap" Coefficient	0.03	0.07
ESCO	Soil Evaporation Compensation Factor	0.60	0.90

6.2.4 Water quality modelling

The SWAT model calibrated above was used to estimate mean depth, total phosphorus and conductivity loadings at the differently disturbed study sites. The study was confined to these water parameters because of the realised strong correlations with the sites' disturbance level of the sites as well as with the *Clarias* fish catch. The water quality prediction from the SWAT model was built through the agriculture impacted routines in the Mpologoma sub-catchment. Information on the non-point sources of pollution in terms of fertilizer application in the identified commercial rice fields within the basin, areas with subsistence farms and natural wetland areas with low to no application of fertilizers was used in the model. Nutrient cycling in SWAT was simulated via transformation and movement of phosphorus (P) within multiple inorganic and organic pools within each HRU. The amount of soluble P was worked on the basis of the soluble P concentration in the top 10 mm of soil, the surface runoff volume, and a partitioning factor. The simulated results for each water quality parameters were compared to the observed values from the Mpologoma wetland.

6.2.5 Fish catch modelling

Potential maximum sustainable yield of freshwater fisheries may be approximated using a variety of empirical methods (Pitcher and Bundy, 1995), including correlative relationships with various limnological parameters such as the recently revived morpho-edaphic index (MEI) (Schnieder and Headrich, 1989; Badjik and Schnieder, 1991) or primary production (Downing et al., 1990). Methods based on primary production may be of more utility for approximate fisheries purposes than the ME1 which has not been very successful in African lakes (Pitcher et al, 1996). A suitable equation for estimating potential catch per unit effort was derived from correlations between fish catch per unit effort (CPUE) and aquatic system characteristics (Egertson and Downing, 2004). In this study CPUE was used to infer the fish abundance in the wetland. Through multi linear regression of independent variables, CPUE prediction model was derived for species-specific and species group catch per unit effort by weight (CPUE) (g $effort^{-1} night^{-1}$), expressed as:

$$CPUE = 2.89 + 3.17 (Cond) - 2.48 (Z) + 1.47 (Chl\ a) \quad (6.1)$$

where CPUE is catch per unit effort (g effort^{-1}night^{-1}), cond is specific conductivity (mScm^{-1}); Z is mean depth (m); Chl *a* is chlorophyll *a* concentration (μgL^{-1}); Chl *a* can be derived from the equation Log Chl *a* = -0.369 + 1.053log (TP) where TP is total phosphorus concentration (μgL^{-1} as P).

6.2.6 Data analysis

To examine the relative effects of different types of land use on water quality, the output curves from different sites with different land use patterns were superimposed from the SWAT model. Because the model could not simulate conductivity values at the different time and it was assumed conductivity did not change signigficantly given that the large scale rice scheme has been in the wetland since the 1970s, the observed conductivity values in the wetland was used in the fish prediction model. SWAT simulated values for total phosphorus and mean depth at the different wetland sites were used in the fish model (equation 6.1 above) to predict the fish CPUE. The SWAT simulated values of the water quality variables were used to predict $CPUE_s$ and observed water quality values in the wetland were used to predict $CPUE_w$ and were compared to the observed values $CPUE_o$ of the small *Clarias* species in the Mpologoma wetland in 2012. The goodness of fit of the model was tested using the Nash-Sutcliffe coefficient (Bicknell et al., 1996). Nash-Sutcliffe coefficient, *NSE*, measures how well the daily simulated and measured flows correspond. This coefficient is calculated as follows:

$$NSE = 1 - \frac{\sum_{i-1}^{n}(O_i - P_i)^2}{\sum_{i-1}^{n}(O_i - Q_{av})^2} \quad (6.2)$$

where O_i is the measured daily discharge, P_i is the computed daily discharge, and O_{av} is the average measured discharge. A Nash-Sutcliffe value can vary between 0.0 and 1.0 where a value of 1.0 indicates a perfect fit while a value of 0.0 indicates that the model is predicting no better than the average of the observed data. An alternative measure for determining fit to the relative trend is Spearman's rank-order correlation (R^2). This was also used to test the model fit and was found to be appropriate for examining relationship between the observed and simulated phosphorus and flow and between the observed and predicted CPUE values. The homogeneity of variance with Levene's statistic test was carried out between the predicted and observed CPUE values. The difference in the mean values of observed and predicted water quality parameters and CPUE were analysed using one way ANOVA and Tukey's *post hoc* test among the differently disturbed sites in the Mpologoma catchment.

6.3 Results

6.3.1 Land use changes in the Mpologoma river catchment

The land use and land cover maps for 1986, 2001 and 2013 were produced from Landsat TM images as displayed in Figure 6.2. The overall accuracy of the land use/cover maps for 1986, 2001, and 2013 was 70.67%, 79.51%, and 70.31%, respectively. Monserud (1990) suggested an accuracy value of <40% as poor, 40–55% fair, 55–70% good, 70–85% very good and >85% as excellent. The accuracy range of 70 to 79% obtained was therefore sufficient for evaluation of land use and land cover changes. Five major land uses were identified during the analysis (Table 6.2). Agricultural activities covered the largest land use since 1986 to 2013 which ranged from 64.98 to 73.19 %, indicating 9.20% increase over 14 years. Built-up areas increased by 3.19% while other land uses reduced in cover in the same time span. The wetland area which ranged from 23.6 to 13.5%, reduced by 10% over the 14 years while the woodland reduced by 1%. However, built up areas, bush land and woodland and tropical forest covered small areas as shown in the land use and land cover change matrix from 1986 to 2013 (Table 6.2). In 1986, agricultural land was the dominant land use (45%) followed by wetlands (23.6%), and this was followed by built-up areas covering 5.7% of the total catchment area. The forest and bush land were both covering less than 6% during this period. After a fifteen year period, wetlands cover drastically declined from 14.7% to 8.9% in 2001. While agriculture area declined by 9.8% to 55.2%. However, other land cover units gained in the same period including bush lands (18.1%) and built up areas (2.3%). In 2013, agricultural land decline continued by 6.6% but it was still the largest land use cover in the basin. Wetlands also continued to shrink by 7.6% to cover 16% of the total area. Other land uses, bushland and built-up areas gained by 5.6% and 11.2% (Figure 6.3).

The transition pixels during the periods 1986–2001, 2001–2013, and 1986–2013 were calculated (Table 6.3). The transitional pixels from 2001 to 2013 in the first set of rows meant that the transition pixels from wetland to wetland were 22, woodland to wetland were 7, agriculture to wetland was 1, bushlands to wetland was 0 and built-up areas to wetland was 0. While wetland area was changing to other land uses. The transition pixels from wetland to woodlands were 28, wetland to agriculture were 2, wetland to bushlands were 21 and wetland to built-up areas was 1. The transition pixels of other land uses to wetlands from 2001 to 2013 were over 71. There was an increase in wetland area between those years. In the last set row the transition pixels from 1986 to 2013 of all other land uses to wetland was 0. Therefore the overall change other land uses to wetland from 1986 to 2013 was zero, while over 24 pixels of wetland area transitioned into other land uses. The resultant error matrix indicated that the commission and omission errors for each year and the overall classification accuracy for all the land uses was over 70%. The class with the highest accuracy was wetland (90.3% in 1986 and 100% in 2013) followed by agricultural land (94% in 1986) and bush lands/grasslands (97.5% in 2001). The highest omission and commission errors were associated with built-up areas and woodland from 1986 to 2013. The resulting classification was then refined to a finer classification that was made possible using data from a field ground referencing study in order to better represent the land cover in the study area.

Table 6.2: Land use and land cover change for the Mpologoma river basin, between 1986 and 2013

	1986		**2001**		**2013**	
Land use Type	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**	**Area (ha)**	**% Area**
Agriculture	317118	65	269557	55	237226.2	49
Bushland	14550	3	103017	21	41377.5	8
Built up areas	28011	6	39417	8	82584.3	17
Wetland	115361	24	43581	9	78220.4	16
Woodland and Tropical Forest	12960	3	32428	7	48590.7	10
Total	488000	100	488000	100	488000	100

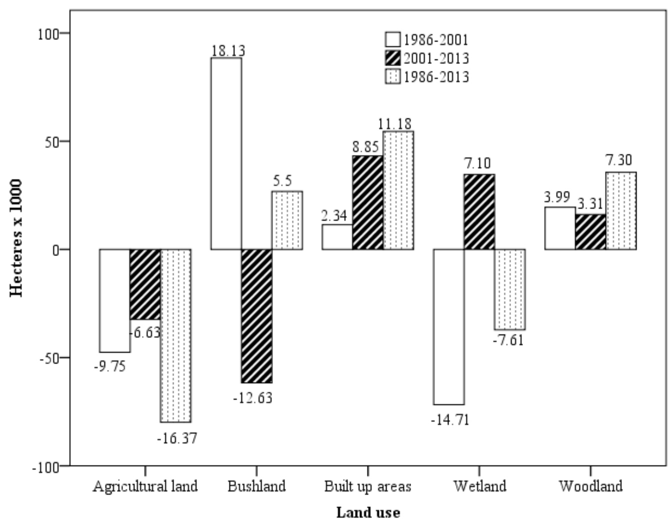

Figure 6.3: Land use changes for the Mpologoma river basin by area and percentage change (numbers above and below bars) since 1986 to 2013

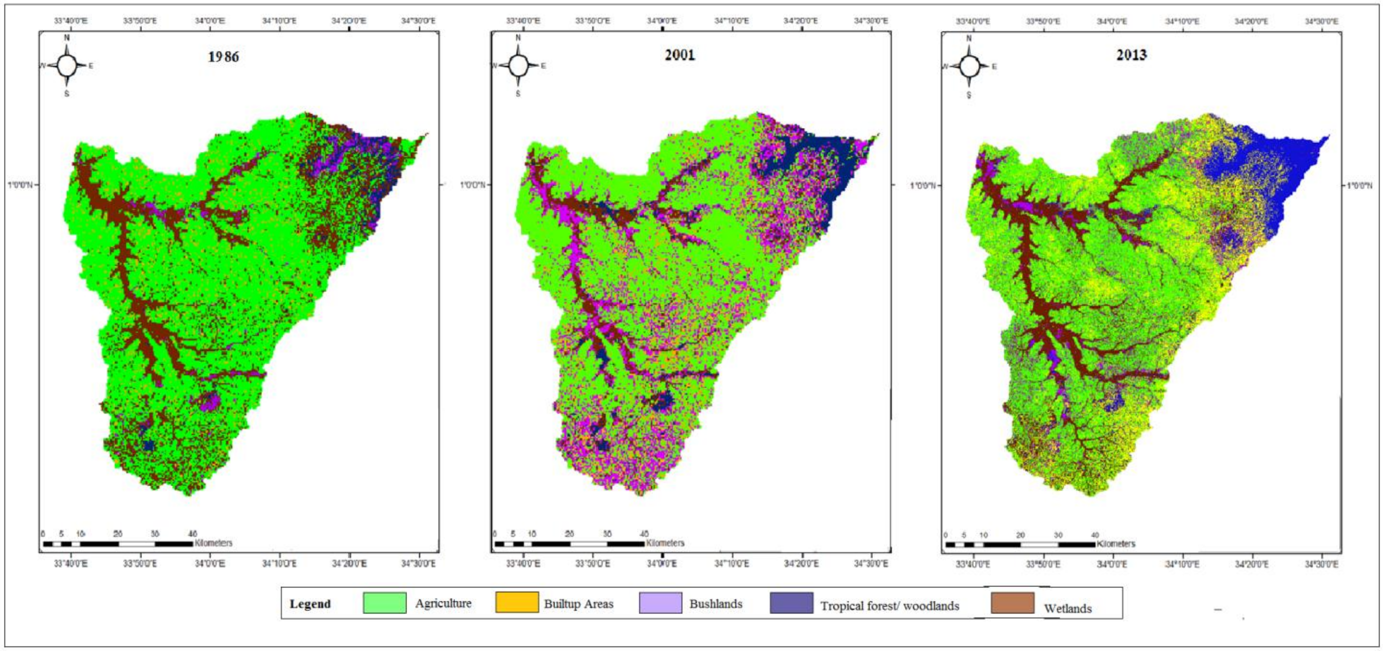

Figure 6.2: Land use and cover of the Mpologoma river basin, 1986 – 2013

Table 6.3: Land use/cover change matrix for the Mpologoma river basin, 1986 - 2013 (Agriculture for both subsistence and commercial scale, Woodlands for woodlands and tropical forest)

	Land use	Wetland	Woodlands	Agriculture	Bushlands/ Grasslands	Built up areas	Total
			2001				
1986	Wetland	22	28	2	21	1	74
	Woodlands	7	70	42	18	1	138
	Agriculture	1	30	153	29	12	225
	Bushlands/ Grasslands	0	35	19	3	0	57
	Built up areas	0	0	0	0	7	7
	Total	30	163	216	71	21	501
	Commission error (%)	0	0	5.56	26.67	53.33	
	Omission error (%)	0	0	26.67	6.67	13.33	
	Accuracy (%)	100	100	67.78	66.66	33.34	
			2013				
2001	Wetland	36	11	2	3	2	54
	Woodlands	25	103	6	5	0	139
	Agriculture	21	9	113	14	32	189
	Bushlands/Grasslands	25	26	22	2	12	87
	Built up areas	0	0	0	0	32	32
	Total	107	149	143	24	78	501
	Commission error (%)	0	27.87	4.21	0	11.27	
	Omission error (%)	0	4.88	0	2.44	9.76	
	Accuracy (%)	100	67.25	95.79	97.56	21.03	
			2013				
1986	Wetland	113	1	4	9	10	137
	Woodlands	0	59	14	3	5	81
	Agriculture	0	94	80	16	28	218
	Bushlands/Grasslands	0	0	51	1	10	62
	Built up areas	0	0	0	0	3	3
	Total	113	154	149	29	56	501
	Commission error (%)	9.68	45.83	3.13	0	12.5	
	Omission error (%)	0	11.43	2.86	20	34.29	
	Accuracy (%)	90.32	42.74	94.01	80	53.21	
	Overall accuracy (%)	72.06					

6.3.2 Water quality parameters

The SWAT model was run for the hydrology of the wetland and a plot of the simulated and observed flows was made using the model's default and observed values (Figure 6.4. The observed flow had a mean (± SD) of 13.16 ± 11.91 cms while the mean simulated flow out was 13.79 ± 11.19 cms at Budumba between 1965 and 1975. The observed and simulated flows were closely related and their mean values were not significantly different (Levene's test, $p = 0.34$). However, the model sensitivity analysis using Nash-Sutcliffe Efficiency (NSE) and correlation coefficient had low values despite the comparable mean values of flow out at the Budumba (Table 6.4). The general trend of flow out for the 10 year period at the different study sites was realised (Figure 6.5). Highly disturbed Nsango site had the least flow compared to the downstream highly disturbed Kapyani site. The trend of river flow was comparable to the rainfall pattern at each two MLWE rain gauge stations (Tororo and Serere). The two MLWE gauge data sets were not significantly different from the data sets of Budumba and Kapyani sites that were derived from daily rainfall estimates (RFE) of meteosat infrared data and artificial gauges at 10 km resolution of eastern Uganda region (ANOVA, $p > 0.05$; Figure 6.6).

Table 6.4: Model evaluation using monthly flow at Budumba site in Mpologoma river catchment between 1965 and 1975

	Minimum	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
Observed flow	0.10	72.32	13.16	11.91	143.09
Simulated flow	0.01	92.59	13.72	11.19	125.31
Valid n	3895				
	Calibration		Validation		
NSE	0.35		0.12		
r^2	0.61		0.52		

[a] NSE = Nash-Sutcliffe Efficiency, [b] r = Correlation coefficient

Calibration and validation were performed for the total phosphorus (TP) concentration and the simulated values were compared with the measured values at the Budumba site outlet (Figures 6.7). A strong correlation was observed in the calibration period indicating that the model was able to simulate good phosphorus loadings with fair accuracy (NSE and R^2 values of 0.23 and 0.54, respectively). The simulated total phosphorus concentration did not change with time at the different sites. But at the highly disturbed Kapyani site, higher values of TP were simulated compared to other sites at the different time (1986, 2001 and 2012) (Table 6.5). There were variations between simulated TP and the observed values in 2012 at the different sites.

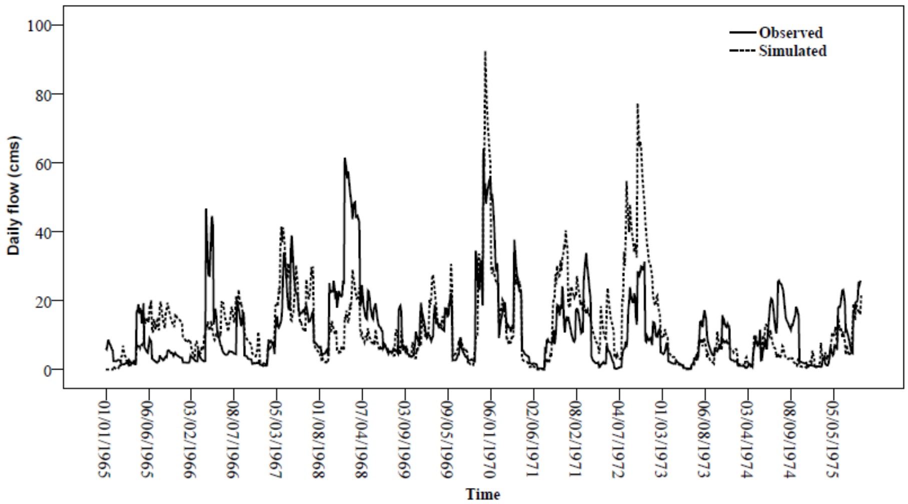

Figure 6.4: Simulated and observed flow out (cms) of Budumba site in reach 15 of the Mpologoma river catchment between 1965 and 1975

6.3.3 Small *Clarias* Catch

The variances of the mean values of the predicted $CPUE_w$ and observed $CPUE_o$ for less disturbed sites, Budumba and Mazuba, and highly disturbed Nsango were homogenous at $p < 0.05$ except for the highly disturbed Kapyani site (Levene's test, $p = 0.39$). From the comparison of the observed $CPUE_o$ and predicted $CPUE_w$, mean values for Budumba, Mazuba and Kapyani sites, the CPUE values were not significantly different (See Table 6.5; Figure 6.8). While the mean CPUE values for the highly disturbed Nsango site were significantly different from the rest ($p = 0.001$). Although the NSE values were low for the less disturbed sites, the fish model predicted CPUE more accurately at highly disturbed Kapyani site (NSE = 0.62). The goodness of fit test of the fish prediction model showed that the means of the $CPUE_o$ and $CPUE_w$ were significantly similar at the two less disturbed sites and the highly disturbed site Kapyani. At the highly disturbed Nsango site, the means of $CPUE_w$ and $CPUE_o$ were significantly different (Figure 6.8). Between 2001 and 2012, an increasing trend of predicted $CPUE_s$ was observed at all sites (Table 6.5 and Figure 6.9). Although, there were no significant difference between

$CPUE_o$ and $CPUE_s$ at other sites in 2012, at highly disturbed Nsango site $CPUE_s$ was higher than $CPUE_o$.

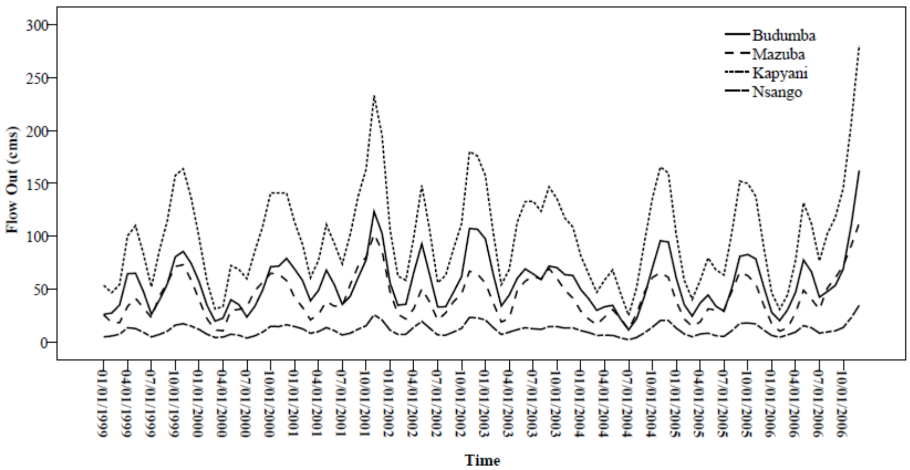

Figure 6.5: Simulated flow out of the different study sites in the Mpologoma river catchment between 1999 and 2006

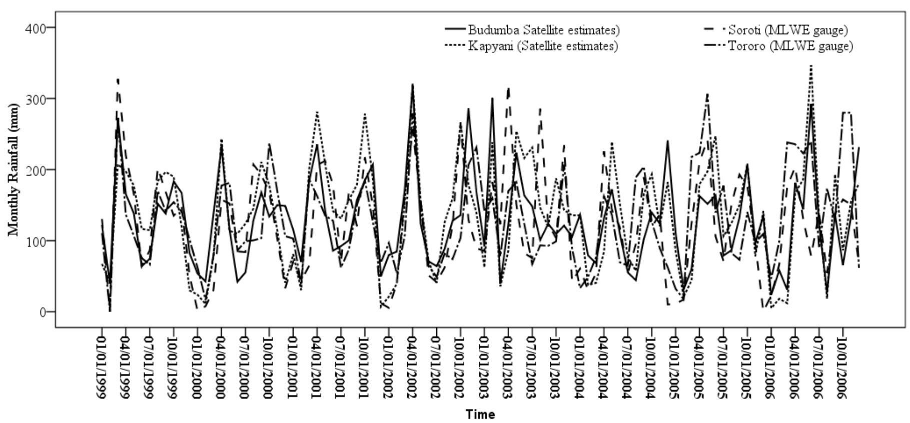

Figure 6.6: The trend of rainfall for two locally and two artificially gauged stations in the Mpologoma river catchment

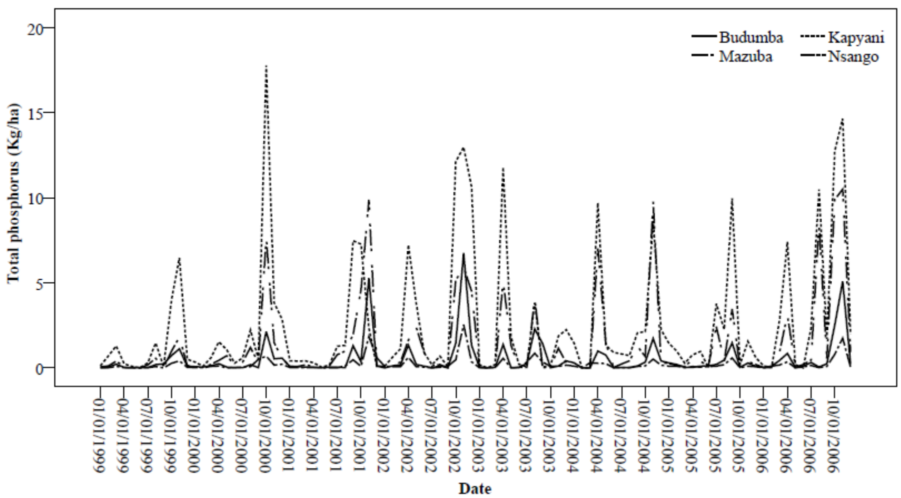

Figure 6.7: Simulated total phosphorus concentration at different wetland sites in the Mpologoma river catchment between January 1999 and December 2006

Table 6.5: Simulated total phosphorus (TP), conductivity and $CPUE_s$ at the different sites and time in the Mpologoma wetland (value are monthly mean ± S.D., $p < 0.05$; values in the same column with the same superscript were not significantly different)

	Year	Budumba	Mazuba	Kapyani	Nsango
TP (mgl^{-1})	1986	0.78 ± 0.35^a	0.99 ± 0.53^a	0.93 ± 0.12^a	0.74 ± 0.13^a
	2001	0.73 ± 0.22^a	0.79 ± 0.25^a	0.74 ± 0.52^a	0.81 ± 0.15^a
	2012	0.65 ± 0.41^a	0.47 ± 0.39^a	0.51 ± 0.24^b	0.27 ± 0.19^b
Conductivity (μScm^{-1})	1986	163 ± 31^a	154 ± 31^a	165 ± 18^b	152 ± 16^b
	2001	160 ± 34^a	168 ± 27^a	218 ± 28^a	272 ± 48^a
	2012	152 ± 32^a	164 ± 35^a	247 ± 55^a	351 ± 55^a
CPUE (g/trap/night)	1986	532 ± 86^a	567 ± 101^a	515 ± 70^a	516 ± 58^a
	2001	519 ± 85^a	521 ± 96^a	484 ± 59^a	485 ± 57^a
	2012	483 ± 73^a	524 ± 98^a	721 ± 177^a	1114 ± 189^b

.

Table 6.6: The predicted catch at the different wetland sites in the Mpologoma river catchment in 2012 (values are mean ± S.D in Kg/night/trap)

Parameters	Budumba	Mazuba	Kapyani	Nsango
Predicted $CPUE_w$	0.48 ± 0.07	0.52 ± 0.09	0.72 ± 0.18	1.11 ± 0.19
Observed $CPUE_o$	0.57 ± 0.18	0.51 ± 0.23	0.68 ± 0.23	0.45 ± 0.08
CPUE prediction model sensitivity				
NSE	0.32	0.23	0.62	-0.11
X^2 Goodness of fit (t test for equality of means)				
t-value	-1.59	0.25	0.43	10.94
p-value	0.13	0.8	0.67	0.001

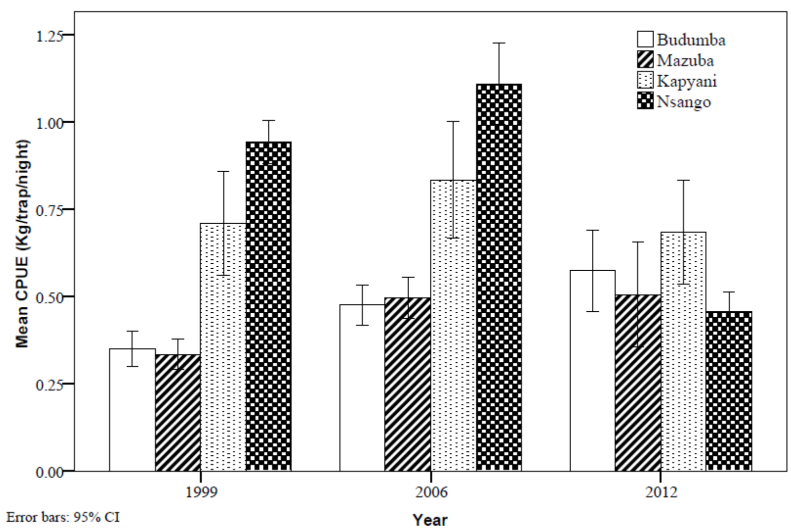

Figure 6.8: The trend of predicted $CPUE_s$ of small *Clarias* species at the different sites in the Mpologoma river catchment between 1986 and 2012

6.4 Discussion

6.4.1 Land use change in the Mpologoma catchment

Land-use/cover changes are driven by a complex of underlying causes including shifting cultivation and increasing population pressure (Kabanza et al., 2013). Demographic changes have been considered as the first local driver for land-use changes along the Mpologoma wetland. The data collected during the present study indicated a decline in natural vegetation particularly in the wetland area as a result of population increase. Uganda's population growth rate of 3.5% has been maintained for the past ten years (MAAIF, 2010). Population densities expand more in riparian countries that border open water and wetland areas leading to increased urbanization and land-use change (Ruecker et al., 2003). More than 80% of the total population of Uganda is engaged in agriculture which comprises a large variety of both crop and livestock products (FOWODE, 2013). With time, the original agricultural land faces decline in soil fertility due to usage of low productivity strategies which have lead to more land being brought into production particularly in wetlands (MAAIF, 2010) thus the increasing trend in the decline of natural vegetation to other land uses in the Mpologoma catchment.

The concepts of net land-use/cover changes coupled to loss, persistence and gain are particularly helpful for analyzing the land-use/cover dynamics (Pontius et al., 2004). Agriculture constitutes the largest land use category in the catchment, but land for cultivation has been declining. In 2001, agricultural land decline was attributed to the prevailing insecurity at the time that had deprived the population of the opportunity to open up land for cultivation. A 15 year interval was observed from 1986-2001, a phase characterised by a number of new developments in the socio-political sphere of the basin and the sub-region. The military cleared the bushes so as to deny insurgents camouflage; this left a number of areas open and bare, and pushed local people into concentration camps, deserting their farms (Ejeru et al., 2010). After 2001, agricultural land increased due to the recovery efforts after the conflict in the sub-region, and households increased their engagement in cultivation for self reliance. The recovery process saw increased encouragement for the population to return to their homesteads and embark on cultivation to secure necessary food supply and a settled life. This therefore accounted for the upsurge in small-scale farming in area around moderately disturbed Kapyani site. Rural development and land-use policies are important local drivers of land use change (Kabanza et al., 2013). The settlement policy affected the distribution of people and land-use with the creation of large, semi-urban villages. This explains the increase in built up areas particularly between 2001 and 2013 when the prevailing security situation allowed recovery of the population in the region. Woodlands were mainly observed at the slopes of Mount Elgon and this was attributed to the higher precipitation received in the area than the rest of the basin due to the influence of the mountain rainy side.

Wetlands covered a large area of the basin but this was drastically reduced between 1986 and 2001 due to various significant gains into other land use units for example agriculture, woodlands and bushland. According to Madebwe and Madebwe (2005), the wetland loss was caused by increased cultivated area and livestock numbers which catered for the increased food demand for feed the increasing population. The introduction of new agricultural technologies is another important global driver of land use change (Kabanza et al., 2013). In the early 1980s, large scale rice schemes were set up in the eastern Uganda region (Musiime et al., 2005). The civil unrest in the area led to a 9.97% decline of some large scale farming areas (commercial farmlands) and the total collapse of other production systems particularly cattle ranching between the mid 1980s and early 1990s (Mushemeza, 2008; Egeru et al., 2010). This explains why areas around Kapyani site where a rice scheme was abandoned, the wetland changed into bushland and woodland. However, the original wetland vegetation did not recover in the abandoned rice schemes. After the war, there was intensification of subsistence farmlands due to the prevailing peace, an increase in the number of households and the realization of rice growing profitability which encouraged opening of more wetland into farm land (Mushemeza, 2008). The observed decline of the hectarage of the Mpologoma wetland is comparable to the findings of Kibwage et al. (2008) in which agricultural cultivation affected the size and facilitated the rapid decline of the Lake Victoria basin wetlands.

6.4.2 Land use change impacts on water quality

There were variations of water quality variables between the different sites over time. This was attributed to impacts of land use changes that were evident both at spatial and temporal scales. Areas with commercial and peasant rice fields have been reported to use agrochemicals including fungicides, nematocides, acaricides, herbicides and fertilizers which, negatively impact the water quality of wetlands and open water systems in the eastern Uganda (Egeru et al., 2010).

The increase in demand for those agrochemicals with time due to agricultural expansion explains the increased water quality variation with time among the sites. The trend of discharge with time was attributed to the contribution of the lateral flow from the various land uses and the rainfall patterns in the region. The expansion of farming activities in the Mpologoma wetland implied that large areas were exposed to direct isolation which had implication on water flow trends in the Mpologoma basin. This could explain the low water levels and stream flows at highly disturbed Nsango site. It was observed that the catchment receives relatively the same range of rainfall.

There were inconsistencies between the predicted and the observed values of water parameters. This was due to low prediction accuracy of the water quality model which was attributed to limited data availability for using in modeling, mainly in the calibration process (Kimwaga et al., 2012). The inconsistencies could also be due to inadequate description of the field rainfall data caused by the limited number of available meteorological stations, as well as by their poor representation in areas of higher altitudes (Stehr et al., 2008). Although the importance of spatial variability of rainfall in simulating runoff was recognized, the assumption of uniform rainfall over relatively large surface areas remains a common practice in many hydrological modelling applications (Abbaspour et al., 2007; Stehr et al., 2008). In SWAT, errors in climate data for every sub basin are furnished by the station nearest to the centroid of the sub basin (Stehr et al., 2008). The rainfall data was also augmented by the satellite generated climate date sets. The calibration of the SWAT model at the watershed was a challenging task because of the possible uncertainties that existed in the form of process simplification, processes not accounted for by the model, and processes in the watershed that were unknown during the analysis. The most common model uncertainties were the effects of wetlands and reservoirs on hydrology and chemical transport, interaction between surface and groundwater, occurrences of landslides in part of the catchment and large constructions of roads and dams that could produce large amounts of sediments for a number of years affecting water quality and quantity (Abbaspour et al., 2007). Eastern Uganda has been increasingly experiencing catastrophic landslides over the years, the largest occured in 2004 which could have affected the model. Although irrigation, agricultural activities and fertilisation were accounted for, these landslides within the Mpologoma catchment were not accounted for in the model during the study period.

Therefore, to a larger extent, model uncertainties were not limited to the errors in the process simplification, but also some uncounted for processes in the basin.

6.4.3 *Clarias* fish catch prediction

When water quality parameters have been used to predict of fish yield, one would expect water quality to reflect the level of fish yield in aquatic systems (Ranta and Kai, 1993, Egertson and Downing, 2004). This is because nutrient levels and their balance enhance the productivity of any aquatic ecosystem. In this study, higher *Clarias* catch was predicted when higher nutrients were simulated and the expectation was that the harvestable proportion of small *Clarias* species population was a function of the Mpologoma wetland productivity. In a situation of wetland conversion to farmland, nutrients enter the aquatic systems from agricultural lands and other sources, and the increase in nutrients can cause great changes in the aquatic systems. One important change can be high primary production leading to increased energy supply for fish production (Egertson and Downing, 2004). When primary production is high, nearly all fish production can be harvested on a sustainable basis (Downing et al., 1990). But there is a likely shift in the fish community toward species tolerance of poor water quality as ecosystem responses to eutrophication. Such systems are characterized by the dominance of benthivorous fish (Ranta and Kai, 1993). Small *Clarias* species are regarded as poor water quality tolerant species (Raburu and Masese, 2010) and they are also benthic feeders (Ssanyu et al., 2014) which explain the high catch of clariids predicted at the highly disturbed sites. The result is comparable to the estimation of potential yield of *Rastrineobola argentea* fishery in Lake Victoria. At high levels of deposition, when oxygen concentrations decline sharply, dense populations of invertebrate planktivores and benthic fish that are tolerant of anoxia were supported instead of planktivorous *Rastrineobola* (Pitcher et al., 1996). The average predicted CPUE ranged from 0.77 $kgtrap^{-1}hr^{-1}$ to 1.07 $kgtrap^{-1}hr^{-1}$ for small fish in rice growing tropical wetlands (Nguyen Khoa et al., 2005). The trend of observed and predicted CPUE compared favourably with each other and even with the nutrient content trend in the wetland on a spatial and temporal scale. The present study estimates of Mpologoma wetland fishery revealed that the CPUE of small *Clarias* was higher at the highly disturbed sites where higher nutrients concentration was observed than at the less disturbed sites.

The small *Clarias* observed CPUE was lower than the two predicted CPUE's from both the observed and the simulated water quality values. This was because observed CPUE accounted for only that of fishermen at the landing sites at the time of sampling. Therefore, a large portion of the predicted CPUE could have been for that fish which was not yet caught. This explained the higher predicted CPUE than the observed CPUE recorded particularly at the highly disturbed Nsango site. The difference between fish production and sustainable yield should reflect either the fraction of fish community production that is unexploited (i.e. rough fish, juveniles) or the amount of fish production that cannot be channelled into fishing mortality (Egertson and Downing, 2004). Another possible reason for the differences in catch was that when fishermen move for long distances, the efforts are large relative to the productive area, resulting in lower observed CPUE compared to the predicted values (Downing et al., 1990). There was a weak correlation between predicted and the observed catches particularly in the highly disturbed Nsango could also be due the decoupling of high values of nutrients in the wetland receiving waste water from Tilder rice scheme. Because nutrients were abundant, nitrogen and phosphorus were no longer the primary production limiting resources. Studies of both algal biomass and fish catch have suggested production approaches an asymptote in nutrient-rich systems (Egertson and Downing, 2004) a factor which the prediction equation did not incorporate.

The fish prediction model is a good predictor of benthic fish yield given that it was derived from strong correlation between fish CPUE and chlorophyll a, conductivity and ecosystem depth. However model has a major challenge of predicting yield exponentially and this was due to the decoupling effect of high concentrations of the nutrients nitrogen and phosphorus from production in the system receiving high inputs from agricultural activities (Egertson and Downing, 2004). There are also some factors not accounted in the model yet they could significantly affect the predicted yield. For instance, suspended solids may lead to light limitation in some aquatic systems, while nutrients may not limit phytoplankton. Other potential reasons for lack of correlations between total fish CPUEw and nutrients could be due to the near lack of macrophytes in the system. Macrophytes add complexity to the ecosystem and allow multiple pathways for nutrients to increase habitat and food for fish (Scheffer 1998). Spatial distributions of fish or errors introduced during collection can increase variability of catch data (Murphy and Willis 1996) and cause low statistical power in the predicted CPUE.

Overall, the study showed that small *Clarias* species CPUE increased with increasing trend of water quality parameters associated with land use changes in the wetland with time and space. The changes in water quality led to an increasing trophic status of the fish habitats in the wetland associated with increasing primary productivity which led to high benthic productivity that supported benthic feeders, the small *Clarias* species. The predicted CPUE based on the SWAT nutrient outputs did not perform well mainly because of the unaccounted for elements in the modelling process of nutrient simulation and the limited number of local rainfall gauging stations in the catchment. However, the performance of the CPUE prediction model evaluated under different assumptions was realized to perform more accurately when observed total phosphorus, conductivity and mean depth in the wetland were used. If the water quality model could predict more accurate the water quality values, the fish prediction model used in the current study could be used for predicting wetland fish yield in future. This is because very few fish prediction models have been performed on African swamps (Ranta and Kai, 1993; MRAG, 1996; Egertson and Downing, 2004). However, the future trend of water quality parameters and how they affect the small *Clarias* CPUE given the increasing trend of land use changes in the Mpologoma basin remains an unresolved question.

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CHAPTER SEVEN:

IMPACT OF *CLARIAS* SPECIES RESOURCE DYNAMICS ON THE SOCIO-ECONOMICS OF THE MPOLOGOMA WETLAND RIPARIAN COMMUNITIES[3]

Abstract

Small-scale fisheries in developing countries are characterised by uncertain future due to the ever increasing pressure on wetland resources. Data on the interconnectivity between wetland fishery, land use changes and socio-economics in the Mpologoma riverine wetland fishery, Uganda, were obtained through interviews and structured questionnaire survey at the four differently disturbed sites. While rice production was the major economic activity at the highly disturbed sites, maize production was the major activity at the less disturbed sites. Of the secondary activities, *Clarias gariepinus* (Burchell, 1815) and *Protopterus aethiopicus* (Heckel, 1851) fishing was more important at the less disturbed sites. Daily fish sale income significantly associated with fishing gear number, fish species caught ($p < 0.05$) and negatvively associated with level of disturbance. 13% of respondents at the less disturbed sites had higher annual income resulting in more accumulated wealth than those at the highly disturbed Nsango site whose fishery was affected by large scale rice scheme. Land use changes in the wetland disturbed the fish habitats of pollution intolerant fish (*C. gariepinus* and *Protopterus* sp) resulting in low fish production at the highly disturbed sites. The socio-economic impact of the small scale fishery was low particularly at the highly disturbed site which was recoreded with the lowest economic and social indicators of fishery importace. The Mpologoma riverine wetland was threatened by overexploitation of its fisheries services and also overlooked and undervalued by policy makers due to lack of fisheries statistics. Therefore, the information derived from this study would facilitate the formulation and design of riverine wetland-specific and small scale

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[3] Publication from this chapter:

GA Ssanyu, J Kipkemboi, JM Mathooko and J Balirwa (2014). Land-use impacts on small-scale Mpologoma wetland fishery, eastern Uganda: A socio-economic perspective. Lakes and Reservoirs: Research and Management 19: 280 – 292. DOI. 10.1111/lre.12073 fisheries management strategies with consideration of local communities' perception of the fisheries.

Key words: wetland disturbance levels, livelihoods, poverty, small scale fishery, East Africa

7.1 Introduction

Tropical wetlands are productive and dynamic systems that support vast livelihoods (Silvius et al., 2000). These wetlands support small-scale fisheries which are important part of the fisheries sector and economy of the rural poor in many developing countries (Nguyen-Khoa et al., 2005; Onyango and Jentoft, 2010). The fisheries play a significant role in socio-economic sustainability of the rural communities and consequently poverty alleviation through generation of revenues, employment creation, and contribution to food security (Bene et al., 2010). However, land use changes in the landscape and the increasing demand for food created by increasing population has led to destruction of fish habitats through natural wetland conversion into agricultural areas. This has significantly influenced, *inter alia*, ecosystem health, livelihoods and employment (Bavinck et al., 2005; FAO, 2005), and also shaping the levels of fishing effort and incomes of the rural people (Hoggarth et al., 1999). Consequently, rural communities have faced a number of challenges which include low standard of living, limited resources, lack of basic food security, lack of entitlement, multiple deprivation, exclusion, inequality and dependency (Bene and Neiland, 2004).

The direct dependence on the wetlands by the riparian rural communities for day to day requirements poses a great wetlands management challenge in East Africa (Opaa et al., 2012). As the population grows, the demands by different users of wetland resources increase, leading to conflicting levels of demands that are detrimental to entire aquatic ecosystems and their dependent fisheries (Torell et al., 2010). For instance, over 7000 hectares of wetlands in eastern Uganda have been converted into rice farms (Anon, 2004) and also the large wetland fish species of lake Kyoga basin, *Clarias gariepinus*, has declined in production from more than 1600 metric tonnes in the 1980s to 1.35 metric tonnes in 2000's (Muhoozi, 2003). The continuing conversion of wetland into farm land could lead to near collapse of the fishery (Onyango and Jentoft, 2010) and can have a profound impact on the social and economic welfare of the majority of the rural population (van der Knaap et al., 2002). This could lead to unsustainable exploitation of marginalized wetlands fisheries and other resources. The households that are predominantly dependent on wetland fishery for livelihoods are most deprived of access to natural resources, for instance, the open lake's fishing grounds (Bene and Neiland, 2004), will continue to be perceived as typically among the poorest (Nguyen Khoa et al., 2004).

For small scale fisheries to deliver their full benefits to the local communities, the various sources of vulnerability must be addressed, involving the investigation of the changes in fishery systems using new management arrangements and approaches. The concern is founded on the reality that these changes that threaten ecosystem health, livelihoods, and food security, among others, remain overlooked and/or underestimated (Bavinck et al., 2005; FAO, 2005). This chapter elucidates the relationship between land use, and the dynamics of a wetland fishery, emphasizing their interrelationship with the other related socio-economic activities. In this regard, we specifically focused on the socio-economic characteristics of the communities, wetland fishery and the relationships between the two attributes across different sites with varying levels of human disturbance in the Mpologoma wetland. Human disturbance is hereafter defined as the conversion of natural wetland into farmland. Less disturbed areas ranged from intact wetland to less than 5% wetland conversion into farmland, and highly disturbed ones should have over 25% wetland converted into farmland. We hypothesized that land use changes in the wetland affect fishery production and consequently the immediate socio economic structure. Information on how subsistence fishing households were coping with and adapted to spatio-temporal variations in relation to land use change in the Mpologoma River wetland was derived.

7.2 Materials and Methods

7.2.1 The case study

This study was carried out in the Mpologoma riverine wetland in Uganda where small-scale fishery complements riparian community livelihoods. The wetland is found within Lake Kyoga complex (1°12' N latitude and 34°40' E longitude), existing as a network of small vegetated valley bottoms in a slightly undulating landscape, mainly in Butaleja, Namutumba, Bugiri, Kibuku and Pallisa districts. The towns nearby the wetland have had a population growth rate of 4.3 % per annum and a population density of about 184 persons per km^2 (UBOS, 2010).

Fishery has been a major human activity since ancient times, but with the increasing population, people have tended to derive other livelihoods from the wetland such as growing crops and livestock grazing. However, poverty and natural resources degradation were still a glaring reality in the Mpologoma river basin (Anon, 2004). The socio-economic survey was carried out at the four differently disturbed sites Budumba, Mazuba, Kapyani and Nsango in the Mpologoma riverine wetland.

7.2.2 Socio-economic data

Data were obtained through face-to-face interviews and pre-tested structured questionnaires mainly with fishermen and other wetland users, respectively. The survey was done between November 2012 and January 2013, collecting a total of 152 responses out of 240 questionnaires that were distributed, accounting for 63.3% return. The interviews consisted of a series of questions focusing on four broad categories: (i) wetland users community structure; (ii) fishery characteristics; (iii) economic and socio indicators of the fishery; and (iv) wetland users' perceptions to wetland management. Due to the scattered nature of landing sites at the study sites, villages and households were considered as fishing units, involved in the wetland fishery. Four fishing units were identified near the biggest landing sites at each of the four differently disturbed sites along the wetland. Secondary information was also collected from available published works like UBOS (2010) and unpublished literature from government departments such as MAAIF (2012).

7.2.3 Data analysis

(a) Community structure

The data were analyzed using statistical elements in the SPSS package for Windows, version 16 (IBM ©). Cross tabulations along with the Chi square test were used to test the association dependency among variables and between variables and study sites. Levene's test was used to test the homogeneity of variance among the variables at the different sites. Where differences were significant in one way ANOVA analysis of the quantitative data, a Tukey's test was used to find the differences among variables. The independent and dependent variables were grouped depending on the question being considered. The independent variables in this study were age, marital status, education level, major economic activities, fish species, fishing gear used, best fishing season, suitable fishing areas, use of small *Clarias* species, number of *Clarias* fish in a bunch and wetland use whilst the dependent variables were the different sites and daily income from fish sale. Multivariate regression model which assumes the dependent factors to be categorical was used to select which variables are significantly affected by the dependent variables (site and daily fish sale income).

$$Y = a + b_1x_1 + b_2x_2 + \ldots b_k \ldots b_kx_k + \varepsilon \qquad (7.1)$$

where Y is the dependent variable; a is the constant (intercept); $b_1 \ldots b_k$ are the partial (regression coefficient; $x_1 \ldots x_k$ are independent variables, and ε is the residual. A multivariate regression model was run for the fish sale income with other socioeconomic parameters along the wetland using site 1 (Budumba), with fishing activity and reduced water as the reference variables. The significant variables were applied in Non-metric Multi Dimensional Scaling (NMDS) using R-statistic software (R Development Core Team, 2008) to measure the relationship between them.

(b) Socio-economic indicators

Three indicators were used to show the contribution of the Mpologoma riverine wetland small-scale fisheries to the livelihoods of the local communities. The indicators used were: (a) estimates of annual small scale fish catches; (b) landed value which was used as a measure of the direct benefit of the small-scale fisheries catch; and (c) employment. The number of fishers' dependants was used as indicators of social benefits of small-scale fisheries. Estimates of annual small-scale fish catches were calculated from the monthly fish catch data collected from both experimental and local fishers' catch at each site from September 2011 to September 2012. Annual landed value was calculated as $V_i = C_i \times P_i$, where V_i = landed value, C_i = annual fish catch and P_i = ex-vessel price which is the per unit fish price that fishers receive when they land their catch (Teh et al., 2011). No distinction between full and part time fishers was made. The number of people directly dependent on small-scale fisheries income was estimated by the equation;

$$D_i = \sum (F_i * d_i) \qquad (7.2)$$

where D_i is the number of individuals directly dependent on small scale fishers at each study site along the wetland, F_i the number of traditional fishermen and d_i the number of dependants per fisherman at that site (Teh et al., 2011). The mean number of dependants per fisherman was estimated from both questionnaire survey and literature. Field results showed that the average fishing household size ranged from 5.3 at highly disturbed Nsango site to 6.7 at the less disturbed Budumba site and an average of 5.8 in the fishing villages whereas the average household size for rural areas in districts bordering the Mpologoma River was 5.0 in 2009 (UBOS, 2010). The average of these two information sources was used to obtain an average rural fishing household size of the each study site.

7.3 Results

7.3.1 Wetland fishery community structure

Of the 152 respondents interviewed, 99.2% were men and their age groups showed a significantly high dependency on the study sites (χ^2 = 31.37, df = 9, p = 0.001). The modal age group of the respondents was 26-35 years. More youths (54.3%) were involved in fishing at the less disturbed sites than those at highly disturbed Nsango site (27.59%; Table 5.1). 69.2% of the respondents had at least primary education and a few having attained tertiary training. The primary economic activities that support the Mpologoma wetland community included fishing (26.8%), rice cultivation (52.9%), maize production (3.4%) and others (Figure 7.1). At the highly disturbed Nsango and the less disturbed Mazuba, 79.3% and 24.1% of the respondents were engaged in rice production, respectively. Each respondent had more than one source of livelihood and fishing was the main secondary activity along the wetland with 54.3% of the respondents dependent on it. Other activities included growing of vegetables and harvesting of wetland macrophytes (papyrus and reeds) for making crafts and fishing baskets. The other activities were higher at Mazuba (17.2%) compared to the others sites.

All along the wetland, 24.8% of the respondents indicated that they targeted all fish species when fishing depending on the fish availability in the wetland. Hooks and baskets traps were the dominant fishing gears used in the wetland (28% of respondents for all sites). At the less disturbed Budumba site, the mean number of hooks and boats used by fishermen were higher than those used at other sites (Table 7.2). The fish catch was higher at the less disturbed site (over 4000 kg annually) but over 73.4% of respondents mentioned that fish catch has reduced over the past years. The major reasons for fish reduction varied with the level of wetland disturbance. More respondents (86.21%) at the highly disturbed Nsango site indicated that fish had reduced over the past 10 years plausibly due to increase in rice growing and water pollution.

Local fishermen earned a considerable income from the daily fish sale, on average ranging from UgX 10,000 to 30,000 (UgX 2500 = USD 1). There were temporal and spatial differences in the catch and CPUE of the major commercial fish species (Tables 7.3 and 7.4). The total landings were dominated by *C. gariepinus* and *P. aethiopicus* catch with a range of 0.45 to 38 Kg/day and 0.25 to 20 Kg/day respectively. Less disturbed sites were recorded with higher catch of these species than the highly disturbed sites. *Tilapia zillii* and *Oreochromis leucostictus* catch were also higher at the less disturbed sites while the small fish species (*Haplochromis* species, *C. liocephalus* and *C. alluaudi*) catch did not vary with sites. When the multivariate regression model was run with all socio economic variables, only eight varied significantly with the sites. The variance inflation factors (VIF) was about 1 and therefore there was no multicollinearity among variables. The model explained 54.49% of the variance and the rest could be explained by other environmental variables. Age group, preferred fish species caught, education level and small *Clarias* fish uses varied positively with the sites while farm size, fishing gear, price of small *Clarias* and land use within the wetland varied negatively with the sites (Table 7.5).

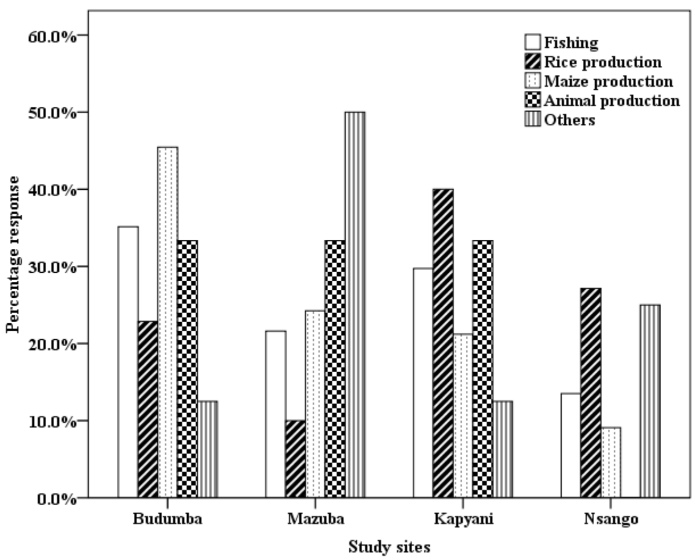

Figure 7.1: The primary economic activities at the differently disturbed sites in the wetland

Table 7.1: Percentage responses of fishing community characteristics in the Mpologoma riverine wetland

	Percentage of Respondents				
Age	Budumba (n=46)	Mazuba (n=29)	Kapyani (n=49)	Nsango (n=28)	Over all (n= 152)
15-25	24.14	24.14	12.24	0.00	15.69
26-35	54.23	31.03	44.90	27.59	41.83
36-45	22.13	31.03	32.65	37.93	30.07
46-60	0.00	13.79	10.20	34.48	12.42
Education level					
Never attended	30.43	6.90	8.16	0.00	13.07
Primary	56.52	89.66	77.55	55.17	69.28
Secondary	13.04	3.45	10.20	44.83	16.34
College	0.00	0.00	4.08	0.00	1.31
Marital status					
Single	4.35	6.90	8.16	3.45	5.88
Married	89.13	86.21	83.67	75.86	84.31
Widow	6.52	3.45	8.16	0.00	5.23
Separated	0.00	3.45	0.00	20.69	4.58
Secondary economic activities					
Fishing	67.39	48.28	30.61	79.31	54.25
Rice farming	15.22	44.83	30.61	17.24	26.14
Maize farming	0.00	0.00	10.20	3.45	3.92
Animals	0.00	0.00	2.04	0.00	0.65
Others	17.39	6.90	26.53	0.00	15.03

7.3.2 Small-sized *Clarias* fishery

The small-sized *Clarias* fish species were mainly captured with hooks and baskets baited with earthworms. The peak season of small *Clarias* fishing was during the rainy season (April to May and October to November; 90% of respondents), with an overall mean catch of 36 fish per hour. The low catch period was indicated as during the dry season (January to February and June to July) with a mean catch of 11 fish per hour. The price of a bundle of 15 to 20 fish ranged between 1000 – 2000 UgX. These small *Clarias* fish were utilized differently along the Mpologoma wetland (Chi-square; χ^2 = 67.1, df = 15, p = 0.001). Although there was a general use of small clariids as food at the other three sites, at the less disturbed Budumba site these small fish were mainly used as bait for fishing *C. gariepinus* and *P. aethiopicus*. This earned the fishermen more money than they would get from the sale of the small fish directly. At the highly disturbed site Nsango and Kapyani, the majority of respondents used the small fish for subsistence (Figure 7.2). The small fish catch had reduced over the past 10 years (overall 73%) and the reasons for the decline were significantly associated with sites (Chi- square; $\chi^2 = 74.99$, df = 18, p = 0.001). Figure 7.3 shows that 86% of the respondents at Nsango site attributed the reduction in fish catch over the years to water pollution and also water reduction in the Mpologoma riverine wetland.

Table 7.2: Percentage response of small scale fishery characteristics of the Mpologoma wetland between November 2012 and January 2013

	Budumba	**Mazuba**	**Kapyani**	**Nsango**	**Over all**
	(n=46)	(n=29)	(n=49)	(n=28)	(n= 152)
Categories of fish species caught					
Clarias gariepinus only	0	20.69	6.12	0	5.88
All fish species	15.22	24.14	26.53	37.93	24.84
All large fish species	15.22	6.9	6.12	3.45	8.5
C. gariepinus and *Protopterus*	52.17	10.34	26.53	58.62	37.25
None	17.39	37.93	34.69	0	23.53
Fishing gear					
Hooks	13.04	3.45	20.41	27.59	16.34
Baskets	2.17	0	8.16	0	3.27
Nets	8.7	10.34	2.04	20.69	9.15
Hooks & Baskets	26.09	41.38	12.24	44.83	28.1
Nets and Baskets	6.52	13.79	0	0	4.58
All	34.78	13.79	26.53	6.9	22.88
None	8.7	17.24	30.61	0	15.69
Fish quantity over years					
Reduced	65.12	71.43	74.42	86.21	73.43
Increased	23.26	7.14	23.26	6.9	16.78
Don't know	11.63	21.43	2.33	6.9	9.79

Table 7.3: The Mpologoma river wetland major fish species catch for the sampling period of January to December 2012 (values are means ± STD, in Kg/day)

Fish species	n	Budumba	Mazuba	Kapyani	Nsango
Oreochromis leucostictus	565	1.56 ± 1.07[a]	1.13 ± 1.51	0.61 ± 0.41	0.29 ± 0.15[a]
Tilapia zilli	703	1.92 ± 1.28[a]	0.86 ± 0.58	0.93 ± 1.14	0.32 ± 0.18[a]
Haplochromis spp	1115	0.26 ± 0.25	0.19 ± 0.09	0.33 ± 0.42	0.19 ± 0.13
Clarias liocephalus	788	0.50 ± 0.32	0.42 ± 0.21	0.66 ± 0.70	0.75 ± 0.52
Clarias alluaudi	419	0.37 ± 0.24	0.30 ± 0.25	0.27 ± 0.19	0.42 ± 0.36
Clarias gariepinus	1062	14.64 ± 6.77[a]	11.28 ± 8.39	15.88 ± 6.56[b]	3.05 ± 1.62[ab]
Protopterus aethiopicus	598	13.38 ± 5.04[a]	9.72 ± 4.78[b]	6.47 ± 3.09[c]	2.25 ± 1.46[abc]

Values in the same row with the same superscript are significantly different and those without a superscript are not significantly different ($p < 0.05$)

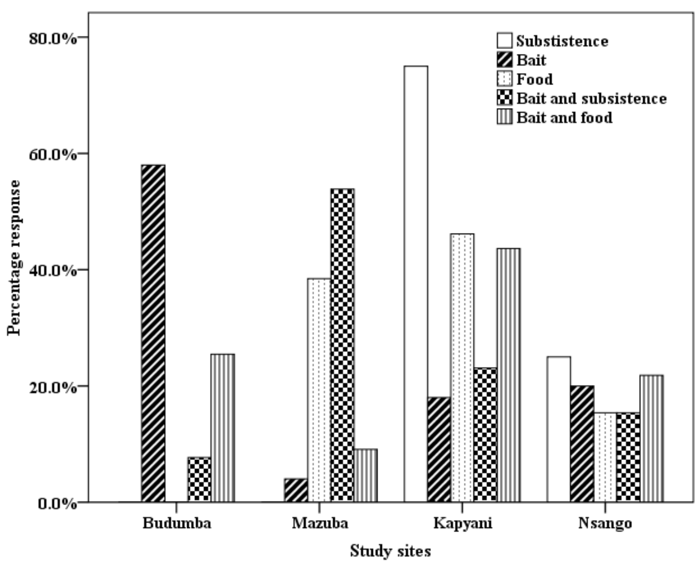

Figure 7.2: The major uses of small *Clarias* fish mentioned at the different sites in the Mpologoma River wetland between November 2012 and January 2013

Table 7.4: The catch per unit effort (CPUE) of the major commercial fish species at the differently disturbed sites in the Mpologoma river wetland between January and March 2012 (values are means)

Gear type	Species	Units of CPUE	Budumba	Mazuba	Kapyani	Nsango
Hooks	*C. gariepinus*	Kg 100hooks^{-1}hr^{-1}`	1.31	1.10	4.50	0.40
	Protopterus sp	Kg 100hooks^{-1}hr^{-1}`	0.86	1.05	1.28	0.54
	Small *Clarias* spp	Kg 100hooks^{-1}hr^{-1}`	0.16	0.20	0.33	0.27
Traps	*Barbus* sp	Kg trap^{-1}hr^{-1}	0.04	0.02	-	0.09
	C. gariepinus	Kg trap^{-1}hr^{-1}	0.09	0.08	0.11	0.05
	Haplochromis spp	Kg trap^{-1}hr^{-1}	0.01	0.04	0.09	0.23
	Protopterus sp	Kg trap^{-1}hr^{-1}	0.11	0.12	0.12	0.05
	Small *Clarias* spp	Kg trap^{-1}hr^{-1}	0.16	0.11	0.18	0.19

Table 7.5: Multivariate regression model outputs of socio-economic parameters that significantly associated with level of disturbance along the wetland (Obs is the number of observations, Parms the permutations, RMSE the root mean square error, R-sq the R square values and F the frequency)

Equation	Obs	Parms	RMSE		"R-sq"	F	P value
	138	9	0.77		0.54	19.31	0.001
Site	**Coef.**		**Std. Err.**	**t**	**P>|t|**	**[95% Conf.**	**Interval]**
Age group	.485		.077	6.26	0.001	.332	.64
Fish species	.075		.037	2.02	0.045	.001	.15
Education level	.765		.114	6.68	0.001	.538	.99
Farm size	-.209		.044	-4.75	0.001	-.296	-.12
Fishing gear	-.081		.038	-2.11	0.037	-.157	-.01
Price of small fish	-.000		.000	-3.62	0.001	-.000	-.001
Small catfish uses	.073		.035	2.06	0.041	.002	.14
Land use	-.072		.034	-2.09	0.039	-.141	-.001
Constant	.766		.568	1.35	0.180	-.358	1.89

7.3.3 Socio-economic indicators

The estimated fish catch composition and annual landing value in the highly disturbed Nsango site was lower than those of less disturbed sites, Budumba and Mazuba (Table 7.6). The estimated annual landed value ranged from as high as UgX 5,757,500 (USD 2303) at the less disturbed Budumba site to UgX 175,000 (USD 70) at the highly disturbed Nsango site. However the estimated annual income from other economic activities was not significantly different between sites (t-test, $P > 0.05$). The daily fish sale income was related to a number of variables (Table 7.7). But more importantly fish sale was significantly related to the sites, other activities, income generated from other activities ($R^2 = 0.306$. F- value = 8, $P < 0.05$). A two dimensional ordination using NMDS analysis was obtained with a final stress of 18.7 at $P < 0.05$, indicating the daily fish sale income was significantly related to the study sites, wetland use and fish species caught at(R^2 of 0.82, 0.86 and 0.71, respectively, all at $P < 0.05$) (Figure 7.4). The vector analysis showed that fish sale income was inversely related to study sites, as the level of disturbance at the sites increased, the fish sale income reduced. Fish sale was directly related to fish species caught. The two large fish species category which consisted of *C. gariepinus* and *Protopterus* sp generated more income than other fish species categories. High fish sale income of 20000 – 30000 UgX (USD 8 -12) was generated by those who caught the two large fish species only. The number of fishermen and dependents on the wetland fishery was higher at the less disturbed sites (Budumba and Mazuba) than at the highly disturbed Nsango sites.

Table 7.6: Mean values of economic and social indicators of the small scale fishery at the different sites along the wetland

Economic indicators	Budumba	Mazuba	Kapyani	Nsango
Estimated Catch (Kg per year)	4494.36[a]	3099.2[a]	3796.39[a]	1236.56[b]
Estimated Annual Landed value ($)	1193 ± 1110[a]	673 ± 269[b]	691± 346[ab]	540 ± 470[b]
Estimated Annual income from other activities ($)	616 ± 377	307 ± 161	650± 351	386 ± 232
Social benefits				
No. of fishermen	42	32	39	17
Estimated house hold size	6.7	5.8	5.8	5.3
Estimated number of dependents	281[a]	186[b]	226[ab]	90

Values with same superscript in the same row are not significantly different at $P < 0.05$.

7.3.4 Fishermen perception of wise wetland use

There was a general consensus among the respondents that there was need for sustainable use of wetlands. 50.7% of the respondents at all sites indicated that there was need to stop wetland degradation to enable them benefit from the wetlands' natural services which according to them included fishing resource, water and papyrus biomass source. However, at the highly disturbed Kapyani site, 38.2% of the respondents stated that they needed part of the wetland for rice growing since it was a major source of income for them. They recommended that the degraded areas should be left for some season for nutrients and papyrus to re-establish themselves and that fishing of the preferred large fish species, *C. gariepinus* and *P. aethiopicus* should be controlled. The size of these fish was reducing drastically and some emphasized the need for a closed season. They were not aware of any other management strategies apart from a few guidelines broadcasted through radio stations. However, the contradicting observation was that fishermen did not want government officers to interfere with their operations by enforcing stringent fisheries and/or wetlands management guidelines.

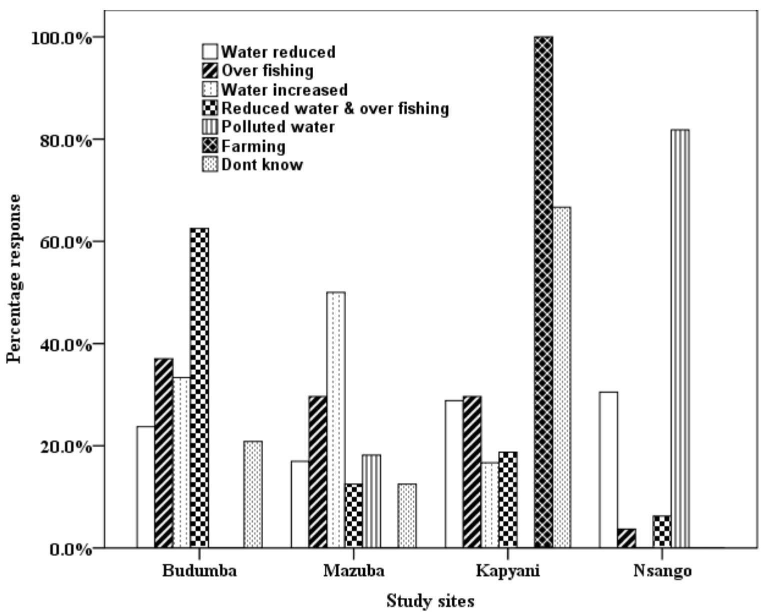

Figure 7.3: The different reasons mentioned to be responsible for the fish catch reduction at the different sites in the Mpologoma wetland between November 2012 and January 2013

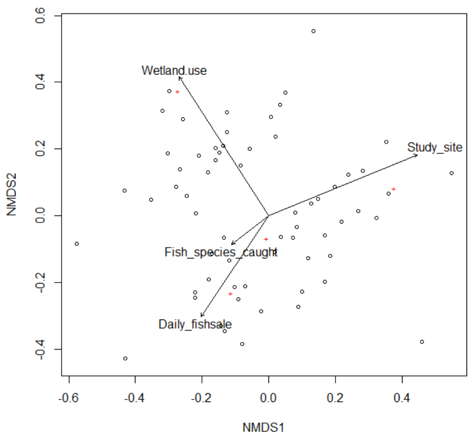

Figure 7.4: Non-metric multidimensional scaling (NMDS) plot for daily fish sale income dissimilarities relationship with study sites, fish species caught and the wetland use

Table 7.7: Multi regression analysis output of daily fish sale income association with socio-economic parameters in the wetland. Probability levels: *p<0.05, **p<0.01 and ***p<0.001; Not significant – NS

Daily fish sale income	Coefficient	Standard Error	T
Mazuba	-12704.9	4511.7	-2.32**
Kapyani	-15583.9	3681.2	-4.23***
Nsango	-12334.5	3873.5	-3.18**
Rice growing	8009.7	3103.7	2.58**
Maize growing	10337.0	7385.2	1.40NS
Animal keeping	8583.9	16793.5	0.51NS
Other activities	15461.6	5392.0	2.87**
Annual Income	-1889.4	1307.6	-1.44NS
Over fishing	4226.8	3543.4	1.28NS
Water increased	-10765.2	11953.1	-0.90NS
Reduced water and over fishing	-8867.9	3822.9	-2.31*
Polluted water	-3924.9	4866.6	-0.81
Farming	-4295.6	6828.9	-0.63
constant	29543.9	3899.3	7.58

7.4 Discussion

7.4.1 Small scale wetland fishery community structure

The small-scale Mpologoma riverine wetland fishery represents an important component of the livelihood of the local riparian community, considering the extent and magnitude of the social benefits and economic profit to the operators. Fishery structure and induced environmental disturbance were responsible for variations in the magnitude of the socio-economic trends at the different sites. Comparing the fishermen community structure, it was mainly male operators who were involved in the various economic activities in the wetland. The modal age range of 30 to 40 years indicated that the wetland users were predominantly middle aged group who had the wetland and fishing experience. This observation agrees with Omwega (2000) who stated that mature fishermen are typical of small scale fisheries within the Lake Victoria basin. All respondents were self-employed and were engaged in more than one economic activity. This was attributed to livelihood diversification, which was a survival as well as a livelihood security strategy for the low income households in these rural communities. Farming was the main activity and many considered fishing and other activities as secondary economic activities, concurring with the findings of Heck et al. (2007) about African fisheries. Fishing normally supplements incomes through an additional source other than the primary jobs (Dickey and Theodossiou, 2006). Many of the fishermen are highly versatile and move in and out of fishing activity at various periods of the year. Because artisanal fisheries usually require low capital investments and have low income, the fishermen become highly dynamic with respect to their engagements (Bene et al., 2010).

The strong seasonality of activity of the fisheries along the Mpologoma River wetland could be explained by the fact that riverine fish populations undergo inter- and intra-annual variations driven by the hydrological regime (Mmopelwa et al., 2009). Subsistence fishing households have always coped with and adapted to these spatio-temporal variations in fish availability with short-term and long-term responses. One important coping strategy is the adoption of multi-gear fishing (Mmopelwa et al., 2009). The fishermen in the study area responded to the hydrological rhythms by using hooks and traps throughout the year and reverting to gill nets to supplement other gears during high water level within the wetland. The use of exploitation regime is another strategy that is commonly used by subsistence fishers but the wetland fishermen are forced into a resting period due to low catch rates and/or the onset of the planting season in the rainy period. According to Heck et al. (2007), the major fishing period is the rising flood and a well-defined integration between fishing and farming is unveiled by most wetland operators. The dry season crises in terrestrial agriculture cause a major migration of people into fisheries (Onyango and Jentoft, 2010) which explained the high drift of fishers to the less disturbed sites where fishing was still worthwhile.

7.4.2 Socio-economic indicators of the importance of the Mpologoma fishery

The incidence of multiple-economic activity holding was substantially higher among the respondents from the highly disturbed sites than from those of the less disturbed sites. At the less disturbed Budumba site, the presence of full-time fishermen was evident, apparently because fishing was highly rewarding than being involved in multiple jobs. During prolonged dry season, the wetland is usually drained, leaving moist and nutrient rich soils which attract small scale farmers to grow rice, maize and other horticultural crops (Kansiime et al., 2007). This was observed at the highly disturbed Kapyani and Nsango sites. Mobility out of fishing is related to the amount of capital invested in fishing assets. It has been observed that in most artisanal fisheries especially in the low-income countries, assets tied up in fishing are low rendering mobility relatively high (Allison, 2004).

The large-sized fish, mainly *C. gariepinus* and *P. aethiopicus*, caught using comparatively low capital fishing technology comprising of gill nets, lines and hooks, and traps, made the largest proportion of the total catch in the whole study area. The small fish species, *Tilapia*, *Haplochromis* and small *Clarias* species, were mainly used as bait for the large fish species. Ten small *Clarias* that could be sold at USD 1, were used to catch a large *C. gariepinus* or *Protopterus* sp. could be worth USD 5 each. Therefore, many of the small fish caught at the less disturbed sites were used again and a few sold at the landing sites while the rest were used for home consumption. However, these small fish species were used as food and for subsistence mostly at the highly disturbed Nsango site where the catch of the large wetland fish species was low. The small catfish species are among the neglected fish species that have proven to be resilient to shocks and crises, and make meaningful contributions to food security and poverty alleviation (FAO, 2003; Bene et al., 2010). The resilience of these small *Clarias* explains the fishing activity and the high proportion of small fish in the daily total catch at the highly disturbed Nsango site.

Substantial social benefits were generated from the small scale fisheries through the direct and indirect employment and the support to a large number of dependants in the fishers' households. It has also been observed that small scale fisheries in southern Africa absorb rural surplus labour and offer a safety valve or labour buffer (Dickey and Theodossiou, 2006). Although the household size did not vary significantly among the wetland sites, the dependants on fishery and the volume of catch were higher at the less disturbed site than in the highly disturbed sites, thus attracting more fishermen at this site. Fishers used their fish sale income to access daily domestic utilities, thus maintaining a certain standard of living particularly during the peak of fish catches. More people engaged in fishing when it was more rewarding with consequent high earnings than the average in other activities, which explained the presence of fulltime fishers at the less disturbed sites. Fishers can access cash all year-round from fish sales contrary, for example, to agriculture where farmers wait for harvest time to get cash (Bene et al., 2010). On a good day a fisher at the less disturbed site could earn about USD 6, a feat which a farmer cannot match on a daily basis. The average landing fish value USD 1.96 per kg was close to the average Ugandan landing value (catfish was USD 2.2 per kg, MAAIF, 2012). But this was lower compared to other small scale fisheries, for example, the Mediterranean region landed value is USD 5.7 per kg (Maynoua et al., 2013). This was attributed to the low returns from poor local people along the wetland even when the fish demand was high. Despite that, records have shown that fishing households tend to be more productive than non-fishing households because fishing provides livelihood during the dry spell (Heck et al., 2007).

In this study, there was no evidence suggesting that those revenues systematically trickled down to the rest of the economy. We can therefore plausibly postulate and support the assertion that the overall small scale fisheries contributed to poverty prevention as mentioned by Bene et al. (2010) rather than poverty reduction. The latter describes situations where people become measurably better-off (accumulate some wealth) over time due to their involvement in certain economic activities while poverty prevention refers to the role of an economic activity in helping people to maintain a minimum standard of living (even below a given poverty line) and to prevent them from falling any deeper into destitution (Béné et al., 2007). This poverty prevention function does not necessarily generate large revenues or wealth but allows a large number of resource-poor and/or vulnerable households in rural communities to survive both economically and nutritionally (Bene, 2005). In this regard, the fishers at the less disturbed sites could meet their daily expenses making them less vulnerable than those at highly disturbed site. The contribution of small-scale fisheries to Mpologoma River community and the country's economies does not seem to lie in the potential rent that they could generate but in their actual capacities to absorb unskilled surplus labour and provide safety-net and risk-mitigation mechanisms for many resource-poor households against vulnerability (Bene et al., 2010).

7.4.3 Management of the small scale fishery

As poverty deepens and fish sale incomes fail to meet the basic food and dietary needs, interest in farming and other economic ventures will increase as a food security strategy for vulnerable rural families (Etim and Ukoha, 2010). This could explain the poverty situation at the highly disturbed Nsango site. Land ownership or tenure was another important driver of fish decline along the wetland. In the flood-prone areas, free land ownership granted all members access to the wetland to clear for their crop or fish as they wish, amplifying the attributes of the tragedy of the commons concept (Hardin, 1968). This leads to economic and possibly biological overexploitation of the resource, eroding profitability and impoverishing the fishing community (Smith et al., 2005). The overall wetland degradation disrupts traditional livelihood activities or reinforces existing patterns of economic, social and political inequity, further marginalizing the vulnerable (Nguyen-Khoa et al., 2004). Unfortunately the open access nature of small scale fisheries and the widely scattered nature of fishing communities and landing sites make it difficult to regulate fishing related activities (Onyango and Jentoft, 2010). All respondents noted the absence of local fisheries/wetland administrators to monitor, control and manage fishing activities as a major factor escalating the wetland degradation. This is compounded by the fact that these rural poor communities normally face social and political marginalization and are overlooked by policy makers in favour of commercial fisheries (Bene et al, 2007; Teh el al., 2011).

It is evident that the Mpologoma wetland fishery is a socioeconomically significant ecosystem to all riparian communities. However, differences in the magnitude of benefits derived from it were dependent on the level of wetland disturbance. The fishery's scale and value provided a poverty prevention contribution to food security, nutrition and employment. Consequently, this small-scale fishery was under-valued and under-appreciated and no management programme was accorded to it despite its socio-economic importance. With the increasing wetland disturbance, Mpologoma wetland will soon fail to fulfil its role in the socio-economic development of the riparian community. Therefore, there is an urgent need to manage the interface between fisheries and the wider external environment. This will require development of a wetland resource utilization policy which should draw its content from the immediate environment and be adapted to the local conditions and also be aligned with the range of livelihood functions performed by the wetland.

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CHAPTER EIGHT:
CONCLUSIONS

This study demonstrates that land use change within the Mpologoma riverine wetland affected the life history parameters of small *Clarias* species (*C. liocephalus* and *C. alluaudi*). The small *Clarias* species' length, weight and fecundity were correlated to water quality parameters that were used to assort the different sites based on the level of disturbance. Rice and maize growing in the wetland served as drivers of fish habitat fragmentation, initiating localized responses in fish species' population dynamics and variations in habitat attributes, in particular, water quality and prey availability. Habitat disturbance conferred population-level benefits and resilience within small *Clarias* species evidenced by their relationships between life history attributes of small *Clarias* species and water quality variables. These are important aspects in community ecology especially in the development of predictive models used to understand how fish community change with the changing environment. Furthermore, they help to quantify the ecological consequences of land use changes and to identify priorities for the sustainable management of wetlands.

Small *Clarias* species used shallow water pools at all the sites along the wetland which was attributed to their search for suitable spawning and feeding habitats. The clariids exhibited a downstream movement during the dry season and upstream movement in the wet season at all sites which was also due to small fish life strategy for seasonal spawning, adaptation to change in environmental variables and avoidance of predators in deep waters. However, the study on habitat use and tagging to track small *Clarias* movements would benefit from further investigation using the radio telemetry and identification of factors influencing the small *Clarias* fish behavior along the wetland. The potential impact of land use change on fish habitats was related to competition for both space and resources between different wetland fish species. Therefore, management effort should focus on preserving these catfish habitats and, where possible, moderate the land use changes within wetlands through provision of other livelihood alternatives.

The Mpologoma wetland small scale fishery was dominated by *C. gariepinus* and *P. aethiopicus* in total catch which, varied among the different sites. The two fish species catch had a strong negative correlation with conductivity and orthophosphate concentration, the water parameters that discriminated sites with different land uses. Small *Clarias* species catch did not vary significantly among sites and did not indicate significant relationships with the various water quality parameters. The differences in individual fish species' resilience to perturbation and pollution was the most plausible reason. Assuming the dominance of wetland fish compositions by the low-trophic species and constant fishing pressure, future fish production may be dominated by the trends in nutrient loads arising from the land use changes. The results should be of interest to resource managers because land use changes in the wetland have the potential to drastically affect the production of the large commercial fish species in the wetland that supports the dynamics of the small scale fishery.

From the *Clarias* production potential prediction analysis, it was realized there was change of wetland cover to agricultural land and an increasing trend in some water quality parameters over time which led to an increasing trophic status of the wetland fish habitats. This supported the increasing catch of small *Clarias* species. But the large wetland fish species catch which supports the small scale fishery would be low at the agriculture encroached areas, posing an urgent need to holistically manage the fisheries and other land use activities within the wetland. This requires development of a wetland resource utilization policy which should draw its content from and be adapted to the local conditions and also be aligned with the range of livelihood functions performed by the Mpologoma small scale fishery.

This study also demonstrated the socio-economical significance of the Mpologoma wetland fishery to the riparian communities but differences in the magnitude of benefits derived appeared to depend on ecological status of the wetland with respect to the level of wetland disturbance. The viability in the livelihoods of the small-scale fishermen was generally threatened by irregular and relatively low levels of catch particularly at the highly disturbed areas with consequent low incomes. Nevertheless, the fishermen continued to concentrate on the fishing activity as it provided self-employment. The fishery's scale and fish catch value provided a poverty alleviation dimension through contribution to food security, nutrition and employment to the local community. This study also revealed that the Mpologoma wetland small-scale fishery was under-valued and under-appreciated and no management programme was accorded to it despite its socio-economic importance. With the increasing wetland disturbance, the wetland could soon lose its vital ecological services and consequently reduction in its contribution to the socio-economic development of the riparian community.

As Uganda's population growth rate continues to rise, the number of people who are food insecure will increase. Therefore, there is need to diversify economies, particularly the exploitation of fisheries resources which are a major protein source in the region. This study provides information on the endemic *Clarias* species' life history, feeding habits and aspects of the overall wetland fishery in response to land use changes. The findings of this study will therefore provide benchmark information for environmental management and sustainable economic utilization of the wetland capture fisheries and land resources.

CHAPTER NINE:

RECOMMENDATIONS AND MANAGEMENT OF THE MPOLOGOMA RIVERINE WETLAND SMALL SCALE FISHERY

The following recommendations emanating from this study were considered pertinent and their implementation would lead to the sustainable exploitaion of the Mpologoma wetland and the continued provision of its services and products to the riparian communities.

1. The impression that emerged from this study was that the population variables and catch of small *Clarias* species increased as they capitalized on the habitat fragmentation and their responses to pollution due to land use change. However, the land use activities could increase at a rate that would result in an overall change of the ecology of the wetland beyond the resilience of these fish species. Therefore, the wetland ecological shift phase needs to be established in order for policy makers to regulate the land use change rate which might have potentially irreversible effects to both small and large fish species of this small scale fishery.

2. Currently, there is inadequate management of the wetland. The central government should endeavour to set up a primary fisheries management strategy for the Mpologoma riverine wetland fisheries. This can be done through creation of awareness of the need for fisheries management and the benefits from pro-active approaches among the riparian communities. There is need to devolve some management authority to local communities, put in place legal regulation of access through individual or community-based formal dedicated access privileges and provide training and capacity-building for community ownership. There should be periodic reviews and guidance from professional managers and scientists for practical, scientifically and socially acceptable methods of fishing and farming that would allow sustainable use of the wetland resource.

3. There are many good policies and regulations that are relevant to the management of wetlands and their fisheries in Uganda such as the water act 1995, the National Environment Act 1995, the National Environment Management Policy 1994, the National Policy for the Conservation and Management of Wetlands Resources, 1995 and the National Environment

Regulations, 2000 which have not been well implemented. There is need to strengthen the local governments to have the political will to advocate for full implementation of at least one management policy in the Mpologoma river catchment. The National Environment (Wetlands, River Banks and Lake Shores Management) Regulations which, provides for the management of wetlands, lake shores and river banks, ensuring water catchment conservation, sustainable utilization and conservation of resources involved, promoting the integration of wise use of resources, and prevent and control of pollution and degrading activities would be a good option. This regulation also provides for a mandatory environmental impact assessment for any development within the wetlands and regulates activities within buffer zones of up to 100 m of river banks. Its implementation in the Mpologoma riverine wetland management will help in the conservation of the remaining natural river banks and restoration of degraded part of the wetland.

4. Comparable to many African wetlands, the Mpologoma wetland is continually being degraded by livelihood activities. There is need to promote sustainable management of the wetland through co-management with local community involvement particularly in the disturbed wetland parts. It has been realised that Mpologoma wetlands performs important eco-hydrological roles as well as providing a range of socio-economic benefits particularly the fishery resource and land for paddy rice growing. Ensuring the sustainability of the wetland, and its associated goods and services, should be a major concern for public and private institutions working in this region. The local or traditional land tenure systems with limited family members or people to access the wetland for paddy rice growing and use of traditional fishing methods such as the use of basket traps and a limited number of hooks should be promoted by government. The above will lead to coordinated and sustainable use, and management of the wetland.

5. Wetland resource managers should monitor the wetland fish communities to evaluate use, conservation and restoration efforts because these large preferred wetland fish species were found to respond quickly to environmental perturbations. This will preserve the existing fish populations. A broad observational campaign involving simultaneous monitoring of climatic change conditions within the Mpologoma catchment and the surrounding region should be

done for use in refining and evaluating the community based management strategies. Climate change is a vital driver of land use change, therefore observations can help in designing wetland wise strategies for the target communities. The study also recommends that wetland resource managers consider using fish species as indicators to evaluate the efficacy of any ongoing restoration and management efforts in wetland ecological integrity and monitoring in the region.

Suggestions for further research

There is a number of knowledge gaps realised in the course of this study and these include: (1) qauntification and prediction of the direct effect of land use change on other wetland fish species distribution, life cycles and community composition, (2) understanding of the effects of extreme land use change in average conditions and response of the riverine systems to other stressors such as climate change, and (3) formulation of counter actions to minimise the adverse effects on the Mpologoma river wetland. Some of the key research insights with respect to the above knowledge gaps are highlighted below.

a. The responses of the large wetland fish species particularly *C. gariepinus* and *P. aethiopicus* population life history parameters to land use changes need to be investigated. These two species were the major contributors to the wetland fishery landings and therefore investigating their population biometrics could lead to a holistic picture of the small scale wetland fishery response to land use change.
b. The is need for more detailed biology of the small *Clarias* species in more controlled environments such as ponds and other culture systesm such that the aspects of their ontogenic food shift, life history responses, diel feeding rhythms, physiological responses and reproduction strategies can assessed exhaustively.
c. There is need to characterise the critical habitats for juvenile stages and spawning phase of key fish species so that a few remaining areas could be conserved to maintain the fish species population. Given the increasing conversion of wetland to rice field, there is need to conserve and sustain those specific habitats essential for maintaining the population of wetland endemic fish species. Another aspect that needs investigation is the mapping of the movement routes of the fishes in the Mpologoma wetland system.

d. It is recommended that the hydrological models should be refined for applicability in the tropical setting of complex Africa environments. This will permit evaluation, comparison and combination of the multiple hypotheses on fish temporal and spatial distribution in African wetlands. Such models will ultimately lead to a more comprehensive understanding of the factors controlling the fish populations. As a result, more accurate predictions of fish yield would be attained.
e. A combination of land use and SWAT model can be used to establish the zonation and optimal mosaic of land use in the Mpologoma river catchment. These are important considerations in the small scale fishery protection through identification of important fish habitat areas to maintain stocks. This may require incorporation of already sustainable existing land use activities and should be fish friendly designs to cater for the community involvement into the wise use of the wetland.
f. There is need to develop and improve best practice habitat sensitive technologies of rice growing and other wetland use activities that will minimise the effects on fish habitats and support the preservation and management of *Clarias* fish habitats. This will result in a proficient integration of rice production and the small scale fishery in the Mpologoma riverine wetland.

APPENDICES

Appendix 1: Questionnaire on Wetland fishery – Land use Socio-economic survey instrument

This survey aims at gathering data that will form part of the study entitled: ***Assessment of Land Use on Ecology and Production of Clarias species (Ensonzi) in relation to Socio-Economic Dimension in the Mpologoma Wetland, Uganda***

All information will be treated by utmost confidentiality and strictly used for the purpose of the study. Your cooperation in this study is therefore highly appreciated

Instructions to the enumerators: please fill the responses in the spaces provided or tick where appropriate.

Date of interview……………………………………..
Name of the interviewer………………………………

1. General information

a. Name of respondent ………………………………………………………………..
b. Age ………………………………………………………………………… (code 1)
c. Marital status ……………………………………………………………….(code 2)
d. Level of education………………………………………………………… (code 3)
e. Occupation ………………………………………………………………….(code 4)
f. Address……………………………………………………………………………………
Village…………………………………………………………………………………….
Sub-county/sub-location/Ward……………………………………………………..…..
County/Location/Division…………………………………………………………………
Province/Region…………………………………District…………………………….

Code 1	Code 2	Code 3	Code 4
1. 15 - 25	1. Single	1. Never attended	1. Self employed in agriculture
2. 26 - 35	2. Married	2. Primary	2. Salary worker in agriculture
3. 36 – 45	3. Widow/widower	3. Secondary	3. Self employed in non-farm enterprises
4. > 45	4. Divorced/separated	4. Middle level college	4. Salary worker in agriculture
		5. University	5. Unemployed

2. Main socio-economic activities

How far is your home to the wetland? ....

What are your main sources of incomes? (Tick all that apply and rank them)

	Activity	Produce	Income	Rank of importance (code 5)
1	Fishing	(No of fish per day)	(Per day)	
2	Livestock		(Per year)	
3	Rice production	(Bags per season)	(Per season)	
4.	Maize production		(Per season)	
5	Terrestrial agriculture - -	(Bags per season)	(Per season)	
6.	Others (brick making, crafts)			

Code 5: 1- most important, 2 – important, 3- least

3. Fishing activity

How many days do you fish per week? ....

Give the fish species caught, number of fish, gear used

Fish species (code 6)	No. of fish caught per day		Type of gear and size	No of gear owned	Price of fish species	Fishing season (code 7)
	Good season	Bad season				

Code 6: 1- Engege, 2- Emamba 3 – Emale, 4 – Ensonzi, 5 – Enkeje

Code 7: 1- all year around, 2- wet season, 3 – dry season, 4- once yearly, 5- very rare)

Do fishermen migrate from one landing site/wetland to another? .... (1- Yes, 2- No)

When do they move? ....

Why do they move?

....

What are the implications of fishermen migration?

To the landing site

....

....

To the community

....

....

To the fishery

....

....

4. *Clarias* species production

How many types or species of Nsonzi are in this wetland?

Name them: ....

How do they differ from each other?

....

....

Which of them is more common in this part of the wetland? ....

And why? ....

When are they caught or fished? ……………………………………………………….(Code 7)

(Code 7: 1- every morning, 2 - evening, 3- once a week, 4- seasonally (specify; dry or wet), 5- yearly, 6- very rare)

Which is the peak season for fishing Ensozi? ....(Code 8)

Code 8: 1- dry, 2- wet, 3- all year around, 4- once a year, 5- once in many years

Can you identify suitable fishing areas and fish breeding sites of *Clarias* (Ensonzi) within the wetlands?... (1-Yes, 2- No)

If Yes, give the characteristics of suitable fishing areas and fish breeding sites

	Vegetation type and cover (code 9)	Water level (code 10)	Substrate (code 11)	Others (specify)
Suitable fishing areas				
Breeding sites				

Code 9: 1- Papyrus, 2- Phragmites, 3 Typha, 5- Grass; cover 1- sparse, 2 moderate, 3- thick

Code 10: 1-< 0.5 m, 2- 0.5 – 1 m, 3- > 1 m

Code 11: 1- gravel, 2 - stones, 3 - silty, 4 - bare ground

Are there changes in fish yield over the years? ………………..………………. (1- Yes, 2- No)

What has been the trend? . ………………………………………. (Code 12)

Code 12: 1- Increased , 2- decreased, 3- about the same, 4- do not know

What could be the cause of these changes? ……………………………………..………

…………………………………………………………………………………………

What is the importance of this catfish to the local people and other consumers, and the rank of importance (code 14)? (Tick all that apply and rank them with code 13)

☐ Food ☐ Source of income ☐ Bait

Code 13: 1- most important, 2- important, 3- least

5. Fish consumption

Does your household consume fish? .... ……………………….(1-Yes, 2- No)

If No, why? ....

If yes, how often? ………………………………………………………..(Code 14)

Code 14: 1- Daily, 2- few days a week, 3- most days a week, 4- Monthly, 5- Not sure

What is your preferred most species?

Fish species	Preference (code 15)	Source (code 16)	Availability (code 17
1. Tilapia (Ngege)			
2. Lungfish (mamba)			
3. Catfish (Male)			
4. *Clarias* spp (Ensonzi)			
5. Haplochromis (Nkejje)			

Code 15: 1- very much, 2- much, 3- average, 4- fairy, 5- poor

Code 16: 1- fishing, 2- buying, 3- both

Code 17: 1- Readily available, 2- available, 3- rare

What is the size? ………………………………………………………………….(Code 18)

Code 18: 1- Very small, 2- small, 3- medium, 4- large, 5- very large

How many Ensozi are in a bunch sold? ....

Price of Ensonzi bunch ....in a good season, ...in bad season

How is the Ensozi eaten? (Tick all that apply)

Code 19: 1- fresh 2 – roasted 3 – fried 4 - smoked 5 - don't know

Has the quantity of fish changed over the past two years? ………………………. (1- Yes, 2- No)

If yes, what extent has been the trend? ....

Code 20: 1- increased 2- decreased 3- the same 4- don't know

Why has the trend been like that?

……………………………………………………………………………………………

Do you know that Nsonzi move along the river/stream at some part of the year? ..(1- Yes 2- No)

When do they move (month)

…………………………………………........………………………………

Why do the move?

....

5. Land use implications

Why do you use wetland? ……………………………………………………………(code 21)
Code 21: Land less, 2- more land, 3-free land, 4- own it, 5- others (specify)

How much of the wetland do you use? ………………………………………………(code 22)
Code 22: 1- Large area, 2- moderate area, 3- small area, 4- very small area, 5- Don't know

Do you know the implications of using the wetland? ……………………………... (1-Yes, 2-No)
If yes, which one? ………………………………………………………………...(code 23)
Code 23: 1- Fish affected, 2- water level reduces, 3- other fauna affected, 4- flooding, 5- Don't know

How often do you meet the fisheries/wetlands officials?
…………………………………………………...
What is usually the purpose of their visit?
....
How best can we use the wetland?
....
....
General remarks (correspondent during the interview or field work)
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………
General remarks (interviewer's observation during the interview or field work)
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………
Thank you.

Appendix 2: Economic impact survey

	Budumba	1	2	3	4	5	6	7	8	9	10
1.	How many fishermen are at this landing site?										
2.	How many boats do they own?										
3.	Is there hiring of boat? at what price? Use by agreement, which condition Use communally?										
4.	How much is one boat?										
5.	How many gears can be used one fisherman? Nets which size How many hooks How many traps/basket traps										
6.	How many trips per days?										
7.	How many dependents of some fishermen?										

Research Permit

Uganda National Council for Science and Technology

(Established by Act of Parliament of the Republic of Uganda)

UNCST

Our Ref: NS 375 **October 17, 2011**

Ms. Ssanyu Grace Asiyo
Biological Sciences Department
Kyambogo University
P.O Box 1
Kyambogo

Dear Ms. Ssanyu,

RE: RESEARCH PROJECT, "A STUDY OF THE ECOLOGY AND PRODUCTION OF CLARIAS SPECIES IN RELATION TO LAND USE IN MPOLOGOMA RIVER WETLAND, UGANDA"

This is to inform you that the Uganda National Council for Science and Technology (UNCST) approved the above research proposal on **September 12, 2011.** The approval will expire on **September 12, 2012.** If it is necessary to continue with the research beyond the expiry date, a request for continuation should be made in writing to the Executive Secretary, UNCST.

Any problems of a serious nature related to the execution of your research project should be brought to the attention of the UNCST, and any changes to the research protocol should not be implemented without UNCST's approval except when necessary to eliminate apparent immediate hazards to the research participant(s).

This letter also serves as proof of UNCST approval and as a reminder for you to submit to UNCST timely progress reports and a final report on completion of the research project.

Yours sincerely,

Winfred Badanga
for: Executive Secretary
UGANDA NATIONAL COUNCIL FOR SCIENCE AND TECHNOLOGY

LOCATION/CORRESPONDENCE

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Curriculum vitae

Ssanyu Grace Asiyo was born on 19th April 1977. She went to Old Kampala SSS and Kitante Hill School. In 2000, she acquired Bachelor of Science degree in Botany and Zoology (Hons). In 2001, she worked as a research assistant at the department of Zoology, Makerere University. In October 2002, she got a Certificate for the International Post Graduate Training Course in Limnology, Institute of Limnology Austrian Academy of Science, Mondsee, Austria. In October 2003, she acquired Master of Science degree in Environmental Science and Technology at UNESCO-IHE, the International Institute for Infrastructural, Hydraulic and Environmental Engineering, Delft, The Netherlands. In 2004, she started working as part time lecturer at Kyambogo University and in 2005, she was appointed into the university as an assistant lecturer. In 2009, she became a full time lecturer at the same University. She taught at the university until 2011 when she started pursuing her PhD studies at Egerton University.

Publications and other scientific contribution

Ssanyu GA, Kipkemboi J., Mathooko JM and Balirwa J. (2014). Response of endemic *Clarias* species population parameters to land use along papyrus dominated Mpologoma riverine wetland, Uganda. African Journal of Aquatic Science, 39 (3): 249 - 261, DOI: 10.2989/16085914.2014.946387

Ssanyu GA., J Kipkemboi, JM Mathooko and J Balirwa (2014). Variation of small scale wetland fishery in relation to land use along Mpologoma riverine marsh in Eastern Uganda. African Journal of Environmental Science and Technology, Vol. 8(12): 716 - 729, DOI: 10.5897/AJEST2014.1733.

Ssanyu GA, Kipkemboi J., Mathooko JM and Balirwa J. (2014). Land-use impacts on small-scale Mpologoma wetland fishery, eastern Uganda: A socio-economic perspective. Lakes and Reservoirs: Research and Management 19: 280 – 292. DOI. 10.1111/lre.12073.

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Rasowo J., Auma E., Ssanyu G. and M. Ndunguru (2008). Does African catfish (*Clarias gariepinus*) affect rice in integrated rice-fish culture in Lake Victoria Basin, Kenya? African Journal of Environmental Science & Technology Vol.2 (10), 336 - 341.

Rasowo J., Auma E., Ssanyu A.G., Ndunguru M. and Oyoo E. (2008). Rice production techniques, seed sourcing, marketing, attitude/perception of farmers on integrated rice-fish farming within Lake Victoria basin, Kenya. Nile Basin Development Forum Nov. 30th – Dec 2nd 2006, United Nations Centre, Addis Ababa Ethiopia.

Training activities related to the PhD programme

Activities	**YEAR**
Egerton University activities PhD seminars (Presentation); Proposal presentation	4th February 2011
Workshops The 7th Egerton University International Conference And Expo, 2012 Agriculture Resources Centre (ARC) - Hotel, Egerton University, Njoro Campus. I presented a paper entitled ***Response of endemic Clarias species population parameters to land use along papyrus dominated Mpologoma Riverine Wetland, Uganda.*** The 2nd Biennial NARO Scientific Conference, Theme: connecting agriculture research to society at the Commonwealth Resort, Munyonyo, Uganda The 9th Egerton University International Conference, Innovative Research and Technology for Global Development, Faculty of Education complex Njoro Campus. I presented a paper entitled ***Modelling Clarias fish production potential in relation to land use in Mpologoma riverine wetland basin***	26th - 28th September, 2012 3rd – 7th November 2014 25th – 27th March, 2015
International exposure (conferences and workshops) Fifth International Conference of the Pan African Fish and Fisheries Association (PAFFA5) African Fish and Fisheries: Diversity, Conservation and Sustainable Management Bujumbura, Burundi. Author AID-IFS Workshop on Scientific Writing and IRD-IFS Workshop on Applying for Research FundingIRD-IFS Workshop on Applying for Research Funding at The African Academy of Sciences Nairobi, Kenya. Decision Support Systems in River Basin Management Refresher course, Addis Ababa, Ethiopia. Organised by UNESCO-IHE.	16th to 20th September 2013 28th May to 1st June 2012 7th to 16th November 2011
Presentations at international forum International Conference of the Pan African Fish and Fisheries Association (PAFFA5) African Fish and Fisheries: Diversity, Conservation and Sustainable Management Bujumbura, Burundi, presented " ***Small scale fishery dynamics along infringed Mpologoma River wetland Uganda"***	18th September 2013
In depth studies (Additional training)	

Regional Fresher Seminar for Decision Support systems in River basin management organized by UNESCO-IHE in collaboration with Nile Basin Initiative, Addis Ababa Ethiopia.	7^{th} to 16^{th} November 2011
Post graduate Data analysis workshop by Uganda Society for Health Scientists in collaboration with Makerere University and Case Western Reserve University	10^{th} to 18^{th} April 2012.
Distance short course in Geo-Information and Earth observation, spatial Decision support systems of the university of Twente, the Netherlands	14 October to 6^{th} December 2013