Ecology and Development Series No. 48, 2006

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Analysis of macrophyte biomass productivity, utilization and its impact on various eco-types of Yala Swamp, Lake Victoria Basin, Kenya

Cuvillier Verlag Göttingen

This work is dedicated to my wife Wairimu, son Thenya, and daughter Nyambura Thuita for their love, patience and support.

ABSTRACT

The overall aim of this study was to assess the sustainability of the current utilization of the wetland resources and the impact of human activities on the Yala swamp ecosystem in West Kenya. The socio-economic results indicate that this swampland provides a wide range of support and products to the local communities. These include direct benefits like thatch material and fish and other benefits such as land for small-scale farming and grazing. Approximately 70% of the wetland products are used at the domestic level with the rest being used to generate modest incomes. Marketing of wetland products is ineffective, resulting in low profit margins, which again discourage sustainable wetland use. Nevertheless, farming is an important activity, which engages 90% of the holdings in the swampland and supplies about 70% of the domestic food requirements.

Post-harvest growth of the macrophyte that are commonly used by the local communities was high in the first four weeks ranging from 5-300% of the initial biomass. This was followed by a lower growth rate in the next 10 weeks averaging 1-30% with the less disturbed eco-types achieving higher values (10-30%) than the highly disturbed eco-types (1-15%). The growth rate after the 14th week was highly diminished in all species. During the dry season, fast growth was also restricted to the first 14 weeks, but with an overall reduction in average height gain, growth rate and biomass in all the ecotypes. This variability was attributed to seasonal ecological dynamics and not to the effect of repeated harvesting. The average biomass was about 1,050g dry wt m^2, which is within the values for other tropical papyrus wetlands. The plant nutrient N:P ratio ranged from 6-3.5, which was above ecological limiting levels of phosphorus. These results indicate that the macrophyte can be sustainably harvested at intervals of 14 weeks if the natural ecological setup is maintained.

Ecological conditions were more favourable for macrophyte growth during the wet season (as compared to the dry season) and in the less disturbed ecotypes (as compared to the highly disturbed ecotypes). Soil parameters were more influenced by eco-type than by season. In contrast, water chemistry was more influenced by the seasons. Both soil total N (0.25 -0.3%) and P (0.07- 0.06%) as well as water P (0.03 - 0.14 mg/l) and N (3.72- 2.01mg/l) were above ecological limiting levels.

Land-cover analysis was done using Landsat satellite images taken in the dry season (February 5, 1973, MSS and February 2, 2001 ETM). The most prominent change was a more than three-fold increase in agricultural land from 1,564 ha in 1973 (7 % of the total wetland) to 5,939 ha in 2001 (28 % of the total wetland). However, this excluded temporary land use during other seasons. This conversion of natural vegetation was mainly located along the swamp edges, in particular on the northern and eastern side of the swamp. The satellite images also allowed identification of the siltation areas, which have increased along the Lake Victoria shoreline. The overall classification accuracy was high at 75% with Kappa statistics at 70%. The Normalized Different Vegetation Index recorded a high reduction of the positives values from +0.909 in 1973 to +0.405 in 2001, mainly due to a reduction in the vegetation cover of the swamp. This was attributed to anthropogenic activities, mainly farming.

The main driving factors for land-use changes in the Yala swamp were identified as (i) household numbers, (ii) household and population densities, and (iii) wetland accessibility (combining swamp coverage and terrain suitability). These drivers act as proxy for a whole range of factors, in particular the demand for farming land and high dependence of the local community on the swamp resources for their livelihoods. The statistically computed land-use change using the conversion index (11,696 ha) show a high co-validation with the land-cover changes derived from the satellite images (11,735.44 ha). In conclusion, it can be expected that under the current utilization scenario, swamp conversion is expected to increase as a function of household densities. The big challenge is to balance between increasing swamp farming and sustainable ecosystem utilization, e.g., macrophyte-based water filtering, while maintaining the benefit flow to the local communities.

Analyse der Biomassenproduktivität und Nutzung von Makrophyten im Yala-Feuchtgebiet, Viktoriasee-Becken, Kenia

KURZFASSUNG

Ziel der vorliegenden Studie war es, die Nachhaltigkeit der aktuellen Ressourcennutzung sowie die Auswirkungen der menschlichen Aktivitäten auf das Ökosystem des Yala Sumpfes in West-Kenia, zu bewerten. Die Ergebnisse der sozioökonomischen Untersuchungen deuten daraufhin, dass dieses Feuchtgebiet einen hohen Nutzwert für die lokale Bevölkerung darstellt. Diese nutzt den Sumpf zur Beschaffung von Material zum Dachdecken, zum Fischfang und als landwirtschaftliche Anbaugebiete bzw. Weideland. Ungefähr 70% der Produkte werden für den eigenen Bedarf der Haushalte und der Rest als bescheidene Einkommensquelle genutzt. Die Vermarktung der Produkte aus den Feuchtgebieten ist nicht effektiv und der daraus erzielte Gewinn daher niedrig. Die Motivation zur nachhaltigen Nutzung dieser Gebiete ist demzufolge gering. Die Landwirtschaft ist jedoch ein wichtiger Bereich, der von 90% der Ländereien im Feuchtgebiet betrieben wird und ca. 70% des häuslichen Nahrungsbedarfs liefert.

Nach der Ernte war in den ersten vier Wochen das Wachstum der Makrophyten, die üblicherweise durch die lokale Bevölkerung genutzt werden, hoch und betrug zwischen 5 und 300% der anfänglichen Biomasse. In den folgenden zehn Wochen lag die Wachstumsrate bei 1-30%, wobei die weniger gestörten Flächen höhere Werte (10-30%) als die stark gestörten Flächen (1-15%) erzielten. Die Wachstumsrate nach der 14. Woche war bei allen Pflanzenarten sehr gering. Während der Trockenzeiten beschränkten sich die hohen Wachstumsraten ebenfalls auf die ersten 14 Wochen; alle Ökotypen zeigten aber dann insgesamt eine verringerte mittlere Pflanzenhöhe, Wachstumsrate und Biomasse. Diese Variabilität kann auf eine jahreszeitliche ökologische Dynamik jedoch nicht auf wiederholte Ernten zurückgeführt werden. Die durchschnittliche Biomasse betrug ca. 1,050g Trockengewicht/m^2, ein Wert, der dem anderer tropischer Papyrus-Feuchtgebieten entspricht. Das N:P-Nährstoffverhältnis der Pflanzen lag bei 6-3.5; dies war oberhalb der ökologischen Grenzwerte für Phospor. Diese Ergebnisse deuten darauf hin, dass unter natürlichen ökologischen Bedingungen die Makrophyten in Abständen von 14 Wochen nachhaltig geerntet werden können.

Die ökologischen Bedingungen waren für das Wachstum der Makrophyten günstiger während der Regenzeit (verglichen mit der Trockenzeit) und in den weniger gestörten Ökotypen (verglichen mit den stärker gestörten Ökotypen). Die Bodenparameter waren stärker vom Ökotyp als von der Jahreszeit beeinflusst. Im Gegensatz hierzu war die Wasserchemie stärker durch die Jahreszeiten beeinflusst. Sowohl Gesamt-N (0.25 -0.3%) und -P (0.07- 0.06%) im Boden als auch P (0.03 - 0.14 mg/l) und N (3.72- 2.01mg/l) im Wasser waren oberhalb der ökologischen Grenzwerte.

Die Landbedeckung wurde mit Hilfe von Landsataufnahmen analysiert, die in der Trockenzeit aufgenommen wurden (5. Februar 1973, MSS bzw. 2. Februar 2001, ETM)). Am auffälligsten war eine mehr als dreifache Zunahme der landirtschaftlichen Fläche von 1,564 ha in 1973 (entsprechend 7 % der Gesamtfläche) auf 5,939 ha in 2001 (entsprechend 28 % der Gesamtfläche). Diese Veränderungen beinhalten jedoch nicht die vorübergehende Landnutzung während der anderen Jahreszeiten. Diese Umwandlung von natürlicher Vegetation war hauptsächlich in den Randbereichen des Sumpfes und besonders in den östlichen und westlichen Bereichen zu beobachten. Auf den Satellitenaufnahmen war eine Zunahme des verlandeten Bereichs entlang der Küste

des Victoriasees zu erkennen. Die Gesamtgenauigkeit der Klassifizierung war mit 75 % hoch (Kappa-Statistiken 70%). Der ‚Normalized Different Vegetation Index' zeigte eine starke Abnahme der positiven Werte von +0.909 im Jahre 1973 auf +0.405 in 2001; dies lag Größenteils an einer Abnahme der Vegetationsbedeckung im Sumpfgebiet, hauptsächlich als Folge der landwirtschaftlichen Nutzung.

Die Hauptfaktoren für die Veränderung der Landnutzung im Yala Sumpf sind (i) Anzahl der Haushalte, (ii) Dichte der Haushalte und Bevölkerung sowie (iii) Zugang zum Feuchtgebiet (Sumpfbedeckung kombiniert mit Geländeeignung). Diese sind stellvertretend für eine große Anzahl von Faktoren insbesondere die Nachfrage nach Land für landwirtschaftliche Nutzung und die hohe Abhängigkeit der örtlichen Bevölkerung vom Sumpf für ihren Lebensunterhalt. Die mit dem konversionsindex statistisch ermittelten Landnutzungsänderung (11,696 ha) zeigte eine hohe Co-Validierung mit den durch die Auswertung der Satellitenbilder ermittelten Veränderungen (11,735.44 ha). Zusammenfassend kann festgestellt werden, dass unter der aktuellen Nutzung die Umwandlung der Feuchtgebiete als Funktion der Haushaltsdichte zunehmen wird. Die große Herausforderung besteht darin, ein Gleichgewicht zwischen der steigendenden rein landwirtschaftlichen Nutzung und einer ökologisch sinnvollen vielfältigen Nutzung, wie z.B. der Einsatz von Makrophyten zum Filtern des Wassers, herzustellen und gleichzeitig der lokalen Bevölkerung die weitere Nutzung des Sumpfs zu ermöglichen.

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1 INTRODUCTION

1.1 Background to the study

Wetland ecosystems are characterized by the presence of standing or slowly moving water on the ground surface or within the plant root zone, which is either temporary or permanent. In addition, they often have unique sodic soil conditions that differ from the adjacent land and vegetation types that are flood tolerant. Both the seasonal and the permanent wetlands cover considerable areas of the world in both the temperate and the tropical areas. However, the greatest concentration of wetlands occurs roughly between 15°N and 20°S (Halls, 1997). It is estimated that in total wetlands cover approximately 6% of the Earth's surface (Maltby, 1986; Mitsch and Gosselink, 1993). This is about 8.6 million km^2 of wetlands in the world, of which 56% are within the tropical and subtropical regions. Approximately 4 % (345,000 km^2) of these are to be found in Africa, which constitute about 1% of the surface of the continent (Denny, 1985). This is a conservative figure since it does not include seasonal wetlands, marine and estuarine wetlands.

Freshwater wetlands in Africa can be divided into six categories namely swamps, marshes, floodplains, bogs, and agricultural and artificial wetland (Muthuri, 1992). Swamps are the most prominent type of wetland in Africa, the biggest being the Sudd swamp in Sudan (150,000km^2) along the Upper Nile (Etherington, 1983). Swamps are characterized by the presence of submerged or emergent macrophyte, which are flooded to a shallow depth, permanently or for the most part of the year. All the major rivers in Africa have a wide diversity of wetlands within their basins. These wetlands are of wide diversity and are also characterized by high endemism, species richness and are of international significance. These include the swamps along the inner Niger Delta, the Sudd swamp in Sudan, the Lake Victoria wetlands and the Okavango wetland in northern Botswana (Halls, 1997).

The prolonged presence of water makes the wetlands suitable for fishing, macrophyte harvesting, farming and grazing, especially in the dry areas. For example, in the Sahel area, wetlands are crucial for the local economies and are highly productive ecosystems that support more than 50% of the respective populations. Another significant wetland area is the Kafue flats in Zambia, which are an important fishing area with an average annual catch of 7,700 tonnes of fish between 1966 and 1985 (Adelaida, 2000) In addition, due to the favourable ecological conditions in the wetlands, the macrophyte are harvested at short intervals both for thatching and craft items.

The Convention on Biological Diversity (1992), Article 15, recognizes the close and traditional dependence of many indigenous and local communities embodying traditional life styles on biological resources. It further acknowledges the desirability of sharing equitably benefits arising from the use of traditional knowledge, innovations and practices that are relevant to the conservation of biological diversity and the sustainable use of its components. However, from a conservation standpoint, unless developing countries recognize the benefits from these resources, the political will to conserve them will be less than might otherwise be the case (Okondo, 1989). Policies will continue to encourage conversion, in some cases even providing subsidies.

According to Panayotou (1994), some wetland losses can be attributed to the missing economic signals to both the local people and the policy makers regarding the values of ecosystem goods and services. Hence, utilization of wetlands under growing populations and poor ecosystem management generate high utilization pressure leading to wetland degradation. A major driving force leading to wetlands loss is the expansion of farming communities especially in arid and semi-arid lands (ASALs) (Thenya, 1998). This affects the ecological base for fishing, grazing and macrophyte production and contributes to the spatial changes in the wetland areas. Unfortunately, there is often inadequate information on wetland ecosystem changes especially in the developing countries. This often results in the failure to accept the magnitude of ecosystem change or the strategic location of these wetland ecosystems, such as fringes of large water bodies, where they act as natural water filters. Satellite remote sensing can be especially appropriate for wetland inventories and monitoring in the developing countries, where funds are limited and where little information is available on wetland ecosystems (Ozesmi and Bauer, 2002).

Most wetland research in Kenya has been concentrated in the large lacustrine wetlands of the Rift Valley, the Kenyan coast and Lake Victoria, with strong emphasis on nutrients, water quality and vegetation dynamics (Thenya, 1998). Even in the Lake Victoria Basin (LVB), most studies have concentrated on Lake Victoria itself with little focus on the littoral wetlands. Mavuti (1992) notes that riverine wetlands, including the flood plains like those of LVB, provide very important ecosystem services and products such as flood control, thatch material, small-scale farming and grazing areas. Therefore, the realization and appreciation of the linkages between bio-economics aspects, wetland environmental services and structural components is crucial to their sustainable utilization. This is especially important in the developing countries, where the rural economies are highly dependent on the natural resources.

1.2 Statement of the research problem

Wetlands are characterized by the presence of a high diversity of flora and fauna, which forms the base for a wide range of wetland products (Mavuti, 1992; Adelaida, 2000). These products include material for thatch and craft items like baskets and mats. In addition to these products, wetlands provide valuable ecosystems services like groundwater recharging and filter functions. For example, the Yala swamp in Lake Victoria, West Kenya, occurs in a highly densely populated area, which is dominated by small-scale farming, where ecosystem services and goods are highly valued. The livelihoods of the local communities are highly dependent on the wetland ecosystem resources due to the prevailing low economic standards (Odak, 1987; Abila, 2002). This creates strong interactions between the local communities and the wetland ecosystem, which is part of the focus of this study. These interactions and resulting effects are poorly understood, since most research efforts have been concentrated mainly in the open water of both Lake Victoria and the satellite lakes in the Yala swamp.

Yala swamp is dominated primarily by rooted *Cyperus* species, mainly *Cyperus papyrus* L., in combination with *C. dives* syn. *C. immensus* Del*, C. distans* L.f. and *C. exaltatus* Retz. Swamp grasses occur along the edges of the swamp (Hughes and Hughes, 1992; Mavuti, 1992), with macrophyte such as *Phragmities mauritianus* Kunth, *Echinocloa species* and *Polygonum* species occurring on the drier raised ground. Further inland, the swamp has a dense mixture of *Typha domingensis* Forst and *C. papyrus*. In the open water, the common macrophytes include *Potamogeton pectinatus* L., *Ceratophyllum demersum* L. These vegetation formations constitute a rich natural resource base for exploitation by the local communities. Utilization includes

The pattern of utilization of these macrophyte varies within the ecosystem depending on the biomass availability, ecological location and species preference of the communities. For instance, while *Phragmites* species are used for making fish traps and thatching, *Cyperus* species are often preferred for making baskets, mats and thatching (Odak, 1987; Ogutu, 1987; Gichuki *et al.,* 2001). Therefore, the study focused on understanding the various uses of macrophyte, species preference and the reasons behind these variations. In order to link macrophyte utilization with spatial distribution and ecological variation there was a need to record the spatial occurrence of the various macrophyte in the ecosystem.

Increased local demand for the macrophyte for building material and mat making as well as for grazing (Abila, 2002) are deemed as having a strong effect on their regeneration capacity and spatial distribution. In addition, the demand for farming land in an area with a high population density coupled with declining soil fertility generates high conversion pressure in the wetlands. Other factors like the increasing need to meet cash economy transactions exert additional pressure on the wetland resources (Kiwazi *et al.,* 2001) leading to land-cover change. The resulting effect is a change in both the spatial coverage and post-harvest growth of the macrophyte as a result of repeated annual wetland conversion, which alter wetland ecology. In addition, this both reduces macrophyte availability and increases the distance to the resources. Although the socio-economic aspects in the Yala swamp have been tackled before (Abila, 2002; Kareri, 1992; Kairu, 2001), analysis of the relationship between temporal land-cover change, socio-economics and associated land-use change drivers have not yet been investigated. Knowledge on these relationships is essential for understanding the trajectories of land-use change in these wetlands.

While it was important to document the current macrophyte utilization, it was also essential to investigate the forces behind the demand for the wetland products and the effect of this demand on wetland ecology as well as on land-cover change over time. The study also investigated the rate of post-harvest regeneration of the macrophyte with a view to proposing a management harvesting procedure to facilitate better planning and management of the ecosystem resources under an increasing resource use scenario.
The main issues that were addressed in this study include:

- Vegetation species and their spatial distribution
- Utilization of the Yala swamp by the local communities
- Natural post-harvest growth dynamics of macrophyte and associated ecological parameters
- Spatial-temporal land-cover changes in the Yala swamp and associated anthropogenic impacts
- Land-use change drivers in the Yala swamp

1.3 Justification and significance of the study

Wetlands perform a host of ecological and hydrological functions that benefit humankind (Davies and Claridge, 1993). Although there has been a global increase in wetland importance, most research studies have been undertaken in the temperate regions with only a recent focus on Africa (Gaudet, 1976; 1977 a and b; 1978; 1979; Mavuti 1989; Thenya, 1998). This is due to socio-political situation and the differences in the research facilities. In Africa, very little scientific research has addressed wetland ecosystems, especially swamps, compared to other ecosystems such as forest in spite of the increasing awareness of their role in supporting livelihoods. In addition, compared to the temperate zone, very few studies in the tropical wetlands have combined bio-economic aspects, land-use change and ecological productivity (Barbier, 1993; Brouwer *et al.,* 1999). Most of the land-use change studies have concentrated on the forest ecosystem leaving a glaring gap in the wetland ecosystems. Thus, although more information on wetland loss may have emerged since the work by Hollis (1993) and Taylor *et al.* (1995), Africa datasets indicate that wetland loss is rarely measured or recorded during wetland inventories. This study therefore, aimed at addressing these gaps as well.

The Lake Victoria Basin supports one of the densest and poorest rural populations in the world with estimated 1,200 persons per square kilometer (Hoekstra and Corbett, 1995). According to ICRAF (2000), population densities in the lake basin areas of Kenya, Tanzania, Uganda, Rwanda and Burundi have a doubling time shorter than their respective national averages. Unfortunately, pervasive poverty hinders sustainable use of the land resources. This leads to considerable land degradation, sedimentation and nutrient run-off, which contributes to changes in the wetland area. Therefore, generation of Yala swamp utilization and land-cover-change data was important especially with regard to swamp ecosystem management and sustainable utilization.

Communities living next to wetland ecosystems derive a significant part of their livelihood from these ecosystems. For example, in the Yala swamp, local communities rely on the ecosystem for food items like vegetables, for medicines, building material and grazing land among others uses (Abila, 2002). In particular, there is a strong reliance on the macrophyte both for building and for raising incomes (Hoekstra and Corbett, 1995; ICRAF, 2000). Apart from these immediate economic gains, the Yala swamp also provides other useful ecosystem services. These include groundwater recharge, water filtration, provision of wildlife habitats and also control crop damage by providing potential pests with natural habitats.

ICRAF (2000) notes that although the communities are concerned about local degradation of the ecosystem, they seem to have little awareness of the offsite effects. For example, the Yala swamp has highly populated catchments, which, due to land-cover degradation, contribute high sediment and nutrient amounts to the water system. The changes in the catchment system have also led to an increase in the discharge of the rivers Yala and Nzoia (Sangale *et al.,* 2001). This can be partly attributed to the lack of awareness of the linkage between wetland bio-economic values and the wider ecological system. This study addressed this linkage. At the local swamp level, increasing population density, small farm sizes plus declining soil fertility in the surrounding farms makes the wetland a convenient fertile farming alternative. The high population around the Yala swamp and the heavy reliance on natural resources constitute a major driving force towards wetland conversion; this fact was also addressed in this study.

Policy-driven changes in wetlands are common in African wetlands, often resulting in a loss of their traditional values and uses in addition to habitat loss (Thenya, 1998; Adelaida, 2000). In the Yala swamp, apart from the efforts by the local communities to drain the wetlands, the ecosystem has also suffered from policy-initiated conversion for agriculture (GoK, 1994). For instance, between 1965 and 1970, some 2,300 ha were drained by the Ministry of Agriculture (MOA) (Aloo, 2003). Following this, there were plans by the Lake Basin Development Authority (LBDA) to reclaim more land. In 2000, some 7,000 ha on the eastern side of the swamp were allocated to a private company for large-scale farming. The effect of this policy decision on the wetland land-use change may take some time to be felt, but it is bound to increase the pressure on wetland conversion. Therefore, an understanding of the bio-economic values and ecological process linkages is useful in promoting sustainable utilization by the local communities and other stakeholders.

There are two reasons for the failure to engage in active wetland management or to appreciate the wetland resources. One is the lack of awareness of the value of the wetland products and the restrictions on profitable modification of these ecosystems. In line with Ramsar 'wise use', "sustainable utilization of the wetlands for the benefit of mankind should be in a way compatible with the maintenance of the natural properties of the ecosystem". However, modifications that increase the socio-economic benefits of the wetlands for the local stakeholders are also likely to increase wetland conservation. However, such modifications must be guided by research findings focusing on resource use and its implications, ecological functions and services. To facilitate conservation and sustainable utilization of the Yala swamp, more research is required on the socio-economic dynamics linkage with ecological dynamics as well as the associated human impacts (Chavangi, 1985; Kareri, 1992).

According to Ocholla (1997), to achieve 'wise use' of the Yala swamp four problems must be urgently addressed. These are (1) clearing of wetland areas for agriculture and human settlement (2) overgrazing and mining activities, e.g., for sand, (3) introduction of exotic species like eucalyptus, and (4) improvement in harvesting of wetland products. This study was therefore very important, because it investigated and quantified the bio-economic utilization of the Yala swamp and post-harvest growth of macrophyte. Furthermore, it investigated land-use change drivers and the resulting human impact on the different eco-types. The study also addressed long term (28 years) temporal land-cover changes that have not been addressed previously in studies in the Yala swamp. Previous studies have covered a shorter period of about 17 years, 1984 - 2001 (Mfundisi, 2005). This study also fits well within both the Lake Victoria Environment Management Programme (LVEMP) and ICRAF research, which focus on natural resources and local communities.

1.4 Limitation of the study

Scientific studies and more so field-based studies are characterized by numerous restriction and limitations and this study was no exception. The main limitations are discussed below

Land-use change: Departure from CLUE-s modelling framework

The model framework of the CLUE (Conversion of Land Use and its Effects at Small regional scale) is a multiple-regression-based spatial model that is used to quantify land-use changes. This is achieved through determination and quantification of the most important biophysical and human drivers of land-use changes on the basis of the actual land-use structure (Verburg *et al.,* 2004). Both the biophysical and human drivers of land-use change are incorporated in the dynamic model so as to describe changes in different areas of the land. Besides tracking past or historical land-use changes, the model can be used to explore possible land-use changes in the near future under different development scenarios over a time horizon of about 20 years.

However, the entry of the large-scale rice project by Dominion Company in 2003 distorted the ecosystem utilization scenario and a new socio-economic scenario developed in the Yala swamp. Land-use change in the wetlands acquired a faster driver that was different from the ordinary local community livelihood on which the proposed use of the CLUE model was based. The project proposal had been formulated in 2001 prior to the commencement of the large-scale project, and therefore the resources available and time frame could not accommodate the new changes in a realistic manner.

However, the objective of the land-use change analysis in the Yala swamp could be achieved through the use of more flexible conventional land-use change methodologies. This involved integration of socio-economic, census and remote sensing data, which is a common approach in land-use change studies (Liverman *et al*., 1998). The data were analyzed using regression analysis to generate land-use change drivers and the spatial changes in the Yala swamp. The results of the statistically computed changes in the spatial coverage of the swamp were co-validated using the spatial data generated from the satellite images of the year 2001. This approach was able to meet the objectives envisaged using the CLUE-s model.

1.5 Research objectives

Overall research objective

The overall aim of this study was to determine bio-economic values and ecological productivity of the Yala swamp and the human impacts in the wetland. This involved spatial characterization using GIS and remote sensing tools, while land-use change and bio-economic interactions were investigated to give an indication of the trajectories of land-use change dynamics.

Specific objectives:

The specific objectives were to:

1. Carry out an inventory of the flora of the Yala swamp and its spatial distribution.
2. Assess the natural regeneration rate of selected macrophyte species based on their bio-economic value and potential for sustainable harvesting.

3. Assess the bio-economic value of various macrophyte species by considering their domestic and commercial values.
4. Investigate the drivers behind wetland land-use transformation.
5. Assess the human impact on the wetland ecosystem.
6. Model wetland land-use development scenario and make recommendations for "wise use"

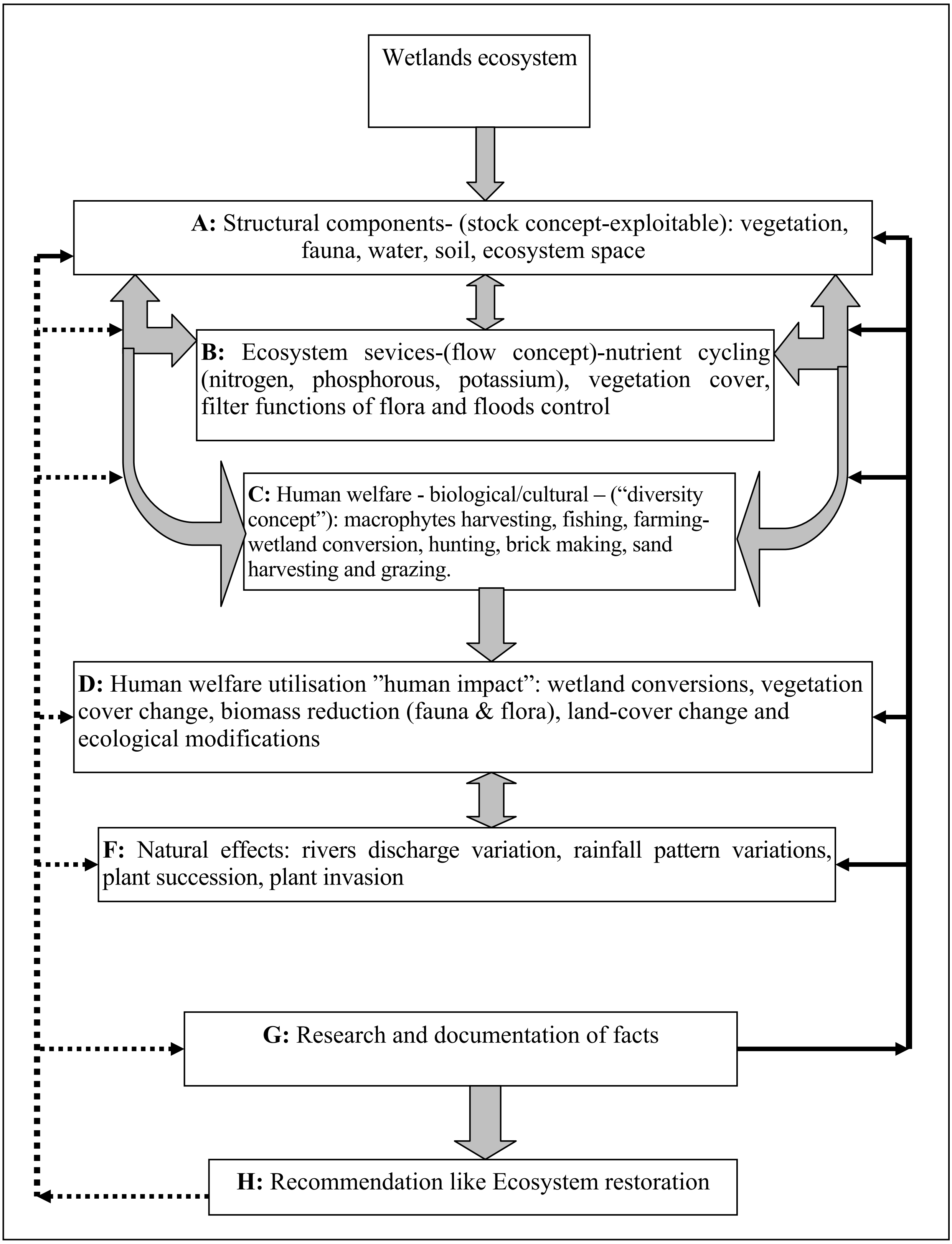

Figure 1.1: Wetland ecosystem functions and interactions (Source: modified from Odum, 1971)

1.6 Conceptual framework

Wetlands like the other ecosystems are organized in systematic and coordinated interactions. The underlying ecosystem relationship concept is organized in terms of ecology: structural components, environmental functions (ecosystem services), biological and cultural diversity "economics", i.e., goods, services and attributes. Structural components (A) include species composition, abiotic and space, i.e., the '*stock concept'* (Figure 1.1). The environmental functions (B) are the result of the interaction of structural components with solar energy. This produces environmental functions like nutrients cycling, primary productivity, energy flows and climate regulation, which constitute ecological *'flow concepts'* that demonstrate the change of *"stock*" as stimulated by the energy flow over time. The biological and cultural diversity (C) on the other hand is determined by the interaction of the environmental and structural components, i.e., *"diversity concept".* The diversity concept represents the organization dimension of any ecosystem. This hierarchical ecosystem organization concept is used in this study to assist in understanding the interactions and their effects.

The structural component (direct use) values like fish, woodfuel, water, wild foods, medicines, agriculture, pasture, transport and building material like macrophyte constitute 'goods' or the direct values (Emerton, 1999). While environmental functions (indirect use) values produce benefit flows over time, e.g., watershed protection by the vegetation cover, sediments retention by marshes, water storage, flood control, shore stabilization, wildlife support and nutrient cycling in the soils, provide 'ecosystem services' or indirect values. The goods and services constitute the tangible and intangible outputs, respectively, which eventually make up biological and cultural diversity that affects the human welfare (C) through the process of ecological production and consumption.

The human welfare from the ecosystem (C) on the other hand constitutes utilization of goods like macrophyte and ecosystem services benefits such as the filter functions of the ecosystem. In addition, this also includes the option and the non-use values. The *option values* are like premiums that are placed on possible future use such as pharmaceuticals and agricultural, industrial, leisure and water use. While the *non-use values* are the intrinsic significance in terms of cultural, aesthetic, heritage and bequest values. An account of the ecosystem benefit accruing to the society is essential for understanding the implications of alternative use or non-use options for the system (Barbier, 1989; Pearce *et al.,* 1989) and the effect of utilization (D). For example, human impact on wetlands can be amplified by natural changes (E) such as rainfall pattern variations or catchment degradation affecting river discharge.

The study focused (F) on the structural components with special interest on the macrophyte, while with respect to environmental functions it focused on essential plant nutrients and the diversity concept emphasizing the utilization and the subsequent impacts. The outcomes of such investigations (G) are significant in aiding policy formulation for ecosystem management as well as pointing out areas of further research. Again, biological diversity, for instance, is important in the developing countries for two reasons: one is that the majority of the world species are located in the tropics and that large human populations in the developing countries depend on natural resources for their livelihood. The conceptual model applied here is highly generalized, since the interactions are more complex than presented here. To achieve this, an interdisciplinary approach was adopted, which fits well within the field of biogeography.

2 LITERATURE REVIEW

2.1 Introduction

Wetlands ecosystems are spread widely from the temperate to the tropical region, covering an estimated 6% of the global land surface (Maltby, 1986; Mitsch and Gosselink, 1993). These ecosystems vary in size, plant diversity and fauna composition. In addition, they have significant global ecological and economic values. While in the temperate regions, wetland are largely used for their ecosystem services like filter functions (Silvan and Laine, 2004), in the tropical region the main priority is the provision of goods and farming.

In terms of biodiversity, wetland ecosystems are globally recognized as important bird habitat. This was the precursor for the formulation of the convention on wetlands, the "Ramsar Convention". The high primary productivity of wetlands forms the basis for the human exploitation of these ecosystem goods. In the developing countries, wetlands are a source of great support to the rural communities, which derive a significant proportion of their livelihood from these areas. For instance, in dry lands, they are often the only source of water and forage in the dry season (Thenya, 2001). However, this wetland exploitation often has negative consequences for the ecosystem, leading to land-cover change and degradation.

2.2 Wetlands ecosystems in Africa

Wetlands are widely distributed on the African continent and cover approximately 1% of the total land surface area and are characterized by species richness and endemism. This coverage excludes coral reefs and some of the smaller seasonal wetlands. The greatest concentration of these wetlands occurs roughly between 15°N and 20°S. The major wetland ecosystems include the Sudd and Okavango swamps in Botswana. Other significant wetlands include those around the Lakes Chad, the Rift Valley Lakes notably Victoria, Tanganyika, Malawi, Turkana, Mweru and Albert (Halls, 1997). Other important but saline wetland ecosystems include the mangrove forests of East and West Africa and the associated coral reefs and sea grass beds. Also included in these saline ecosystems are the coastal pans/lagoons and marshes such as the Ebrie and Tadio lagoon complexes of Cote d'Ivoire. Significant wetlands outside this limit of 15°N and 20°S include the oasis, wadis and chotts of north-west Africa, the Sidi Moussa lagoons in Morocco and the Limpopo River floodplains in southern Africa. This also includes the largest estuarine system in Africa, the St. Lucia wetlands in South Africa, which has a rich biodiversity with over 350 bird species (Halls, 1997).

Tropical wetland ecosystems display species richness in terms of both numbers and endemism. Wetlands that are located in areas of high rainfall and warm climates in Africa such as the Congo Basin display richer species diversity than those of the drier regions north and south of the 15°N and 20°S zone. For example, out of the over 2,000 species of indigenous freshwater fishes in Africa, 700 are found in the Zaire River basin, with 650 being endemic to this basin (Halls, 1997). Other specific wetlands with high endemism and of international significance include the Inner Niger Delta in Mali and the seasonal floodplain of the Central African Republic like the Bangweulu Basin in Zambia. Also included in this category are the Sudd swamps in Sudan, Lake Victoria, Lake Kyoga in Uganda, the western Tanzania wetlands and the Okavango in Botswana.

Wetland ecosystems are particularly important as avifauna habitats, and various wetlands have large concentrations in both number and species of birds. These include the Sahel wetlands in West Africa like the Senegal and Niger Rivers and Lake Chad, which support over a million waterfowl. The Djoudj National Bird Park in Senegal and the Diawling National Park, Mauritania, are havens for migratory birds hosting over three million birds of nearly 400 species. Remarkable is also the seasonal Sebkhet el Kelbia wetland in Tunisia in the shallow depression of the semi-arid parts of North Africa, which support large numbers of wintering birds.

Globally, Africa probably has the largest area of freshwater swamps (Muthuri, 1985). These are mainly dominated by papyrus swamps, which are confined to the belts across the equatorial part of Africa, forming areas of great ecological and socio-economic importance (Muthuri, 1985). According to Beadle (1974), the papyrus swamps are not restricted to the conspicuous water bodies but are also found inland in valleys along streams. The largest swamp areas in tropical Africa are located in the central, eastern and southern parts. In contrast, the West Africa is characterized by predominant papyrus scarcity due to pronounced river seasonality (Thompson, 1976). In Kenya, papyrus swamps are common along lakes, rivers and valleys but the total area is less than in Uganda or Sudan (Etherington, 1983). This can be attributed to the high percentage of arid land in Kenya (75%) compared to Uganda (>25%). Although the actual figures are scarce, swamps cover hundreds of thousands of square kilometers, mostly exceeding the area of open waters of all lakes (Beadle, 1974). Unfortunately, because of the transformation of these wetlands, their spatial coverage could have been reduced by a big percentage, although again no data of such losses are easily available (FAO, 1998).

Apart from the importance of these wetlands in terms of biodiversity, African wetlands provide support to the livelihood of the rural communities in several ways (Wood, 1997). These include subsistence farming and fishing both for domestic and commercial use (Odak, 1987; Aloo, 2003). Other uses include grazing and macrophyte harvesting. Those wetlands occurring in dry areas such as the Sahelin region are especially important as a source of forage and water during the prolonged dry season. For example, the Inner Niger Delta floodplain supports about one million sheep and goats (Halls, 1997).

2.3 Wetlands ecosystem in Kenya

According to the Kenya National Environment Action Plan (GoK, 1994), wetlands cover approximately 2 - 3% of the country's surface. These wetlands are of diverse types and distribution. Some of the larger freshwater wetlands in Kenya are shown in Figure 2.1, and include the Lakes Nakuru and Naivasha. Also included in this category are the Lakes Magadi, Kanyaboli, Jipe, Chala, Elementaita, Baringo, Ol'Bolossat, Amboseli, Kamnarok and the edges of Lake Victoria. Other important wetlands include the Lorian, Saiwa, Yala, Shompole, Lotikipi (Lotagipi) swamps and the Kano plains, the Kisii valley bottoms as well as the Tana Delta (Mavuti, 1992).

Kenya has also significant coastal wetlands including mangrove swamps, sandy beaches, sea grass beds and coral reefs (FAO, 1998). In addition, various seasonal and temporary wetlands occur where internal drainage allows water to collect. These include the rock pools and springs in the southern part of Nairobi, west of the Ngong Hills and in Limuru. The human-made wetlands include dams primarily meant for hydropower such as those found along the Tana River. Also included in these artificial wetlands are the water supply reservoirs and those wetlands created for the purpose of wastewater treatment like those in Ruai, Nairobi.

Kenyan wetlands play a very significant ecological role and have great potential as resources of great economic, cultural and scientific value (Abila, 2002). Among the critical values are provision of habitats for a wide range of flora and fauna including endangered species. Their biodiversity includes a large number of aquatic plants, fish, herbivores and resident and migratory birds like those found in the Lakes

Nakuru and Bogoria (Mavuti, 1992). The wetlands are also valuable for recharging wells and springs that are often the only source of water to some rural communities, both for watering livestock and wildlife support systems. The aquifer recharge raises the water table making the groundwater easily accessible. This has been the case in eastern Kenya along the Tana River corridor and in the Chyulu hills catchment area of the Mzima springs.

Apart from those ecological roles, the wetlands are also important as sources of livelihood for the rural communities. In particular, they are important sources of water for human consumption, agriculture and watering of livestock (Thenya, 2001) For example, the Tana delta combines the ecological role of provision of habitats for endemic species like the Sokoke owl as well for farming, grazing and as a water source for the rural community in the area (Terer *et al.,* 2004). In addition, the delta also provides other products such as fuelwood, building material, medicines, honey and various types of natural foods. In particular, those wetlands that are located in dry areas such as the Lorian and Ewaso Narok swamps play an important role in the provision of water and pastures for the pastoral communities during the dry periods (Thenya, 2001).

Kenya ratified the Ramsar convention on wetlands in 1990 and has since designated the Lakes Nakuru, Naivasha, Baringo, Bogoria and Elementaita as wetlands of international importance (Ramsar Sites) in accordance with the convention requirements. The convention definition, however, seems to cater only for the sectoral interests of conservationists whose main concern is water birds. In this respect, through the National Wetlands Standing Committee (NWSC) Kenya defined its wetlands as:

"areas of land that are permanently, seasonally or occasionally waterlogged with fresh, saline, brackish or marine waters at a depth not exceeding six meters, including both natural and man-made areas that support characteristic biota".

The above national definition has also an inclination towards biodiversity conservation, but allows exploitation of wetlands under the "wise use" principle.

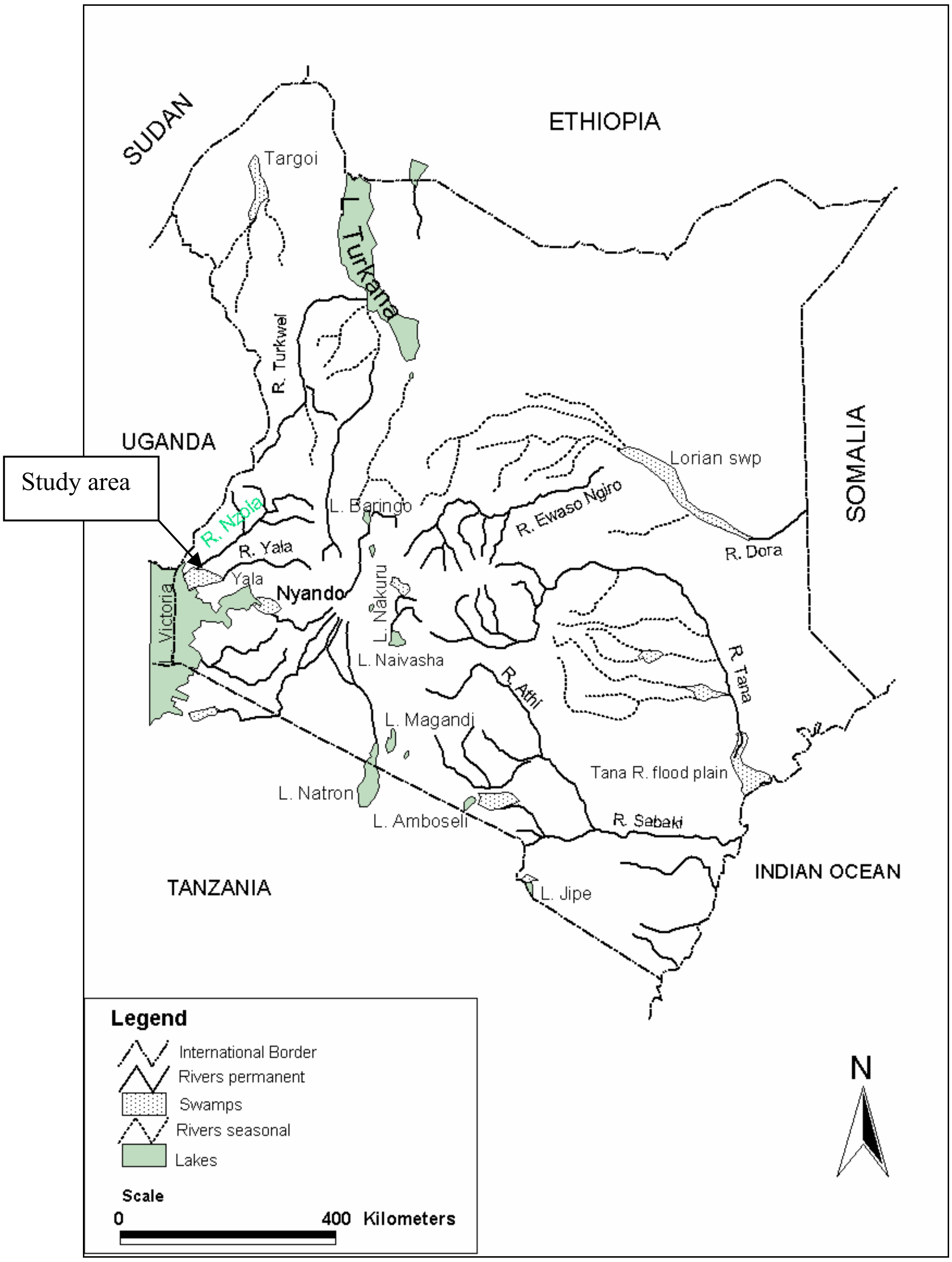

Figure 2.1: Major aquatic systems in Kenya (Source: Modified after Mavuti, (1992) / SK 72/1978 map series

However, in spite of this focused definition, the country still lacks coordinated national inventory and management. Various sectors in the country have conducted inventories to satisfying their sectoral needs like research (Mavuti, 1989; Thenya, 2001) and local management (Terer *et al.,* 2004). However, the management of wetlands within the gazetted protected areas, which are the national parks and game reserves, is under the Kenya Wildlife Service (KWS), which has the mandate of conserving Kenya's natural resources including wetlands. As in the case of the Yala swamp, this leaves a large percentage of wetland ecosystems out of the protection framework and planned management. Thus, a holistic approach to wetland management is still lacking in the country, and most wetlands lack management plans and are under increasing conversion pressure from the growing farming community.

2.4 Ecological characteristics of wetland

Wetlands are characterized by specific sequential eco-types of various macrophyte species depending on water regime and ecological status. These species occur in continuously wet and relatively nutrient-rich sites and range from submerged species like *Potamogeton* species to the emergent Nymphaea genus, e.g., water lily. This graduate to rooted emergent species such as *Cyperus papyrus* and *Typha domingensis*, and *Phragmites mauritianus* that occur along the edge of the wetlands include *Echinocloa haploclada* (Stapf) Stapf and *Sporobolus* species. The relatively homogenous stands of these species often extend over large areas and have short temporal biomass turnover especially in the tropics.

The most extensive wetland ecosystem type in the tropics including Africa is the papyrus swamp. This ecosystem is associated with the littoral zone of flooded freshwater systems, which provide diverse habitats for plants and animals. Symoens *et al.* (1981), distinguished between two types of swamps, i.e., those in which the dominant plants are rooted in the sediments and those in which they are rooted in a floating mat. The former type is the most prominent in tropical Africa and is dominated by emergent macrophyte such as *Typha domingensis*, *Cyperus papyrus*, and *Phragmites australis* (CAV.) Trin ex Steul, while the floating type is dominated by *Vossia cuspidate* (Roxb.) and *Cyperus papyrus*. The Yala swamp falls within the first category, where the macrophyte are rooted in the sediments, although there are some floating sections in open waters such as Lake Kanyaboli.

The emergent macrophyte forms some of the most productive plant communities in swamps, marshes and floodplains. Although the emergent macrophyte cover only about 1% of the continental land surface, they have been estimated to produce as much as 5% of the total annual primary biomass. The productivity of swamps and marshes greatly exceeds that of bogs partly due to the increased nutrient availability in the swamp environment. In terms of specific species dominance, *C. papyrus* forms the most dominant emergent vegetation in most of the permanently flooded wetlands of tropical Africa. It is amongst the largest of the herbaceous species, with culms growing to a height of 5 m and above-ground standing biomass often in excess of 12.0 t C ha^{-1} (Hughes and Hughes, 1992). Since papyrus is a C4 plant, it has a higher rate of photosynthesis, which gives it a bigger competitive edge in the dense wetland vegetation communities. In contrast, ecological units along the edges of the swamp that receive relatively reduced flooding are characterized by extensive coverage of *Cyperus distans* L.f. *C. dives* syn. *C. immensus* Del and *C. exaltatus* Retz. They are physiognomically smaller in size and have lower ecological productivity.

Since the emergent macrophytes are rooted in the sediments, they act as a connection to the overlying water, influencing ecological productivity and biogeochemical cycles (Barko *et al.,* 1991). These plants are able to alter the sediment chemistry by moving oxygen from their shoots to their roots through aerenchyma. An important biogeochemical consequence of this process is the change in redox potential, which strongly affects macrophyte productivity and nutrient availability (Wigand *et al.,* 1997; Kyambadde *et al.,* 2004). For example, a low redox potential in wet anaerobic conditions decreases phosphorous availability through encouraging the adsorption of phosphorous onto the soil particles.

It has been observed that the ecological status of wetlands, including transformations like cultivation, affects plant species composition and biomass dynamics. For example, a rise in the amount of nitrogen and phosphorous in the wetland ecosystems leads to an increase in highly nutrient-tolerant species like *Typha* and *Phragmites* (Davis, 1991; Chambers *et al.,* 1999; U.S. EPA, 2002). Other wetland transformations, like increased salinity, favor *Phragmites* species and *Typha angustifolia* L. On the other hand, soil disturbance favors *Typha* and *Phragmites* species, *C. dives, C. exaltatus* and *Phalaris arundinacea* L. (Apfelbaum, 1985; Urban *et al.,* 1993; U.S. EPA, 2002). Increased flooding on the other hand, leads to high biomass of *Typha* species, *C. papyrus*, *Phragmites australis*-(Cav.) Trin. ex Steud, and *Phalaris arundinacea* L. Another effect of flooding, apart from exporting nutrients, is inhibition of the regeneration of the harvested species. However, this effect is more species specific (Seabloom *et al.,* 2001). Thus, the prevailing ecological conditions and nutrient level in particular wetland ecosystems have a direct effect on macrophyte productivity.

Wetland ecosystems are characterized by a rapid nutrient turnover, which includes high nutrient uptake by the macrophytes. Apart from their high nutrient uptake, the macrophytes also retain a significant amount of toxic materials, thus acting as a buffer zone to the downstream ecosystems. Upon decomposition of the vegetation matter, the nutrients are released to the bottom mat and sludge (Silvan and Laine, 2004). The most important nutrients are nitrogen, phosphorous and potassium, which limit ecological productivity (Gaudet, 1976; Thompson 1976; Muthuri, 1985; Thormann and Bayley, 1997). Therefore, determination of their level in the wetland ecosystem is important with regard to macrophyte growth. In addition, the organic soils and substrate generally have large amounts of phosphorous and nitrogen tied up in organic form. However, these nutrients may not be available to the macrophytes in this form, consequently limiting plant growth (Gaudet, 1979; Gaudet and Muthuri 1981; Muthuri, 1985; Thormann and Bayley, 1997).

The seasonal variations of the physical and biotic components of the wetlands are attributed to the variability of the water inflow, which keeps wetlands at intermediate succession stages (Carter, 1955; Beadle, 1974; Gaudet, 1978; Muthuri, 1985; Davis and Froend, 1999). For example, Talling (1957) observed that in the Sudd swamps, out flowing water in the dry months was more concentrated in terms of nutrients than during the wet season. Gaudet (1978) recorded similar observations in Lake Naivasha's northern swamp and Thenya (1998) in the Ewaso Narok swamp. Apart from the effect of water on nutrients dynamics in the wetlands, the geology of the catchment also exerts high influence on the water chemistry. For example, rivers draining the porous volcanic rock regions in East Africa contribute highly alkaline material to the wetlands in regions such as Lake Naivasha and the Ewaso Narok swamp (Gaudet and Melack, 1981; Thenya, 2001).

However, primary productivity is low in the dry season due to the reduced nutrient circulation. The dry seasons are also characterized by heavy utilization of the swamp by humans, livestock and wildlife. This disturbance triggers the release of nutrients from the substrate, which in turn are washed away from the ecosystem. On the other hand, primary productivity increases tremendously during the wet period due to the reduced wetland utilization coupled with the increased nutrient circulation.

In terms of specific nutrient variability, wetlands act as nitrogen sinks with accumulation in the plant biomass or soil organic matter. The nitrogen is later transferred to the catotelm, which is the lower waterlogged layer where nitrogen can be locked for 30 to 50 years. The peat soils, which have a higher organic material content than papyrus swamps, have higher nitrogen percentages ranging from 1.57 - 2.87%. In the papyrus swamps, values are lower (around 0.56%) and the absence of nitrate is attributed to the prevailing anaerobic conditions (Driessen and Suhardjo, 1977). Most of the nitrogen in the wetland ecosystems occurs in organic form, but nitrate availability increases with soil draining as a result of oxidation. Further loss also occurs through microbial conversion of nitrate to atmospheric nitrogen (Groffman, 1994) as well as through leaching.

Phosphorous, on the other hand, like nitrogen is present mainly in organic form, but occurs in much smaller amounts than nitrogen. It is often conserved in the ecosystem through plant uptake or alternatively trapped in the sediments through adsorption by iron and aluminium oxides. Those wetlands occurring along rivers with high clay deposition retain a high amount of phosphorous due to the presence of aluminium and iron in the clay soils. Phosphorous is also lost from the ecosystem through precipitation of aluminium, iron and calcium phosphates as well as through plant uptake. However, phosphorous is leached from the decomposing wetland organic matter much faster than nitrogen (Okot-Okumu, 2004). Also, as the organic matter decomposes, phosphorous is released to the water surface from where it is exported.

A significant proportion of nitrogen and phosphorous is concentrated in the plant biomass of both above and underground organs. Through translocation of the nutrients from senescing leaves, the plant is able to mitigate the nutrient losses to the catotelm (Silvan and Laine, 2004). This is especially common in nutrient-poor ecosystems and is reflected in low amounts of nutrients in the soil and substrate subsystem.

Numerous researchers have suggested using the N:P ratio to address the question of species-specific nutrient limitation levels (Chambers and Fourqurean, 1991; Fourqurean *et al.,* 1992). This argument is based on the fact that nitrogen and phosphorous are the primary nutrients limiting productivity in wetland ecosystems, thus determining net primary productivity (NPP) (Schlesinger, 1991; Bridgham *et al.,* 1996). A common measure of NPP is through the use of above-ground biomass and stem height, which is expressed as biomass per m^2 per year ($g/m^2/yr$). The simplest way of computing NPP of emergent herbaceous vegetation is by harvesting all the standing above-ground biomass (Broomer *et al.,* 1986). This method however, underestimates biomass loss through herbivores, which is common in the tropics and mortality during growth. Although increase in stem density reflects vigorous plant growth, it is not recommended as a measure of the ecological effect on productivity. The alternative method of tagging vegetation is labor intensive and time consuming and not recommended for wetland ecosystems.

The other important parameters in ecological productivity are pH level, cation exchange capacity (CEC) and soil bulk density. The pH varies widely depending on the presence of organic compounds, organic acids, exchangeable hydrogen and aluminium, iron sulphide and other oxidezable sulphur compounds. High amounts of organic acids result in low pH in the range of 3 - 4.5, which contributes to deficiency in minerals due to the low amount of cations likely in poorly decomposed peat and organic material (Gilliam *et al.,* 1999). This is due to the fact that cation exchange properties depend on negatively charged sites, which adsorb Ca^{++}, Mg^{++}, K^{+} and Na^{+} cations, replacing the hydrogen ions. The high exchange rate associated with organic soils, especially decomposing peat in wetlands, is due to the presence of hydrophilic colloids (humic acids and hemicelluloses), mainly carboxyl radicals (Volarovich and Churaev, 1968; Nair *et al.,* 2001). Thus, wetland CEC is pH dependent and increases with alkalinity, since hydrogen ions remain tightly associated with acidic material and do not exhibit exchange properties. CEC also varies with the wetland flooding level, decreasing in the dry season due to the reduction of hydrophilic colloids.

Soil bulk density measurements on the other hand are important in interpreting soil analytical data, particularly those indicating fertility levels. Low bulk density values are indicative of high CEC levels common in the highly organic wetland soils (Lucas, 1982). The level of soil bulk density depends on extent of soil compaction and botanical composition of the materials. In the highly fabric soils with undecomposed organic materials, values range from approximately 0.05 g/cm^3 to less than 0.5 g/cm^3 in the well decomposed organic materials (Driessen and Rochimah, 1976). Nair *et al.* (2001) observed that in wetland, soil bulk density increased with organic matter and appeared to support more vegetative growth. This appears to be a general feature of most tropical peats under natural conditions. In contrast, due to the effect of climate, temperate areas are characterized by peat accumulation, while tropical wetlands are characterized by the production of a high amount of organic material with a high decomposition rate. Therefore, lower bulk density values are expected in natural unconverted swamps than in the converted areas.

2.5 Bio-economic aspects of wetlands

Apart from the important ecological roles played by wetlands in biogeochemical cycles and biological diversity, wetlands also have important attributes like cultural uniqueness/heritage. In addition, they provide numerous products and services that are significant in supporting human life. It is for this reason that the historical association between people and the wetlands dates back to the beginning of human civilization.

A significant percentage of the African rural population is still dependent on the numerous wetlands types with their high plant and animal diversity (Halls, 1997). The Convention on Biological Diversity (1992), Article 15, recognizes this close and traditional dependence of many indigenous and local communities embodying traditional life styles on biological resources. It further acknowledges the desirability of sharing equitably benefits arising from the use of traditional knowledge, innovations and practices relevant to the conservation of the biological diversity and the sustainable use of its components. However, the people who benefit the most from the services and products provided by wetlands in Africa (and other developing regions) are generally unable to influence decision making at a political level (UNEP, 1997). This means that localized sustainable use practices are often discouraged by the political decisions made without consultation of the local community. Thus, the future of African wetlands lies in a stronger political will to protect them that is based on sound research findings, policies and wide stakeholder participation.

Over the years, communities living next to these wetlands have developed adaptations and strategies to make best use of them (Halls, 1997; Abila, 2002). The abundance of water and fertile soils within many wetlands provide the potential for considerable agricultural resources. In addition, among other uses, wetland plants are used for making mats and baskets in many parts of Africa. In Rwanda, for example, *Cyperus papyrus* L., with its high calorific content, is used to make fuel briquettes. The use of high-calorific papyrus rhizomes has also been recorded in the Ewaso Narok swamp, Kenya (Thenya, 2001), and Simiyu wetland, Tanzania, in the LVB (Katondo, 2001). In the Okavango Delta, roots of the palm *Hyphae, Phragmites* and palm hearts are used for food and to make wine at the subsistence level.

Wetlands are also important for providing dry season grazing areas especially in the arid and semi-arid areas as well for tourism. For example, the Inner Niger Delta floodplain supports about one million sheep and goats (Halls, 1997), and the Kafue flats in Zambia provide important grazing areas on highly productive *Vossia cuspidata* and

Echinocloa species vegetation. In some African countries, wetlands are also important for the tourism industry due to the abundance of wildlife that provides a means of income for the local communities. For example, the Kafue wetlands provide a habitat for the endemic Kafue Lechwe (*Leche kafuensis*), while in Kenya, the Amboseli swamps are the only source of water in the surrounding area. The rich riverine vegetation of the Mara River in the large Masai Mara Game Reserve, Kenya, supports a wide variety of antelopes and African water buffalo (*Syncerus caffer*) among other species.

The use of papyrus plants (*Cyperus papyrus* L.*)* for making papyri (papyrus paper) has been documented in Egypt since 3600 BC. This technique was later adopted in Greece, in Middle East countries and the Roman Empire and continued to be a common practice until the medieval ages. In addition, papyrus was used to make sandals, fans, fences, huts, boxes, ropes, mats, cloth, medicines, cordage, formal bouquets, funeral garlands, boats, and as building materials. The pith and rhizomes were also boiled and eaten, or dried and used for fuel (Lind and Morrison, 1974; Duke, 1983; Burnmeister, 2001). Duke (1983) reported that in historical times (up to 200 AD) papyrus was used to cure many diseases. Currently, papyrus is still used by the local communities especially in central and eastern Africa for both domestic and commercial items including building (Lind and Morrison 1974; Katondo, 2001).

Ogutu (1987) and Kareri (1992) note that among the Bukusu and Luhya tribes in Kenya, *Papyrus* reeds, bulrushes and other herbaceous macrophytes were important sources for beehive construction material and fishing gears. The products made from macrophytes included baskets fishing traps and cages for the birds. Clay combined with macrophytes is still used to construct houses and granaries around Lake Victoria by the Luhya tribes (Odak, 1987; Kareri, 1992). The Luhyas also collect wild greens known as "enderema-*Basella alba"* among other vegetables as well as fruits during the dry season (Ogutu, 1987; Kareri, 1992). However, the changing land ownership system that encourages privatization has reduced the importance of gathering wild greens and the grazing area among other subsistence uses. Nevertheless, the pastoral communities in Kenya continue to rely on the wetlands as dry season grazing areas in such areas as the Ewaso Ngiro basin (Thenya, 2001). Species useful to the cattle in wetlands include *Phragmites*, *Vossia*, *Echinochloa* and *Panicum*. Although, grazing is still a common practice, the formerly controlled social grazing areas are declining as individual landowners take over (Kareri, 1992). The result is high land-use pressure on the remaining and further declining communal wetlands.

In the LVB, the Yala swamp contributes significantly to the economy of the rural communities, especially in terms of grazing and the use of macrophytes for building and commercial products like mats. However, the increased conversion of wetlands to single agricultural use is threatening this economic base and thus the livelihood of the local communities (ICRAF, 2000). Despite this, only little research has been focusing on the linkages between wetland bio-economic uses, ecological dynamics, land-use changes and their drivers.

The LVB supports an estimated 21 million people, who rely primarily on subsistence agriculture and pastoralism for their livelihood (ICRAF, 2000). Sedentary communities have lived in the LVB for a long time and intensified exploitation of the catchment areas dates back to the 1930s. Currently, there is a strong reliance on the wetland resources as a significant source of income for the local communities (Hoekstra and Corbett, 1995; ICRAF, 2000; Abila, 2002). The important resources are the *direct values* attached to the wetlands, which include products like fish, fuelwood, building poles, thatch material, water, wild foods, land for agriculture and pastures, transport and recreation. This study focused on some of these direct values, but also paid special attention to the ecosystem services.

In spite of the above-mentioned importance with respect to local livelihoods, wetlands are experiencing immense pressure from human activities. The most important conversion pressure is drainage for agriculture, settlement and excessive exploitation by the local people. The increasingly widespread unsustainable use of the wetlands can be attributed to the lack of awareness of the traditional values of these wetlands combined with the desire for modernization (Panayotou, 1994; Maclean *et al.,* 2003). Typical development projects in African wetlands are the construction of large-scale hydro-agriculture projects to boost food production. These interventions result in drastic transformation of the hydrological conditions and vegetation communities that reach far beyond the actual reclamation area. For example, the construction of dams and dykes on the upper part of the Senegal River for rice cultivation has altered the plant communities in the lower Djoudj National Bird Park (Halls, 1997). Similar wetland transformation through land-use changes have also been recorded elsewhere in Africa (Drijver and Van Wetten, 2000).

2.6 Application of remote sensing skills in wetlands

The absence of comprehensive data on wetland conversions is of great concern to both conservationist and resources managers especially in the developing countries. In addition, in spite of their value, wetlands are generally not sufficiently monitored in the developing countries, mainly due to the financial and technical limitations. Use of remote sensing skills is especially important, since ground data collection is restricted in wetlands due to the unstable wet landscape. In addition, remote sensing provides a viable source of data that can be extracted and updated efficiently as well as cheaply due to the repeat coverage of the satellite imaging (Ozesmi and Bauer, 2002). This is especially appropriate for wetland inventories and monitoring in the developing countries, where funds are limited and where little information is available on wetland areas, surrounding land uses and wetland losses over time (Ozesmi and Bauer, 2002). Through such monitoring, changes can be detected early and action such as policy formulation or change of management implemented in good time. The resulting maps are digital and can be easily manipulated and evaluated in a Geographic Information System (GIS) environment.

Landsat-MSS has been used successfully for the study of relatively larger wetlands (Work and Gilmer, 1976; Mugisha, 2002) as well as Thematic Mapper (TM) (Otieno *et al*., 2001; López, 2002; Van der Kwast, 2002). In addition, use of remote sensing data has been successively applied in land-cover studies in LVB wetlands in Sango Bay, Uganda (Fuller *et al.,* 1998), in Nyando, Kenya (Van der Kwast, 2002), and in the Yala swamp (Otieno *et al.,* 2001; Mfundisi, 2005). However, temporal comparative analysis for the Yala swamp has only covered a relatively short duration of 17 years (1984-2001) by Mfundisi (2005). This study aimed at focusing at comparatively longer period of time 1973-2001. Unfortunately, a number of factors limit use of Landsat images. First, cloud-free images in the tropical regions are very rare (Jha and Unni, 1982; Ducros-Gambart and Gastellu-Etchegorry, 1984; Pilon *et al.,* 1988; Alwashe and Bokhari, 1993; Mas, 1999). Second, the spatial resolution (20-30 m) makes it difficult to identify small wetlands. Third, the use of Landsat images is limited for vegetation species identification and discrimination. This is especially critical in the inland wetlands, which are usually small in area and have a complex species composition. Although tropical papyrus wetlands are characterized by a large coverage of monotypic vegetation, species diversity increases along the edges. This presents a great challenge for vegetation classification, using both spectral and spatial resolution. In addition, the overlaps of the spectral signatures between wetlands and other classes such as agricultural crops and upland forest also limit the application of Landsat images.

Nevertheless, quantification of landscape fragmentation through pattern indices such as the Normalized Difference Vegetation Index (NDVI) helps to overcome the above-mentioned limitations when mapping vegetation changes (Saura, 2003). Both the terrestrial and the wetland vegetation biomass can be mapped and analyzed on the basis of vegetation indices using multi-temporal images. For example, variations in the NDVI can be used to analyze such changes, which help to overcome the shortcomings of Landsat images in vegetation mapping. In addition, use of ancillary data such as aerial photographs, topographic maps, and soil data minimizes the limitations. For example, stereogram photographs taken along the same flight line and with a 50% overlap can be viewed in three dimensions using a stereoscope. This is very useful for identifying landscape features (Lillesand and Kiefer, 1994). In addition, they can be overlaid with satellite images making it easier to interpret the features in satellite images, such as shape, size, tone, shadow, patterns and texture, which help to discriminate different types of land cover and vegetation.

2.7 Land-use change

Land-use change is determined by a combination and the interaction in space and time of biophysical factors like soils, climate and topography. Other determinants include human factors like population, technology and economic conditions. Most recent land-use/land-cover changes are clearly driven by human activities rather than by natural changes. These human induced land-use changes have important consequences for the natural resources through the impacts on soil, water quality, biodiversity and global climate (Turner II *et al.*, 1995).

Among the reasons for studying land-use changes is the fact that these changes interact with biogeochemical cycles, climate, ecosystem processes, biodiversity and human activities (Turner *et al.,* 1995; Lambin *et al.*, 1999). The purpose can be description, explanation, prediction, impact assessment and evaluation of land-use changes (Briassoulis, 2000). Due to the complexity of land-use systems, descriptions and future projections should integrate three dimensions of driving factors and their dynamics: (1) socio-economics, (2) biophysical factors, and (3) land management

(Turner II *et al.,* 1995; Veldkamp and Fresco, 1997). This approach was used in this study in the analysis of land-use changes in the Yala swamp.

There are many and very different causes of wetland loss and degradation (Hollis, 1990). Some of the land-use changes in wetlands are within planned development schemes, e.g., draining for rice farming on the upper part of the Senegal River (Halls, 1997; Drijver; Van Wetten, 2000), while others are the result of uncoordinated – and often illegal – activities of the local people (Panayotou, 1994). Demographic changes coupled with poor environmental policies have in many cases aggravated the degradation of the wetland resources. For example, the breakdown of the traditional and sustainable wetland utilization in Ethiopia has been attributed to the combined effect of changes in policy and political regimes as well as demographic dynamics (Wood, 1997; Wood *et al.,* 2002). It has also been observed that the concentration of human activities along the Nile River and its tributaries has led to a significant reduction of the papyrus swamps, especially along the White and Blue Nile. Currently, only small remnants are left in the highlands of Ethiopia, (Thompson, 1976), due partly to the human activities in the Ethiopian highlands (Wood, 1997).

Wetland conversion is not a new phenomenon. It is estimated that more than half of the wetlands in the world may have disappeared since the start of the 20th century, with the greatest loss being in the developed countries (Barbier, 1993), while dramatic losses have occurred over a short space of time in developing countries (Maltby, 1988). Again, wetland loss is on the rise in the developing countries as a result of conversion to agricultural land, fishponds and urban settlements (Maltby, 1986; Farber and Constanza, 1987; Maltby, 1988; Mohamed, 2002). The most comprehensive data on wetlands loss are from the United States. However, in the tropics, precise data on area lost, loss rates and the causes for these losses are often lacking due to the absence of the necessary administrative framework (Gosselink and Maltby, 1990). In addition, wetland data and conversion rates in Africa are scanty and hard to compare (FAO, 1998), because different sources provide different figures and the different country maps are at different scales. However, Uganda recently prepared a significant documentation of the country's wetland coverage and its conversion mostly to small-scale farming. Other recent studies in East Africa also indicate expansion of small-scale farming and horticulture in wetland areas (Mugisha, 2002; Reid *et al.,* 2004). Therefore, documentation of land-cover change and its causes in the Yala swamp contributes towards the gathering of information on wetland-cover changes in the developing countries.

2.8 Land-use change drivers

Scientists have offered several explanations for the variations in land use. In the 19th century, von Thuenen (1966) considered agricultural land use a function of distance to the market centers and the transport cost. This explanation provides a foundation upon which theories and explanations of land use are built, although it overlooks several biophysical and socio-economic factors affecting land use. Later, Boserup (1965) argued that population increase represents the driving force of land-use change, and this has been supported by numerous scientists (Ruthenberg, 1976; Binswanger and McIntire, 1987; Pingali *et al.,* 1987). However, this school of thought overlooks other factors that may also drive land-use change like demand for goods, and biophysical factors like soil fertility, government policies and accessibility.

Recent studies conducted at a variety of scales have demonstrated the great variety of driving forces of land-cover changes such as tropical deforestation (Geist and Lambin, 2002). On a broader scale, these drivers can even include international agreements, such as IMF trade liberalization, that penetrate from national policies down to the farmers decisions on land use. Other broad-scale determinants of land use for instance include extreme weather events like droughts and floods (Turner *et al.,* 1989). However, on a finer scale, several factors form a complex web of interactions and feedback processes that blur the cause-effect relationships (Geist and Lambin, 2002). These include infrastructure, population, resources demand, e.g., for timber, farming land and the general economic situation.

Population growth in particular has been viewed as the primary cause of land-use change (Hardin, 1968; Stonich, 1993; Brown, 1994) and according to Rudel and Roper (1996), few other variables have been identified as possible causes. However, the role of population depends on the specific settings in a given region. These settings include population density (Pender, 1998), land availability (Jones, 1998), type of land use (Schelhas, 1996), and labor cost. Population density in particular has received great attention in the Land Use and Cover Change (LUCC) and deforestation literature (Huigen, 2004). Long-term investigations for large areas have used population density as a proxy for a whole range of other variables such as wages and distance to markets (Templeton and Scherr, 1997). At detailed scales such as household or village, population density can mostly be directly linked to the intensity of land-use change (Kok, 2004). This latter approach was used in the Yala swamp to analyze the land-use changes through spatial and statistical analysis so as to identify the driving forces of the changes.

One of the major proximate causes of land-cover changes in tropical Africa have be identified as the changes in agricultural systems (McConnel, 2001; Veldkamp and Lambin, 2001; Geist and Lambin, 2002). The expansion of agricultural production is clearly related to population demand for settlements, infrastructure development and food supply. It is deemed as one of the main dynamic causes of land-cover change in the world (Lambin *et al.,* 2001; Rasul *et al.,* 2004). However, studies on land-use changes have focused mainly on deforestation, leaving a great gap in studies on wetland conversion. Most of the studies on wetland ecosystems focus mainly on ecology, policies and utilization (Muthuri, 1985; Gichuki *et al.,* 2001; Thenya, 2001; Silvan and Laine, 2004). Thus, they only imply possible consequences, but do not determine the drivers of land-use change.

There is increasing interest in interdisciplinary studies to incorporate social and natural sciences and remote sensing. This aims at improving our understanding of the biophysical forces and the human activities that shape land-use/land-cover changes. This understanding of the causes and processes would allow an in-depth interpretation of the patterns of land-cover change derived from remotely sensed observations (Rindfuss and Stern, 1998; Rindfuss *et al.,* 2004). A combination of this approach was used in this study in the Yala swamp through integration of remotely sensed data, ecological data, census and household/socio-economic data. A synthesis of the methods for merging socio-economic/household survey data with remote sensing-based information is given by Liverman *et al.* (1998). The major challenge of this approach is the definition of the appropriate scale for the integration of the household and remote sensed biophysical data. However, most of the studies linking remote sensing data and household-socio-economic data have been performed at the scale of administrative units, which are often used for collection of household data (Green and Sussman, 1990; Pfaff, 1996; Wood and Skole, 1998).

2.9 Specific land-use change drivers in wetland

The driving forces of wetland conversion are mainly a combination of demographic factors like population increase, the need to create settlement schemes, expansion of farming activities and lack of institutional support, for example, non-implementation of management plans (Hollis, 1990). Studies on the longer term change (1959-2000) of land cover in Uganda using remote sensing data observed a 50% rise in small-scale farming near wetland areas such as Lake Mburo (Mugisha, 2002). Use of socio-economic data provided useful explanatory power to land-cover changes derived from satellite data. Expansion was related to population densities, land scarcity, soil fertility decline and lack of markets. In Kajiado, according to Githaiga *et al.* (2003), subsistence agriculture expansion into arid and semi arid areas has led to communal wetland conversion. These changes have also been linked to global changes, e.g., IMF structural adjustment programmes as well. However, even with the increase in land-use studies in East Africa, specific focus on wetlands is still scanty and efforts have concentrated more on ASALs due to increased population migration and the emerging conflicts of use between wildlife and pastoralists there.

A major driving force towards wetlands loss is the expansion of farming communities and settlement schemes in Kenya, especially in ASALs (Mohamed, 2002; Thenya, 2001). Several wetlands in the upper north drainage basin of the Ewaso Ngiro River, among them the Pesi, Mutara, and Rware wetlands in the Laikipia plateau, have been converted by the small-scale farmers into farming areas. These wetland conversions followed the sub-division of the former large-scale ranching farms located in semi-arid regions, where rainfed cultivation is not possible (Thenya, 2001). The few remaining wetlands such as the Ewaso Narok swamp and Lake Ol' Bolossat are under great pressure from the expanding farming community. In addition to habitat destruction, this deprives the pastoralist community of their dry season grazing area.

According to Mugo and Shikuku (2000) and Gichuki *et al*. (2001), the use of wetlands in the LVB for subsistence farming is relatively extensive. This is due to a combination of inadequate rainfall for rainfed cultivation, declining soil fertility and small land-holding size in a high population density area (Mango, 1999). The high population density around the Yala swamp exerts both direct and indirect pressures on the swamp. The growing population together with the demand for farming land leads to increasing wetland conversion (Johnson *et al.,* 2000; Kairu, 2001). This first occurs along the edge of the swamps and gradually encroaches inward over time. Furthermore, the absence of a management plan in the Yala swamp creates a favourable environment for wetland conversion.

Land-use changes are at times policy driven and this has also been the case in the Yala swamp. In the early 1970s, a plan was drawn by the Kenyan government to drain the swamp. As part of the reclamation plan, some 2,300 ha were drained in the first Phase (GoK, 1994; Aloo, 2003), which led to changes in the flooding pattern in the swamp, allowing a longer farming period in some sections. Two further reclamation phases were earmarked, with Phase II constituting 6,000 ha and Phase III an additional 9,200 ha (Mavuti 1989; Mavuti 1992; Ocholla, 1997). Recently, the government leased out some 10,000 ha to a private company for farming including part of the 2,300 ha drained in the early 1970s. This reduced the area available to the indigenous community for farming and grazing without providing an alternative in an ecosystem without a management plan.

3 DESCRIPTION OF THE STUDY AREA

3.1 Geographic location and biophysical characteristics

The Yala swamp is located in the Kenya part of the Lake Victoria Basin (LVB). Administratively, the swamp is found in Siaya District, in Nyanza province, south-west Kenya. Altitude in the area ranges between 1,140m and 1,500m above sea level (GoK, 1994). The landscape is characterized by undulating and rolling uplands with slopes varying between 2 and 16%. Siaya district covers an area of 252,000 ha with 209,800 ha (83%) being suitable for agriculture, while the remaining area is made up of swamps, slopes and rivers.

The total coverage of the catchments of the LVB in Kenya is approximately 8,420,000 ha, Lake Victoria itself covering an area of 6,889,000 ha of which 413,340 ha are located in Kenya. It is the second largest freshwater body in the world and the largest in the tropics, with immense economic and environmental importance to both the eastern and central African region (ICRAF, 2000). Out of the 177 fish species, which are found in the lake, 127 are cichlids (Hughes and Hughes, 1992). The littoral wetlands of Lake Victoria on the Kenyan side cover an estimated 78,000 ha, with papyrus swamps covering 21,000 ha (M'mayi *et al.,* 1997). The two largest swamps on the Kenyan side of Lake Victoria are the Yala and the Nyando swamps (Aloo, 2003). These swamps provide vital habitats for various species of birds, mammals, reptiles and fish (Mavuti, 1989; Hughes and Hughes, 1992). The macrophytes are ecologically important, since they act as a natural filter of agricultural and industrial pollutants from the catchment (Mavuti, 1989; 1992).

The Yala swamp is a deltaic wetland dominated by *Cyperus species* among them *C. papyrus, C. dives, C. exaltatus* and *C. distans* (Figure 3.1). The swamp is located between the Rivers Yala and Nzoia at 0°07' N – 0°01' S / 33° 58' – 34° 15' E. It was formed through the backflow of water from Lake Victoria and the flooding of the Rivers Nzoia and Yala. The swamp is mainly fed by the River Yala, which flows through the swamp, while the contribution from the River Nzoia is only small, the latter flooding only a small section in the north-eastern part of the swamp. The swamp extends inland for 25 km in an east-west direction and 15 km in a north-south direction along the lake shore, finally covering a total of 30,000 ha. According to Abila (2002), this is one of the few habitats in Kenya where the threatened Sitatunga antelope (*Tragelaphus spekeii*) is found.

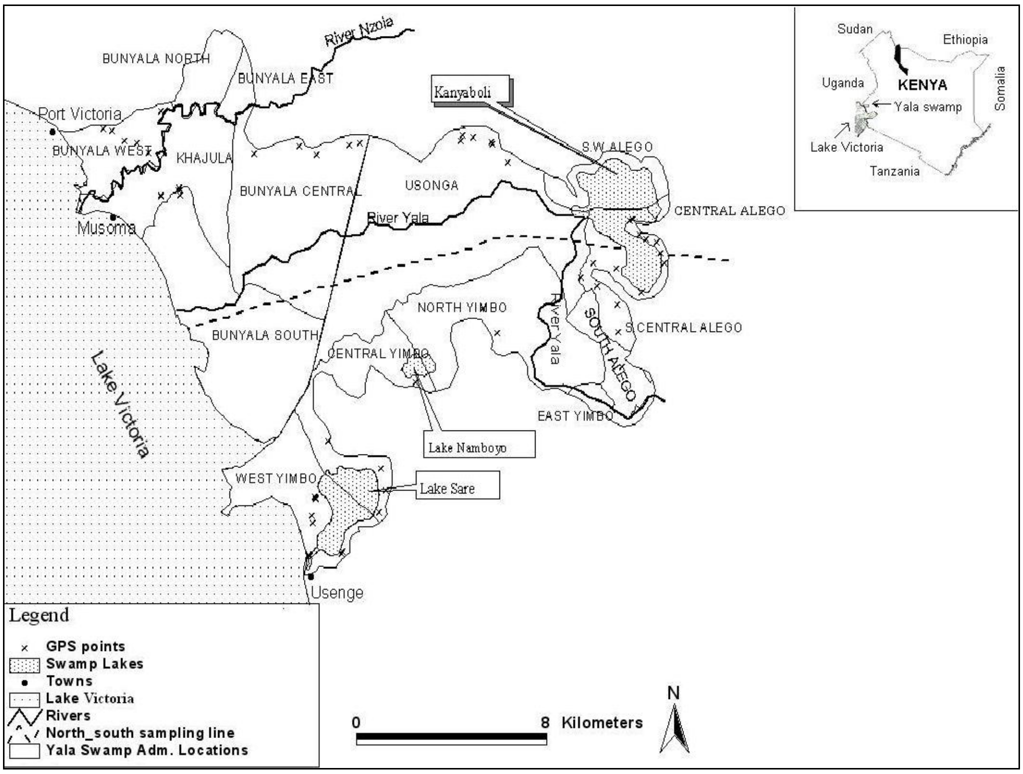

Figure 3.1: Location of the study site (Yala swamp) in Kenya (Source: Modified from SK 72/1978 map series)

The Yala swamp ecosystem encompasses three small lakes, namely the Lakes Kanyaboli, Sare and Namboyo (Figure 3.1). These lakes contain some of the critically endangered haplochromine fish species, some of which are no longer found in Lake Victoria and which are in acute danger of extinction (Kaufman and Ochumba, 1993). Lake Kanyaboli is located on the eastern side at an altitude of 1,156 m ASL covering a total area of 1,500 ha, with a maximum depth of 3 m. The lake is characterized by high electrical conductivity (Ec), chloride and total hardness due to evaporative concentration. In addition, the lake receives reduced water flow from the River Yala as the constructed canal, which was meant to feed the lake, has been blocked by vegetation and siltation. Like the other two lakes, the common macrophytes are *Potamogeton pectinatus, Ceretophyllum demersum, Typha, Cyprus dives, Cyperus distans, Pistia stratiotes* and *Lemma* sp.

Lake Sare, which was formally a gulf but was blocked during the reclamation in Phase I, is now connected to the Yala swamp through a raised culvert. It is the second largest lake in the swamp, covering an area of 500 ha with a maximum depth of 5 m. The physico-chemical characteristic of this lake is influenced by the flow of the

River Yala (Aloo, 2003). Before reaching Lake Sare, the water passes through the filtering systems of the swamp and therefore contains very low amounts of salts, nutrients and suspended matter (Mavuti, 1989; Aloo, 2003). It has a relatively lower Ec compared to Lake Kanyaboli due to the filtering effect of the macrophytes. Lake Namboyo is located on the southern side of the swamp between Lake Kanyaboli and Lake Sare and has a total area of 1ha. Like Lake Sare, Lake Namboyo is influenced by the Yala swamp ecology, since it is surrounded by macrophytes (Aloo, 2003).

The LVB on Kenyan side is divided into two catchment areas, the northern and southern sub-basin (Figure 3.2). The southern sub-basin is drained by the River Nyando from the North of Mount Tinderet forest (0° 06’ S/ 35° 21’ E) and Sondu from the dip South-western slope of the Mau Escarpment, while the Rivers Gucha and Migori drain from Mount Kijaur (0° 45’ S / 34° 58’ E) at 2,166 m ASL and Moita (1° 05’ S / 34° 44’ E at 2,037m ASL), respectively. The northern sub-basin on the other hand is drained by the Rivers Sio, Ewaso Rongai, Koitobos and Kuywa from Mount Elgon (Figure 3.2). Other rivers draining this sub-basin include the River Nzoia from Cherangany hills and Rivers Yala and the Nyando rising from the Tinderet forest (Hughes and Hughes, 1992).

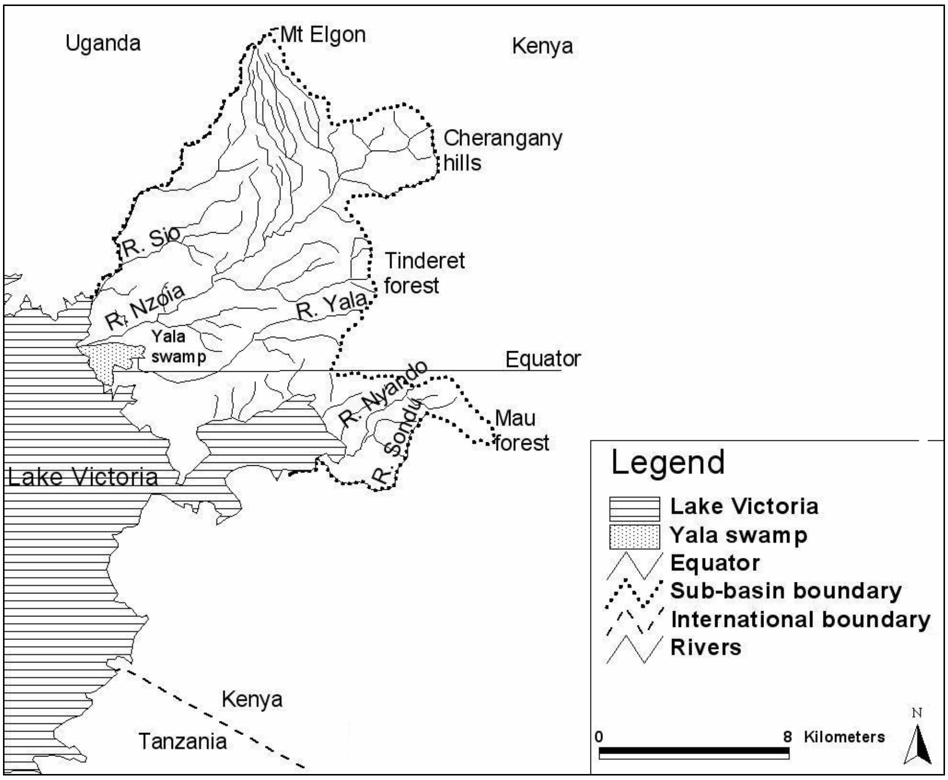

Figure 3.2: Lake Victoria north sub-basin including the drainage to the Yala swamp (Source: Modified from Crafter et al., 1992)

It is from this north sub-basin that the Yala swamp gets it water that is mainly from the River Yala and a minor contribution from the River Nzoia. Due to the flat terrain in the landscape approaching the lake, several of these rivers form extensive swamps on the Lake Victoria shoreline. These wetlands are made up of mixed grass and papyrus with scattered stands of arborescent swamp forest (Mavuti, 1992). Vegetation cover dynamics in these wetlands responds significantly to changes in the water regime between the wet and dry periods. In the case of the Yala swamp, flooding is triggered by high rainfall in the upper catchment areas leading to high discharge in the Rivers Yala and Nzoia.

3.2 Climatic and hydrological characteristics dynamics

The LVB experiences a modified bimodal equatorial type of climate due to the combination of strong relief and the Lake Victoria effect. In terms of annual distribution, the long rains occur in the month of March-May while the short rains falls in Oct-Dec (Figure 3.3). Precipitation is influenced by altitude and wind direction, with the area towards the lake shore becoming drier. The northern highlands, which form the catchments of Rivers Sio, Yala and Nzoia, receive between 1,800-and 2,000 mm per annum (convectional and relief rainfall) (Hughes and Hughes, 1992), while the lowland is characterized by low precipitation levels of between 800 and 1,600 mm per annum (conventional rainfall). The average rainfall around the lowland Yala swamp is approximately 760 mm, which is inadequate for rainfed farming.

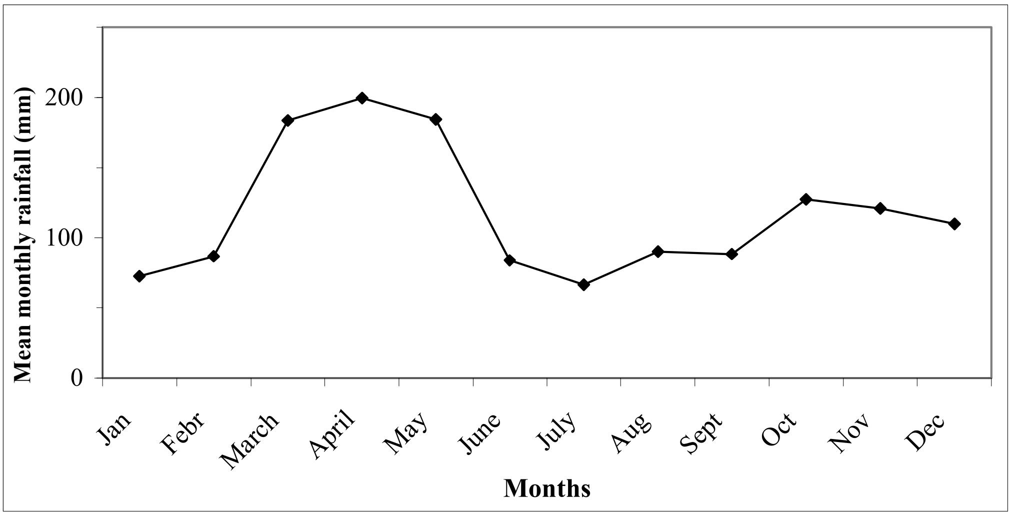

Figure 3.3: Annual rainfall trends in the Lake Victoria basin, Kenya (Source: Lake Victoria Environment Management Programme)

The variability of the hydrological aspects in the northern sub-basin indicates that the rivers discharge have increased between 1950 and 2000 (Sangale *et al*., 2001). The average discharge in the period 1990-2000 (Nzoia-142.2 m^3/s, Yala-28.6 m^3/s) is higher than for the period 1950-60, (Nzoia-108.8 m^3/s, Yala-20.7 m^3/s). This has been attributed to the increase in over land transport due to the soil cover destruction in the catchments. Comparatively, JICA (1991) had projected an increase within the range of 118.65 m^3/s (Nzoia) and 16.28 m^3/S (Yala), which correlate well with findings by Sangale *et al*. (2001). These changes are attributed to the destruction of the indigenous forests in the catchments and subsequent low level annual cropping or fallow as well as overgrazing. Other land-cover changes in the catchment include the replacement of indigenous forest species with pine plantations. In addition, adverse effects of cattle grazing in the forests have also contributed to great reduction in infiltration capacity in both the hardwood and the softwood forests. The overall effect of these changes has been increased stream flows with a subsequent approximate 18% reduction in interception and evapo-transpiration losses (JICA, 1980).

3.3 Demographic and socio-economic aspects

The LVB supports an estimated 21 million people, who rely primarily on subsistence agriculture and pastoralism (ICRAF, 2000). The basin supports one of the densest rural populations in the world with estimated 1,200 persons per km^2 (Hoekstra and Corbett, 1995). The area around the Yala swamp has an average population density of 240 per/km^2 (Table 3.1). The population in the LVB including the area around the Yala swamp is characterized by high out migration (GoK, 1994) to urban centers in search of jobs. This is attributed to the fact that the households are generally poor, with livelihoods mainly derived from subsistence farming and indigenous livestock. Other sources of livelihood include fishing, occasional wage labor and macrophyte harvesting (Gichuki *et al.,* 2001; Abila, 2002).

Table 3.1: Population per location around Yala swamp (Source: Central Bureau of statistics, 1999 census data)

Administrative Location	Location area Km^2	Total population	Population density per Km^2	Household numbers
Bunyala Central	39.18	6,249	159	1,660
Bunyala East	15.01	347	23	842
Bunyala North	12.25	5,473	449	1,250
Bunyala South	36.65	4,977	137	1,256
Bunyala West	13.63	12,662	1,129	3,020
Central Alego	6.52	3,968	214	1,019
Khajula	18.38	5,829	323	1,468
South Central Alego	33.24	11,321	174	2,954
South West Alego	26.24	6,618	252	1,667
South Alego	14.23	2,374	126	582
Usonga	71.49	7,474	104	1,991
Central Yimbo	52.23	7,071	137	1,648
East Yimbo	27.07	3,807	120	931
North Yimbo	55.03	7,177	124	1,700
West Yimbo	29.95	17,693	555	4,459
Total	**411.93**	**103,040**		**26,447**

In addition, due to the declining soil fertility around the swamp coupled with high population and small land holding sizes, reliability on the wetland is relatively high. The Yala swamp is an important ecosystem in terms of livelihood support, mainly macrophyte harvesting, fishing and farming. Farming in the swamp takes place seasonally in form of semi-permanent cultivation, which is determined by a combination of soil fertility and flooding pattern. These utilizations lead to spatial changes in the wetland cover.

3.4 Agricultural potential variability in Siaya district

Soil fertility in the Siaya District ranges from moderate to low with levels of nitrogen and phosphorous being particularly low (GoK, 1994). Most of the soils in the district are underlain by plinthite (Murram) at a shallow depth, resulting in low moisture retention. This results in low crop yields, poverty and malnutrition with soil fertility decline being regarded as a major problem.

The farming system in Siaya has evolved from shifting cultivation via fallow-based farming to permanent agriculture, mainly due to increasing population pressure and market integration (Mango, 1999). Farming areas are under considerable pressure from an increasing population, while crop yields and economic returns from farming are declining. As a result, there is insufficient food production, increasing rural poverty, malnutrition and incomes are low. Low food production in the district is also attributed to the spread of *striga,* a parasitic weed in maize. Other constraints include rainfall unreliability, drought, shortage of land and labor, soil erosion, pests and diseases. The result of the reduced agricultural potential in the district is a high dependence on the swamp resources, conversion for farming to supply domestic food and macrophytes harvesting to raise incomes.

The principal causes of soil nutrient losses in the Siaya District include crop harvests, leaching, runoff and soil erosion (GoK, 1994; Mango, 1999). In addition, continuous subdivision of land has left many farmers with areas inadequate to meet their subsistence needs. The average cropland holding is in the range of 1 ha in the high rainfall zone, 1.25 ha in the medium-rainfall zone and 1.7 ha in the low-rainfall zone (Mango, 1999). In this regard, the Yala swamp offers alternative source of supplementing income and food supply. At the same time, pervasive poverty hinders sustainable use of the land resources, leading to considerable land degradation, sedimentation and nutrient runoff, which also contribute to spatial changes in the wetland area.

3.5 Historical changes in the Yala Swamp ecosystem

Until the mid 1960s, the Yala swamp used to cover 17,500 ha as natural swamp. However, between 1965 and 1970, 2,300 ha were reclaimed for farming by the government of Kenya (Aloo, 2003). In the process, a 9-km canal diverting the Yala River from Lake Kanyaboli was created, reducing the buffering effect of the swamp to the lake. A feeder canal to Lake Kanyaboli, which is now blocked with vegetation, has resulted in reduced water flow to the lake (M'mayi *et al.,* 1997). Currently, the only feeder into the lake is from the River Rapudo, a small stream flowing from the east as well as through some broken dykes (Abila, 2002). The River Nzoia is also canalized to some extent.

The Lake Basin Development Authority (LBDA) had earmarked two other phases for reclamation, with Phase II constituting 6,000 ha and Phase III an additional 9,200 ha (Mavuti 1989; Mavuti 1992; Ocholla, 1997). However, this did not materialize due to resources and management constrain. Nevertheless, in 2002, some 10,000 ha, including a large section of Phase 1 LBDA 2,300 ha drained swamp area was leased out for rice farming to a private company. This study covered the whole of the Yala swamp including the section drained by the Lake Basin Development Authority (LBDA).

4 MATERIALS AND METHODS

4.1 Introduction

Both primary and secondary sources of wetland related information were consulted. The primary data collection involved field measurements of vegetation height, above-ground biomass weight and laboratory analysis of plant nitrogen and phosphorous. The geographical positions of the various macrophyte species were marked with Geographical Position System (GPS). Soil and water samples were collected for analysis of ecological variability. Laboratory work was carried out at the World Agroforestry Centre – ICRAF soil laboratory. Oral interviews using questionnaires were used to collect bio-economic data of the swamp at the household level. The swamp was stratified for collecting various types of data.

Sources of secondary data included, among others, the extensive socio-economic data gathered by the ICRAF in association with the Ministry of Agriculture and Rural Development like participatory rural appraisal (PRA's) report. Other sources included the ICRAF field and annual reports. Yala swamp administrative Location shape files were obtained from the ICRAF geographical information system (GIS) database. The 1999 population census and household data were obtained from the Kenya Central Bureau of Statistics (CBS). Further secondary data were extracted from topographical maps and satellite images. Various wetland-related literature and research records were reviewed. Remote sensing and GIS techniques were used to analyze the spatial and temporal dynamics in the wetlands. The study commenced in May 2003 and the data were collected up to the end of April 2004.

4.2 Sampling strategy

To facilitate effective analysis of the homogenous and the heterogeneous ecological zones, stratified random sampling was used to avoid the clustering effect of simple random sampling (Smart and Grainger, 1974). The delineated wetland area was stratified into three strata based on vegetation physiognomy and height, vegetation communities and the water level status. Other factors included human activities and the existing physical environmental factors like rivers in and around the wetland. The three strata were used for the collection of the vegetation, water and soil data. Area Sampling Units (ASUs) were selected randomly along these transects, depending on accessibility, ecological factors and time. Where the physical conditions restricted perpendicular transects into the swamp, transects were established along the delineated wetland edge. In addition, GPS readings were taken at all vegetation, soil and water sampling sites, which facilitated the overlying of vegetation communities spatial distribution with satellite images in the land-cover analysis (Figure 3.1 & 4.1). A total of 56 plots were sampled, 14 plots in highly disturbed eco-type, 28 in medium disturbed eco-type and 14 in the low disturbed eco-type. The layouts of the vegetation sampling site are presented in (Figure 4.1) and their characteristics are discussed below;

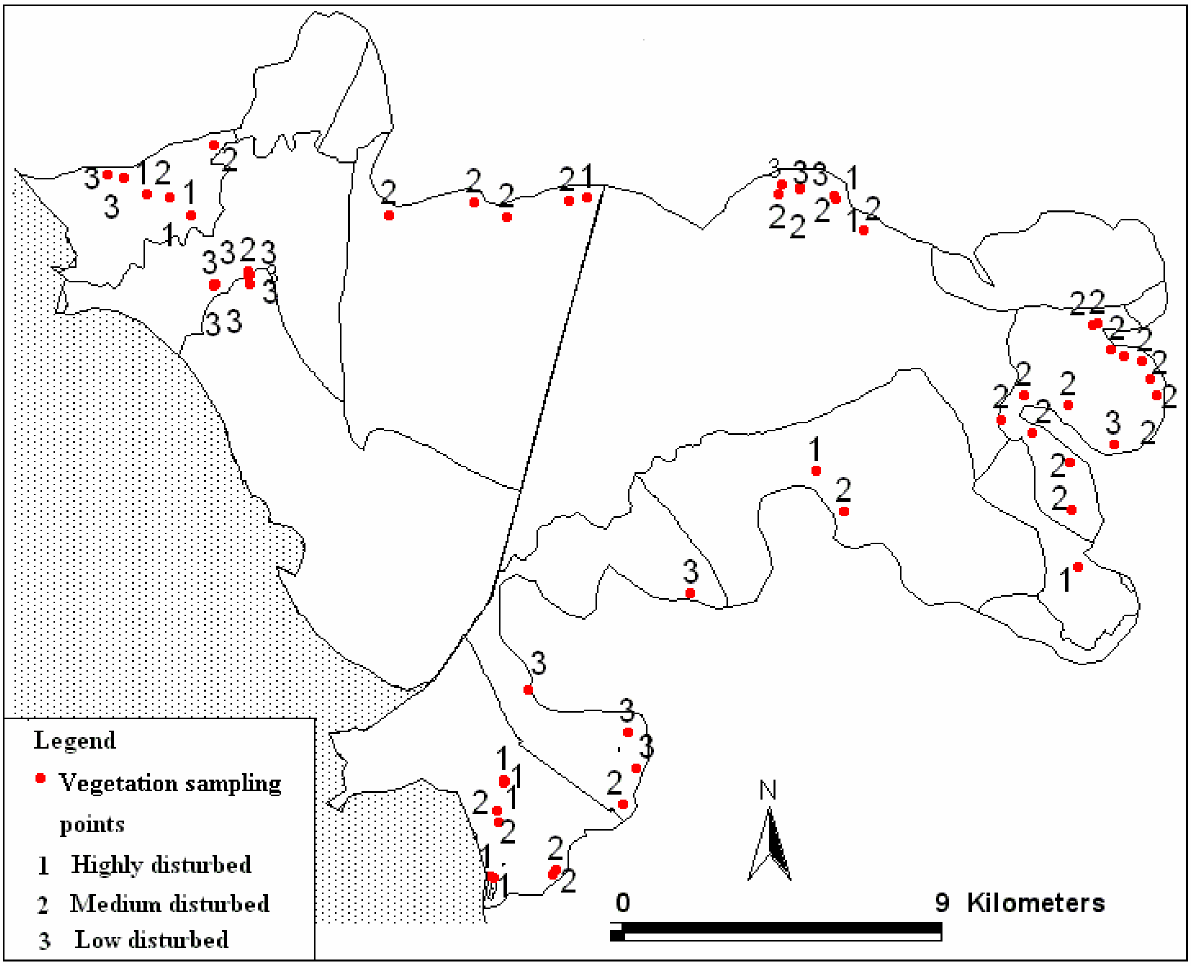

Figure 4.1: Vegetation sampling plots

4.2.1 Stratum 1: Highly disturbed eco-type (HD)

This eco-type was characterized by low flooding due to the sloping landscape, and hence farming activities were relatively high compared to the other eco-types. It was also, characterized by frequent fires during the preparation of land for farming. The crops cultivated here included arrow roots, sugar cane, cabbages and beans. The presence of *Typha domingensis* Forst. and *Phragmites mauritianus* Kunth, which are common in poorly drained land, agricultural land and draining ditches, was a good indicator of this wetland eco-type. Although *Phragmites* species are common in natural ecosystems, they are frequent invaders of disturbed ecosystems.

4.2.2 Stratum 2: Medium disturbed / Transitional eco-type (MD)

This eco-type also indicated relatively low flooding due to the nature of the landscape and it had high incidences of grazing. In contrast, fire frequencies were not as high as in the case of the highly disturbed eco-type due to the reduced farming activities. This eco-type had a mixture of natural wetland vegetation species like *C. papyrus*, but was also highly dominated by transitional eco-type species like *C. distans, C. dives* and *C. exaltatus.* Also present was the disturbed wetland species like *T. domingensis*. However, most of the farming in this eco-type took place in the adjacent farms and only a few farmers had plots in the wetland, mostly along the edge as compared to the highly disturbed eco-type (stratum 1) environment.

4.2.3 Stratum 3: Low disturbed eco-type (LD)

This eco-type indicated extensive flooding leading to reduced human activities. The presence of high concentrations of *C. papyrus* stands was a good indicator of the natural state of this eco-type. Farming was low and restricted to the dry period, with grazing and fire incidences being very limited.

In socio-economic data collection, the swamp was divided into two major sections based on topography, accessibility and the socio-economic status (Figure 3.1). The first section encompassed the southern section, which covered the area between the Yala Bridge to the eastern edge of the swamp next to the former LBDA farm and Lake Sare near Usenge beach to the western side. The northern section covered the area, stretching from the former LBDA farm to Musoma beach including the area along River Nzoia on the northern side. A separate survey was conducted in these two sections, targeting market centers close to the swamp, which traded in macrophytes products. This stratification reflected the similarity in socio-economic structure and ethnicity as depicted in the results. Abila (2002) used a similar stratification in the Yala swamp based on the socio-economic status and restricted the survey to within 5km. This approach was adopted for this study.

4.2.4 Wetland utilization survey

The Yala swamp was perceived as providing numerous benefits to the local community both for subsistence as well as income. In this regard, efforts were directed at collecting information on the wetland products as well as on direct uses like farming. This information was captured using both structured questionnaires at household level (Appendix 1) and in the nearby markets (Appendix 2) as well as from field observation as outlined below. Abila (2002) used a similar approach in the Yala swamp.

Socio-economic data were collected at the household level in all administrative Locations surrounding the swamp using a structured questionnaire (Appendix 1), which was administered through personal interviews. This approach has been used by several researchers to collect socio-economic data (Muiruri, 1977; ICRAF, 2000; Thenya, 2001). A total of 350 questionnaires was randomly distributed within the two sampling sections and restricted to 5 km from the border of the swamp. Data collected focused generally on products from the wetland, farming area, seasonal variations and preferred future development. Local enumerators, familiar with the local dialects, were trained and used as interviewers to avoid possible misunderstandings or loss of information that often occur in interpreter-mediated surveys. These enumerators were hired to work within their locality, which they were familiar with, to maximize on interview time.

Specific surveys were conducted in the nearby markets on the northern and southern side of the swamp to establish the outlets of the wetland products (Appendix 2). The market surveys were planned to coincide with the different market days for the individual towns both on the northern and southern side of the swamp. Centers where marketing data were collected within close proximity of the Yala swamp were: Usenge on the southern side near Lake Victoria, Siaya town, Boro, Daranja to the west, Ratuoro, Ombwende and Marenga. Others towns included Ngiya, Port Victoria, Musoma and Nyandorera to the north. This distinction was necessary so as to capture the variety of goods arriving at the market especially those allied to the wetland. Questionnaires were randomly distributed in the market depending on the presence of wetland goods. This was based on prior field information that traders specialize with particular goods like fish, macrophytes or baskets on specific days.

4.2.5 Sampling of vegetation height and biomass

Vegetation sampling involved field measurements of growth height and above-ground biomass. The data were collected from 56 sampling plots that were randomly selected from the three strata and marked with GPS. Different species were selected for the estimation of post-harvest macrophyte growth and biomass dynamics depending on availability and accessibility per stratum. The macrophyte species selected for monitoring were those that are regularly used by the local communities (Gichuki *et al*., 2001; Katondo, 2001; Kiwazi *et al*., 2001; Abila, 2002). Vegetation data were collected from plots measuring I m x 1 m, which were marked with corner posts and sisal twine. This methodology has been used by several researchers both in the tropics (Kipkemboi *et al*., 2002; Kansiime *et al*., 2003) and in the temperate regions (Keeland *et al*., 1999; U.S. EPA, 2002; Silvan and Laine, 2004) for assessing macrophyte productivity dynamics.

In May 2003 prior to commencing with vegetation measurements, the plots were completely harvested and the macrophyte left to regenerate for the first generation biomass data. Thereafter, height measurements were taken in weekly intervals. This involved taking three height measurements from different macrophyte stems of the same species and then averaging them to get the mean height gained. The same stems in each plot were measured throughout the 14 weeks monitoring period. To achieve consistency in the height measurements, the selected stems were marked with polythene paper. The monitoring duration (14 weeks) was based on the period when the incremental gain became minimal. Other factors included senescence signs, like when the leaves started turning brown as well as the duration used by other researchers (Keeland and Conner, 1999; Kipkemboi *et al*., 2002; Kansiime *et al*., 2003).

From the 1m^2 vegetation plot set up, a sub-sample of the plot, measuring 50 cm^2, was used to collect species specific above-ground biomass data. The vegetation biomass clipped from each subplot was placed in separate plastic bags, marked with species name plus GPS position and fresh weight taken. The samples were brought back to the laboratory weighed and oven dried at 70°C to a constant weight. The dried vegetation clippings were then used for analysis of nitrogen and phosphorous content. This was done on the second and third post-harvest plant material. The initial plant samples were not used since the growth period was not known and the last sampling plants were too few due to the effect of the dry season (January-March). Some plots had also been burnt in March 2004 during land preparation prior to the 4th sampling.

To get the second-generation post-harvest height and the biomass data, the macrophytes were harvested again in the 14th week and left to regenerate. This procedure was repeated for the 3rd and 4th harvesting sessions. This method has been found to be reliable (Broome *et al*., 1986; U.S. EPA, 2002; Kansiime *et al*., 2003) in assessing macrophyte productivity. To get the maximum possible height, some macrophyte from the first post-harvest generation were left standing in each plot. Comparative height measurements were taken from these plants after the second post-harvest period.

4.2.6 Water sampling

Water samples were collected from as near to the vegetation plots as possible using plastic bottles. Where the vegetation cover did not allow direct sampling with the bottle, a beaker was used to collect the water, which was then transferred into the sampling bottle. The sampling bottles were soaked overnight with 10% hydrochloric acid. During sampling, the bottles were rinsed three times with swamp water at each sampling plot prior to taking the water sample. In order to halt microbial activity in the water, 5ml of 5% concentration formaldehyde was added to the water samples; the bottles were sealed and stored in a cool-box, taken to the laboratory and stored at 4°C before analysis. This procedure is frequently used in wetland studies (Gichuki *et al.*, 2001; Thenya, 2001; Githaiga *et al.,* 2003).

4.2.7 Soil sampling

Soil samples were collected in the vegetation plots over the same period, between 0-20cm depths. This collection depth is often used for analysis of soil fertility (Mbuvi and Kironchi, 1994). They were collected from different points inside the plots using a soil auger, then mixed to make a composite sample and placed in a plastic bag. The samples were labeled with the respective plot number, GPS position and transported to the laboratory for analysis. Prior to the laboratory analysis, the samples were air-dried and crushed using a rolling pin. Then they were shaken to pass through a 2mm sieve for determination of pH, cations and phosphorous (ICRAF, 1995). Samples for the determination of total nitrogen, were ground to pass through a 50-mesh sieve (0.3 mm).

Soil samples for determination of soil bulk density were collected during the dry season at field condition in undisturbed state using a standard metallic sampling disc. The sampling procedure involved weighing the empty disc prior to the samples collection, followed by taking weight of the fresh samples plus the disc. In the laboratory the samples were oven dried to a constant weight at 105°C and the bulky density computed from the dry weight.

4.3 Laboratory analysis

4.3.1 Analysis of plant nutrient content

The above-ground macrophyte biomass that had been obtained from the vegetation plots and oven-dried at 70°C, were ground to pass through a 1 mm sieve. The samples were then subjected to Kjeldahl digestion with concentrated sulphuric acid (Anderson and Ingram, 1993; ICRAF, 1995). Thereafter, nitrogen and phosphorus were determined calorimetrically (Parkinson and Allen, 1975).

4.3.2 Water pH

Water pH was determined in the laboratory on unfiltered samples according to Landon (1984). The pH meter was calibrated with a pH buffer of 4 and 7 to unit compliment of ± 0.02 pH unit of the theoretical values prior to taking the readings.

4.3.3 Water electrical conductivity

Electrical conductivity (Ec) of the water samples was measured in the laboratory after calibrating the meter by immersing the electrode directly in the water and taking the readings when the meter stabilized.

4.3.4 Water-soluble carbon

Water-soluble carbon was determined using the wet oxidation method of acidified dichromate, the Walkley-Black method as outlined by Olsen and Sommers (1982).

4.3.5 Water total nitrogen and phosphorous

The total water nitrogen was determined colormetrically using the wet oxidation Kjeldahl method. The procedure involved oxidizing both organic and ammonium-N to nitrate, which was determined by the nitration of salicylic acid (Robarge *et al.,* 1983). This process involved mixing 10 ml of the water sample with 5 ml of the persulphate oxidizing reagent, followed by autoclaving at 121°C and 15 psi for 60 minutes. Then 0.5 ml of the digested extract was mixed with 1.0 ml of 5% salicylic acid and mixed in a vortex mixer, followed by the addition of 10 ml of 16% NaOH and mixed again in the vortex mixer. The mixture was allowed to cool and readings taken at 410 nm absorbance/concentration with spectrophotometer. Those samples with concentrations above the standards were diluted and the procedure repeated.

Total phosphorous was determined using the Mehlich method (double acid method) as outlined by Olsen and Sommers (1982). This process involved mixing 10 ml of the water sample with 5 ml of the persulphate oxidizing reagent, followed by autoclaving at 121°C and 15 psi for 60 minutes. Thereafter, 3 ml of the digested extract was mixed with 4 ml of ascorbic acid plus 3 ml of molybdate reagent and mixed thoroughly. The mixture was allowed to stand for one hour for the color development to take place. Total phosphorous readings were taken at 880 nm absorbance/concentration with the spectrophotometer. Samples with concentration above the standards were diluted and the procedure repeated again.

4.3.6 Soil pH

Soil pH was determined using a soil extract made to a ratio of 1:2.5 (water-soil) according to Landon (1984). The pH meter was calibrated with pH buffer of 4 and 7 to unit compliment of ± 0.02 pH unit of the theoretical values prior to taking the readings.

4.3.7 Soil cation exchange capacity (CEC)

Soil cation exchange capacity (CEC) was determined by first leaching the samples with 1N sodium acetate at pH 7.0. Then the total cations were determined using an atomic absorption spectrometer (Thomas, 1982).

4.3.8 Soil exchangeable potassium and extractable phosphorous

The procedure involved the modified Olsen method, which was convenient, since both inorganic phosphorous and exchangeable potassium could be determined from the same extract. Extractable phosphorous was obtained by mixing 2.5 ml of soil with 25 ml of extracting solution (0.5 M $NaHCO_3$ + 0.01 M EDTA, pH 8.5) and stirred for 10 minutes (Hesse, 1971). The mixture was gravity filtered with Whatman No. 5 filter paper. Then, extractable phosphorous was colorimetrically determined by mixing 2 ml of the filtered extract with 8 ml of deionized water and 10 ml of the working phosphorous color reagent. Prior to adding the phosphorous coloring reagent aliquot for potassium determination was taken since the coloring reagent contains potassium, which could contaminate the extract. Potassium readings were taken using flame photometer. The mixture was allowed to stand for one hour for color development to take place and phosphorous readings taken at 880 nm absorbance/concentration using the spectrophotometer.

4.3.9 Soil total nitrogen and phosphorous

Total soil nitrogen was determined using the wet oxidation -Kjeldahl method (Bremner and Mulvaney, 1982). The procedure involved digesting 0.4 g of soil with a digestion mixture of sulphuric acid Selenium as catalyst instead of the traditional mercury and salicylic acid. Salicylic acid was added to allow recovery of nitrate-N. In order to achieve the required digestion temperature 1.8 g of potassium sulphate (K_2SO_4) was added. The mixture was allowed to stand overnight and then heated in a blockbuster for one hour at 100°C. Then the mixture was allowed to cool and 3 ml of hydrogen peroxide was added as oxidizing reagent. The samples were placed back in the blockbuster again and the temperature raised to 250°C for one hour and then to 360°C. After the samples were allowed to cool, 70 ml of deionized water was added to make a final total volume of 75 ml. Then the concentration of total soil nitrogen was determined colorimetrically using the spectrophotometer at 655 nm absorbance. Total phosphorous readings were taken at 880 nm absorbance.

4.4 Land-cover data collection and analysis

4.4.1 Sampling of vegetation distribution

To collect information on the vegetation species distribution around the swamp, perpendicular line transects were made towards the swamp at 57 sampling points and marked with GPS. These points were selected randomly around the swamp, paying attention to broad vegetation formations. This approach has been used in sampling vegetation (Gaudet, 1977a; Tandiga, 1990; Thenya, 2001). Transects varied in length depending on the accessibility at each point and ranged between 10-50m. Unfortunately, due to heavy flooding or thick macrophyte cover, it was not possible to make deep transects into the swamp, a limitation observed often in wetlands (Odland and Moral, 2002). Plant species layouts were marked along these transects from the edge of the swamp towards the inner section. At the end of accessibility of each line transects the vegetation layout to the inner part of the swamp was recorded where possible. Macrophyte diversity decreases towards the inner part of the swamp, making this approach convenient.

Due to the frequent changes in the ecological status of the swamp due to flooding variability, plant species were continuously updated from each point for the entire sampling period. In addition, plant samples that could not be identified directly in the field were referred to the University of Nairobi Herbarium for identification. To enable correct future reference of the vegetation species at each of the sampling points along the three strata, specimen were collected and preserved, marked with GPS and surrounding information recorded. The samples were preserved for the entire sampling period. Pratt and Gwynne (1978) plant community physiognomic classifications system was adopted where vegetation communities are named according to the most dominate vegetation species. This classification scheme has been applied previously in the tropics in Ewaso Narok swamp in Laikipia District (Thenya, 1998). Vegetation species sampled from the swamp were grouped into communities, depending on ecological occurrence or ecosystem disturbance and the plant species association. Detailed methodology for the procedures applied in the vegetation survey can be found in Cain and Castrol (1959), Gaudet (1977a) and Tandiga (1990).

4.4.2 Satellite imageries

A combination of Landsat MSS and ETM satellite images were used to assess land-cover dynamics in the Yala swamp between 1973 and 2001. The two Landsat images were acquired over the same period in February, MSS image was acquired on 5th February 1973 and the ETM image on 2nd February 2001. The MSS bands 1, 2, 3 that corresponds to the green, red and near infrared of the image reflectance spectra, were selected to characterize changes in the swamp. While the ETM bands 2, 3 and 4 were chosen based on their proven suitability for wetlands studies (Harvey and Hills 2001; Seto *et al.,* 2002). The process of generating land-cover dynamics in the Yala swamp involved visual interpretation of the images based on feature tone (color), pattern, shape and texture. In addition, computer-aided hybrid classification analysis and normalized difference vegetation index (NDVI) were used. As a supplementary source of information, aerial photographs were used for the interpretation of features in the images especially in the 1973 MSS images, since they were taken around the same time. In addition, flight surveys were carried out in February 2003 to generate information on the inaccessible areas and photographs taken to help in ground truthing. Existing topographic maps and vegetation maps were also used to support the ground truthing process. The processed images were imported into ArcGIS for presentation and final adjustment.

4.4.3 Selection of satellite images and aerial photographs

Two considerations were made in the selection of the two images (1973, February 5th and 2001, February 2nd). The first was the availability of the same season images from the Global Land Cover Facility (GLCF, U. S. Geological Survey, 1973 and 2001) to allow temporal comparison. The second consideration was clouds free images. The problem of availability of cloud-free images in the tropical region is very common and has been recorded by several scientists (Jha and Unni, 1982; Ducros-Gambart and Gastellu-Etchegorry, 1984; Pilon *et al*., 1988; Alwashe and Bokhari, 1993).

The two satellite images were downloaded from MSS path 183; row 060 and from ETM path 170 row 060, which was within the study area. They were already orthorectified to the Universal Transverse Mercator (UTM 36M) projection with the WGS84 datum spheroid. Since both images were taken during the dry season, spectral changes due to phenological differences of vegetation were expected to be lower than changes due to land-cover transformation. The two images were then used in conjunction with the aerial photographs from the early and late 1970s. The first series taken, in 1970, 1971 and 1973, were obtained from the Survey of Kenya (SOK) (Figure 4.2), while the second from 1978 was obtained from Photomap-Kenya. The use of the aerial photographs as ancillary data was necessary to supplement inaccessibility in the swamp. Since the stereo aerial photographs were at a larger scale than the images, it was possible to view features that were masked by scale effect in the two images. This information was useful in refining the classification of the two images.

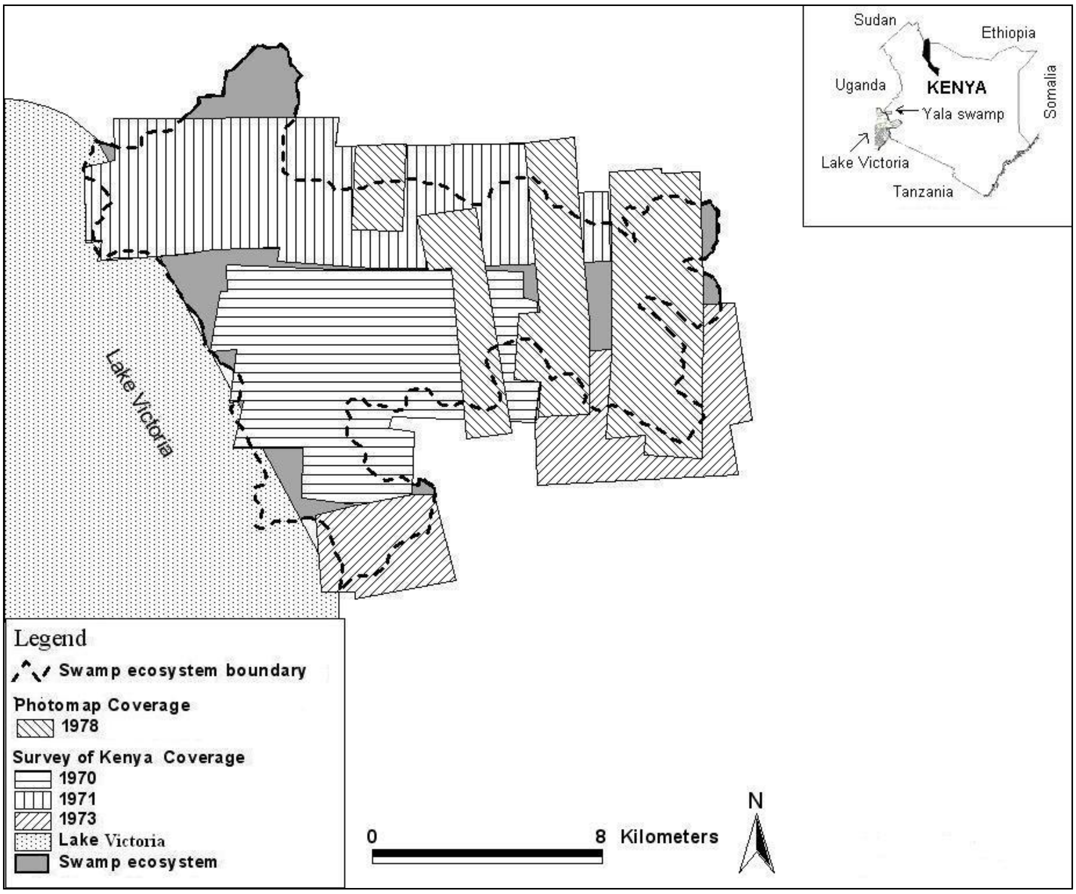

Figure 4.1: Coverage of the aerial photographs in the Yala swamp, Kenya

4.4.4 Ground data

To facilitate overlying the vegetation species distribution collected in the field with the land-cover classes derived from the two images, 57 ground sampling points were collected along the edges of the swamp using GPS (Figure 3.1). These ground points covered different types of vegetation associations as well as agricultural land, and were, also used as training sites in the supervised classification. These GPS points were later loaded onto the two images to assist in overlying the spatial distribution of vegetation species with the land-cover classes derived from the two images.

4.5 Satellite images processing

4.5.1 Sub-setting of the study area

Since the two Landsat images covered a larger area (185 x 170) km, than the study area (300 km^2), it was necessary to subset them to reduce the storage space and the image processing time. The sub-setting process involved two stages. The first Area of Interest (AOI_a) covering the Yala swamp and the surrounding area was initially digitized in

ERDAS 8.6 and selected using the enquire box. Then the resulting cover was subset again after radiometric corrections this time focusing specifically on the Yala swamp ecosystem coverage (AOI_b). The boundary selection was guided by GPS points (Figure 3.1), topographical maps and based on the researcher's field knowledge. This latter subset (AOI_b) was used for the change detection analysis.

4.5.2 Images corrections

There are two major sources of errors that are inherent in satellite images, these are geometric and radiometric sources (Mas, 1999). Change detection procedure requires that images be corrected for these errors so that the changes being detected can be separated from those that may appear as a result of geometric and radiometric errors. Radiometric correction encompassed relative radiometric correction, both haze reduction based on the Tasseled Cap Transformation algorithm and noise reduction, on the 1973 image while the 2001 image was only corrected for noise reduction since it has inbuilt capability of haze reduction. Since the two images were already geometrically corrected they were only registered to each and checked for features overly in Erdas.

4.5.3 Image re-sampling

To enable comparison of the two images which had different spatial resolution, it was necessary to aggregate them to the same scale. While the 1973 MSS image had a spatial resolution of 57 m x 57 m, the 2001 ETM had a spatial resolution of 28.7 m x 28.5 m. Thus, the year 2001 with a pixel size of 28.5 m was degraded to the 1973 pixel scale of 57 m in ERDAS 8.6 using the nearest neighbor re-sampling technique (Lillesand and Kiefer, 1994). This involved degrading the year 2001 by a scale factor of 2 in the X and Y direction using the majority rule to give a pixel size of 57 m equivalent to the 1973 pixel size. The underlying assumption is that through applying the majority rule, where the degraded image pixels are assigned the most frequent class, this produces adequately similar patterns to images obtained at coarser resolutions (Turner *et al.,* 1989; Benson and Mackenzie 1995; Wu *et al.,* 2002; Saura, 2003). The degraded 2001 image was then used for change detection together with the 1973 image including the computation of the NDVI.

4.5.4 Land-cover classification

A hybrid classification procedure was employed in the image analysis. This method is more able to analyze and visualize the class definitions than either type of classification can provide independently (Kloer, 1994). Initially, unsupervised classification was carried out using the ISODATA method. Anticipating 7 classes, a classification scheme of 15 classes was adopted, which was refined to 7 classes based on the data collected from the field using GPS.

The refining of the land-cover classes was facilitated through a signature file, which was created as an output of the unsupervised classification. Using the training samples collected in the field using the hand held GPS, (Germini-type) some signatures were added to the signature file while others were merged. However, for the data collection inside the swamp this was not possible due to the thick macrophytes and the unstable wet ground. This meant that only limited field data could be collected along the swamp edges and most information had to be inferred from the remote sensed data.

The updated signatures were then used to run the classification again, this time as a supervised classification using the maximum likelihood algorithm. The grouping of the spectral classes was based on the land-cover types. However, prior to running the supervised classification, the two signature files were associated with the respective image. Thereafter, using the two classified images, the GPS points with vegetation information were then loaded, to assist in assigning the correct vegetation and land-cover types. Since the various vegetation species had already been grouped into five broad vegetation communities, they was easily applied on the image.

4.5.5 Evaluating signatures

Transformed Divergence (TD) algorithm was used to test the separability of the refined signatures through probabilities. This procedure employs a measure of the distances between the signatures (Van der Kwast, 2002). The larger the separability values, the better the final classification results. Those divergences that are greater than 1900 are considered as having good separability, with those between 1700 and 1900, separation is reasonable, while those below 1700 are considered as poor.

4.6 Post classification

4.6.1 Normalized difference vegetation index (NDVI)

The NDVI was computed according to the formula by Rouse *et al*., (1974) where,

$$NDVI = (NIR - red)/ (NIR + red).$$

The resulting NDVI values are fractional real numbers ranging between –1.0, indicating no vegetation, to +1.0 for maximum vegetation presence. The computation of the NDVI for the two images, was in two stages. The first stage involved the computation of the individual image NDVI values followed by the analysis of the magnitude of change between the 1973 and 2001 images. To compute this magnitude of change, the 1973 image was subtracted as 'before' image (layer 3, MSS +NIR band) from the year 2001 (layer 4, ETM+NIR band) as 'after' image using 'float single' for the data type. Those pixels with increases were set to highlight as green, while those with decrease were set to highlight as red. The threshold for the change was set at 50%.

4.6.2 Accuracy assessment

Classification accuracy was determined by creating an error (confusion) matrix. The GPS points collected in the field were loaded as UTM points into the 2001 image in Erdas 8.6, less the points used as training sites in the classification. However, due to the limited accessibility in the swamp, random points were generated to cover the whole swamp area. Land-cover identification and allocation in the accuracy assessment was also assisted by ancillary information from both the aerial photographs and the topographical map.

4.6.3 Land-use change matrix

The two classified images (1973 and 2001) were converted into vector layers in Erdas 8.6 and imported into Arcview 3.2 as themes. Then the attribute tables of the two themes were checked for land-cover classes grid code consistence and adjusted where necessary to match. This was followed by intersecting the two themes, with the 1973 as the input theme and the year 2001 as the overlay theme using the geoprocessing wizard facility in Arcview 3.2. The Arcview output file was exported as delimited text and opened in Excel to generate a land-use change matrix table.

4.6.4 Aerial photographs

The two sets (early 1970s and the 1978) of black and white aerial photographs stereo pairs, were scanned with an A4 flatbed scanner and overlaid with the 1973 MSS image (Figure 4.2). It was not possible to obtain a set covering the whole swamp and also for the same season; however, the photographs were still useful as ancillary data in the satellite images analysis.

The photographs were scanned to 600 dot per inch (dpi) geometric scan resolution value, approximately 42 µm pixel size and saved as tiff images so as to preserve most of their features (Greve, 1996; Linder, 2003). During the scanning, the photographs were placed on the scanner so that the scanner movement charge coupled device (CCD) beneath the glass plate was in the direction of the flight (Linder, 2003).

The 1973 MSS image was used to georeference and create a mosaic as there were only few cultural features like roads in the area covered by the swamp, and this therefore limited the use of the topographic map of the area. Such features were only restricted to the areas outside the swamp or along the edges. Consequently, this limited the use of the area topographic map. Wetland physical features like the vegetation edges and water bodies provided ideal reference points for mosaicing the aerial photographs. This was done using Arcgis 8.3 and the results exported to Arcview3.2 for presentation and further processing.

4.7 Land-use change analysis

The computation of wetland demographic and land-use changes indices involved combining population census, household and spatial data. These indices were later subjected to statistical analysis. Serneels and Lambin (2001) used a similar approach in land-use studies in Narok District. The procedure used in the computation of these indices is outlined below;

4.7.1 Computation of demographic indices

Statistical analysis between the swamp administrative coverage and the census data were performed at the scale of the local administrative units (Locations). Since the data collected at the households level could be linked to the respective administrative Location level, it was also necessary to aggregate all other data to this scale to make the analysis possible. The accessible swamp area (Access_area) of each Location was computed as the swamp spatial coverage per Location less the open water. The basic assumption was that water bodies were, considered inaccessible for farming purposes but the rest of the land could be cultivated depending on demand. The resulting accessible swamp area was used to compute proportionate demographic aspects as per the respective swamp Location area. This computation was based on the assumption that population and households are distributed equally across the respective Location unit with proportionate use of the swamp. The respective Location swamp population (New_pop_No.) and household numbers (New_hsehold_No) were calculated by multiplying the total Location population and the household numbers with the percentage of the Location area in the swamp (Access_area). The swamp population (New_pop_density) and household (New_hsehold_density) densities were calculated by dividing the respective swamp population (New_pop_No) and household (New_hsehold_No) numbers computed earlier by the Location swamp area (Access_area). These indices represent the proportionate sources of the population and the household pressure on swamp utilization, which were assumed to be directly and indirectly exerting conversion pressure.

4.7.2 Computation of land-use changes indices

The household data collected in the field using questionnaires like the wetland farm holding unit was combined with the census data and the spatial data to compute household pressure on the wetland. This involved computation of several indices as follows. Using the population and the household indices computed above, the respective administrative Locations wetland land-use data was computed. This approach was used since there were no data available on the swampland distribution per household. Using conversion factor (Conver_Fct) index, which was the average of the wetland land unit held by each household per Location that was obtained during the field survey, the household land demand (Hsehold_demad) index was computed. This was then the index for land requirement at the household level based on the current wetland utilization and the 1999 census data. The household land demand (Hsehold_demad) index was calculated by multiplying the conversion factor (Conver_Fct) index with the new household number (New_hsehold_No) computed earlier. This was followed by the computation of the household share (Hsehold_share) index per Location, as an average of the land allocation per household based on the computed accessible swamp area and the 1999 census data. The index (Hsehold_share) was calculated by dividing the accessible area (Access_area) with the household demand (Hsehold_demad) for the swampland. This index gave an indication of the population pressure (of dividing out) on the wetland, based on the 1999 population number and the available land.

Thereafter, the percentage in the use (Perc_in_use) index was computed as the portion of the mean swampland holding (Conver_Fct) by the households that was under cultivation, since households only cultivated a portion of their swampland holding. The index (Perc_in_use) was computed from the field household data as an indicator of the utilization level. To get the area under use (Area_underuse) per the respective Locations, the percentage land under cultivation (Perc_in_use) was multiplied by the household land demand (Hsehold_demad). This gave an indication of the swampland that was under cultivation against what was available per administrative Location. The computed area under use per Location (Area_underuse) was then divided by the accessible area (Access_area) to give the intensity of wetland utilization (Use_intsy). This index gives the magnitude of the pressure exerted on the wetland as a function of utilization, where this pressure increases with the rise in the swamp area under use.

To compute the anthropogenic land-use change indices, the total accessible area in the swamp and the household per Location were first converted into percentages. These factors were used since they were seen as being important in determining land-use change in the Yala swamp. The second step was to take the average of the two percentages per Location to get one indicative figure of the conversion.

4.7.3 Co-Validation

This involved two levels. In the first level, co-validation was performed at the ecosystem level, where the statistically computed household conversion figures for the whole swamp were compared to the conversions derived from the 2001 satellite image. The second level was performed at the individual Location level, where the statistically computed household conversion figures were compared to the conversions derived from the 2001 satellite image.

4.8 Statistical analysis

4.8.1 Ecological parameters

Different statistical approaches were used to analyze post-harvest vegetation growth and the ecological parameters data. To compare the vegetation growth among the different species and between the different eco-types, the means of the respective species were computed and plotted graphically to display change in height. In addition, the comparative rate of growth among the different species was computed as the percentage rate of change in growth on weekly basis from the means computed earlier. Kansiime *et al*. (2003) used a similar approach in Uganda. The overall mean height and growth rate for each post-harvest period was calculated. Also computed was the means for the first four weeks and after based on the growth data.

Analysis of variance (ANOVA) was used to test whether the ecological parameters means between the different eco-types and the seasons were significantly different from each other to enable deduction of their effect on macrophytes growth. This was done using Genstat Edition 1. The means that indicated significant differences were subjected to post hoc analysis using the Least Significance Difference (LSD) test (Steel and Torrie, 1986) to find out which ones were significantly different at $\alpha = 0.05$.

4.8.2 Wetland utilization

The socio-economic data were analyzed using SPSS version 12 contrasting the northern and southern side of the swamp, due to the varying ecological and socio-economic status. Abila (2002) used a similar approach in socio-economic analysis of the Yala swamp. The data were analyzed using a combination of descriptive, correlation and chi-square statistics. These statistics have been used before to analyze socio-economic data from wetlands ecosystems (Muiruri, 1977; Terer *et al* 2004). The variations between the two sides are quite significant. The southern side is relatively hilly, which limits the extent of flooding to the valley bottom and the communities on this side were mainly Luo ethnic tribe. In contrast, the swamp slopes gently towards the northern side, which experiences extensive flooding that displaces a large number of the households in the wet season. In addition, the communities on this side have a combination of both the Luo and the Luhyas ethnic tribes; the latter are Bantus, who are more inclined towards farming.

4.8.3 Land-use change

To determine the interactive significant effect of the explanatory factors on the wetland land-use change drivers, both the demographic and land-use data variables were subjected to the Pearson correlation analysis. This was followed by stepwise regression to explore, the influence exerted by each of the variables. The stepwise regression function was used, since it is able to discard insignificant variables so that they do not influence the prediction model. Use of regression analysis to explore trajectories of land-use change in tropical regions has been applied before by Serneels and Lambin, (2001).

5 ANALYSIS OF MACROPHYTE PRODUCTS UTILIZATION, FARMING ACTIVITIES AND LIVELIHOOD DYNAMICS

5.1 Introduction

The area around the Yala swamp has low rainfall, approximately 760 mm per annum, which is unreliable and inadequate for rainfed agriculture. In addition, the area is characterized by high population density in a scenario of declining soil fertility (Mango, 1998) and small land holding sizes outside the swamp that range between from 1-4 ha. This results in high demand for farming land in the swamp where land holdings average about 2 ha per household. Most of the local communities activities in the wetlands are synchronized to the pattern of flooding. These activities include farming, macrophyte harvesting, fishing, grazing and business. However, income levels remain exceedingly low in this area due to a combination of poor marketing, lack of skills and poor infrastructure.

Wetlands in developing countries, especially in the arid and semi-arid regions are important for the livelihoods of rural communities, mainly at the subsistence level. In the Yala swamp, living standards are low and more than 70% of the houses are semi-permanent, 50% having thatched roofs made of different macrophyte species. Literacy level was also low with many years spent in the primary schools. Since rainfall is unreliable and inadequate for rainfed agriculture in these areas, wetlands provide a valuable alternative farming area throughout the year. The swamp also plays an import role as dry season grazing area and it is also used to raise modest income especially from macrophytes products. Further to these two uses, wetlands also provide means of income from the various wetland products such as macrophyte and fish.

5.2 Household characteristics

The composition and the structure of the households around the Yala swamp vary widely but had the similar trends on both sides of the swamp. Of the surveyed households 50% were male headed with a single wife while polygamous marriages constituted 26% (Figure 5.1). The female-headed households varied between 5% and 15%. However, families were small on both sides of the swamp, averaging about 9 persons, the majority of whom were young children of less than 12 years. In contrast, there were variations with regard to ethnicity. The Luo ethnic group dominated in the southern side of the swamp while on the northern side the number of Luos equaled that of the Luhyias, making up a total of 95%. However, the Luhyias were more concentrated towards the western side of the swamp. The remaining population was made up of Kalenjin and Kikuyu immigrants. The area around the Yala swamp is the ancestral home of the Luo and Luhyias, hence high composition of the two tribes would be expected.

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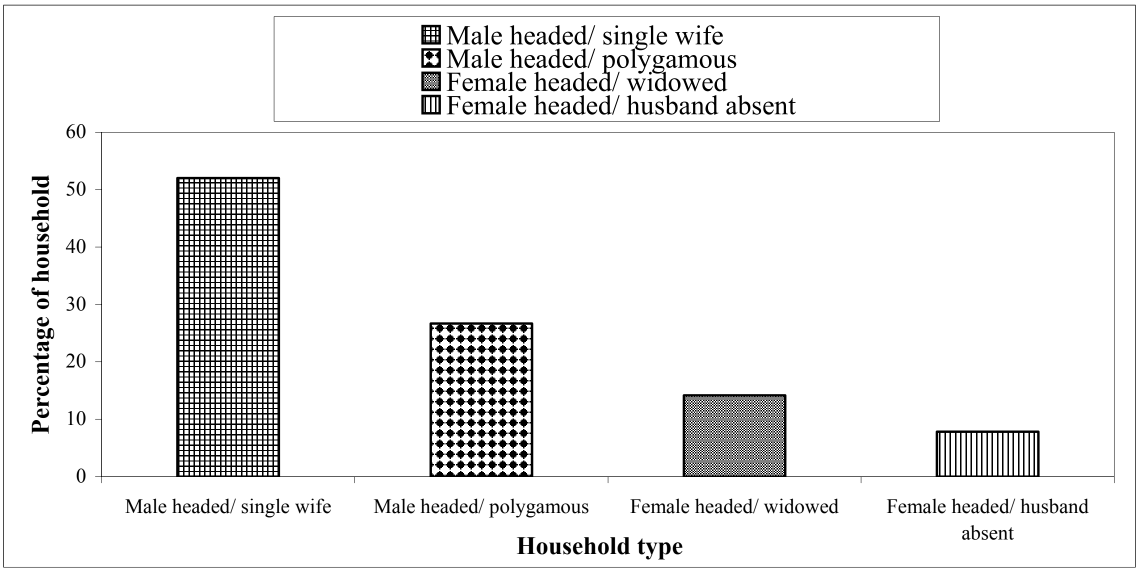

Figure 5.1: Characteristic of household in the study area

Education levels on both sides of the swamp were almost the same, with a high dominance of primary school levels. In terms of the highest education attained, 52% of the husbands interviewed had primary level education in the south, 17% secondary level, 22% tertiary and 9% no education (Figure 5.2). In contrast, 64% of the wives had primary level education, 8% secondary, 5% tertiary and 21% none. The situation was slightly different in the north, where 58% of the men had primary level, 17% secondary, 9% tertiary and 16% no education. Women had a slightly lower education level in the north with 55% having primary level, 7% secondary, 2% tertiary and as many as 36% no education. There was wide variation in the average number of years of schooling for the husbands, which ranged between 0 and 18 years. The average years of schooling in the south was 8.54 ± 0.419 and 7.76± 0.286 in the north, with the majority (39%) having been to school for 7 and 13 years in school. Similarly, the same wide variation trends were observed with the wives, who had been to school 0 and 19 years. The average number of years of schooling was 5.77 ± 0.336 in the south and 6.36 ± 0.264 in the north, with the majority (44%) having 7 and 13 years of schooling. This means that the men have on average higher education than women which might be linked to the high proportion of male headed household. Note however, that the high number of years (average 19) spent in school, indicate some discontinuity in learning. This can be attributed to inadequate finances, with the low economic situation prevailing in the area, although this aspect was directly not investigated.

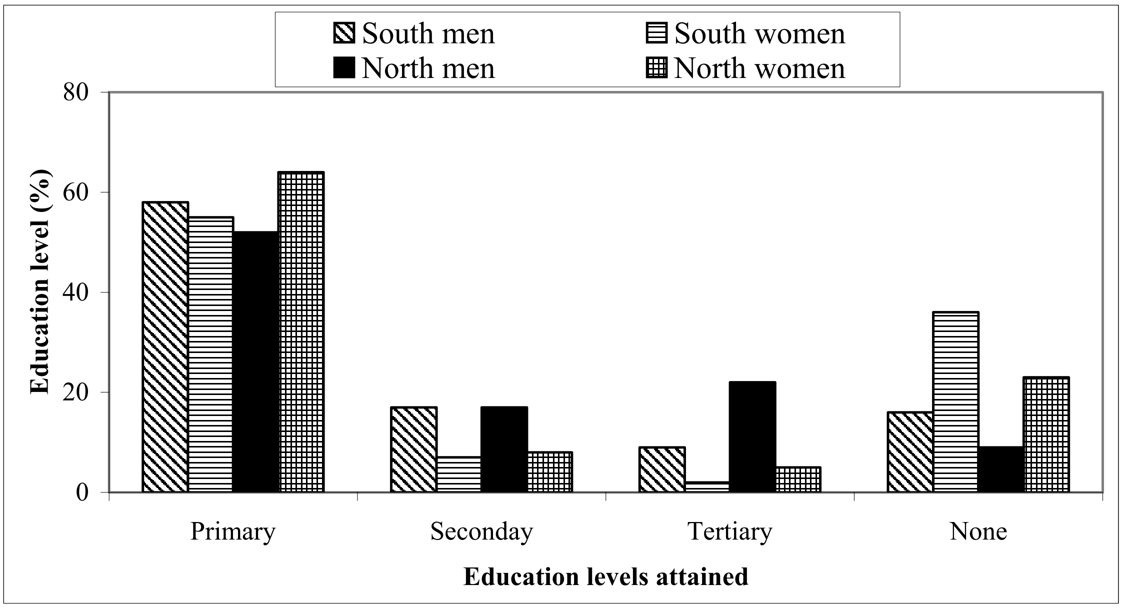

Figure 5.2: Education level in the study area

The process of settlement in the area around the swamp dates back to the 1920s, spread over the years up to present times. In the south, 19% of the households settled there before 1950, 13% in the 1960s, with a high settlement rate (34%) in the 1990's and after, (Figure 5.3). Approximately half (46%) of the households settled in the south between 1960 and the 1990s. However, in the north, settlement was slightly different, with 28% settling before 1950, and only 18% in the decades before 1990. Field data indicate that the northern side had an earlier settlement relative to the southern sides, which might be attributed to good farming soils. About half (45%) of the population settled in the period between 1960 and 1990. The households that have settled, around the swamp had migrated from the nearby districts of Bondo, Siaya and Busia with some from west Uganda, which is within the LVB.

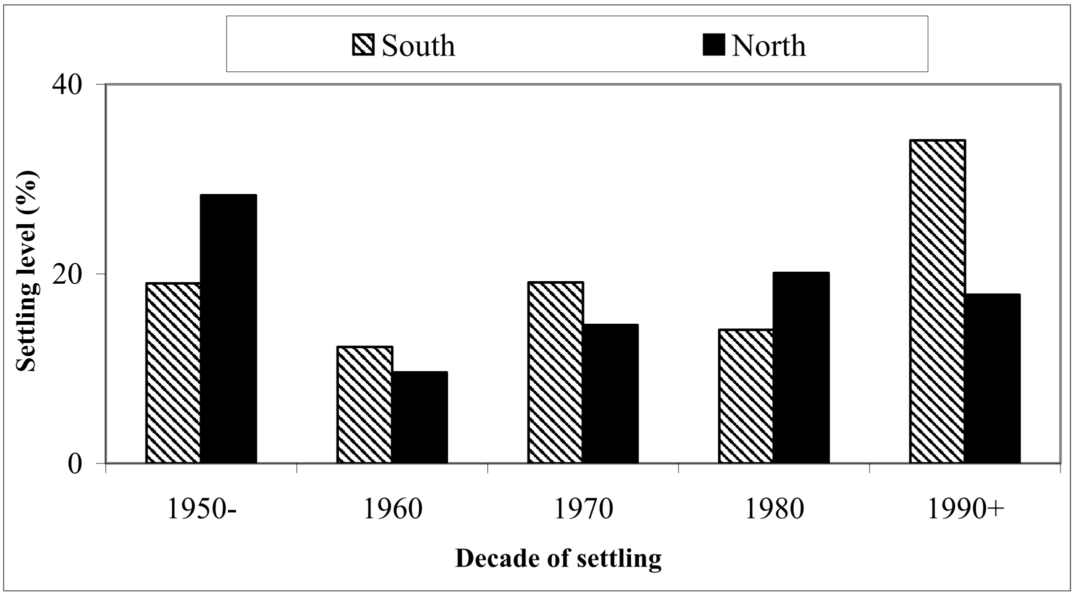

Figure 5.3: Settlement pattern in the study area

The majority (<95%) of the households was largely sedentary on both sides of the swamp, living on their land throughout the year even during the flooding period. However, in the northern section, flood displacement was common especially in the northwest along the River Nzoia floodplain during the wet season. This was attributed to the fact that the swamp slopes gently towards the northern, resulting in significantly higher flooding levels compared to the hilly southern side, where the swamp is confined to the valley bottom. This topographical scenario affected the location of the homesteads relative to the swamp. While in the south, the average distance to the swamp was ca. 645 m ± 71.65, it was much shorter in the north with at ca. 304.34 m ± 24.62. This close location of the homesteads in the north was attributed to the gentle landscape, while in the south most homesteads were located on raised grounds away from the swamp.

5.3 Household land tenure around the swamp

The inherited family land holdings with or without title deeds dominated the system of land tenure. Access to land in the area is mainly through membership of a kin group through inheritance. Due to the high population and small land parcels, the proportion of land that exchanges hands through selling is relatively low. Most of the land sale transactions are mainly between the local people and not outsiders. For example, in the south, the inherited land constituted a high 70%, purchased land coming second with 23% with only 5% of the land being rented. Other forms of land holdings, which included communal land, made up only 2% (Figure 5.4). In the north, a similar trend was also observed, where 82% of the land was held as family land, a low 11% as purchased land and an even smaller 1% as rented land. In addition, there was a slightly higher percentage (6%) of communal land. The average land holding size outside the swamp was relatively small ranging between 1 and 4 ha, mean 4.33 ± 0.375 in the south and 3.05 ± 0.162 in the north.

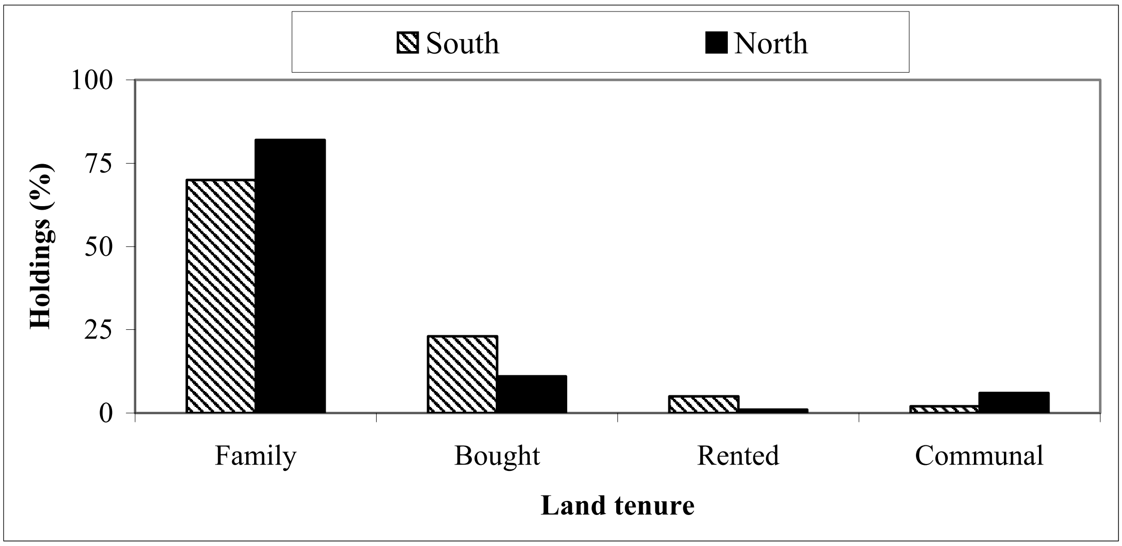

Figure 5.4: Nature of household land tenure in the study area

5.4 Wetland utilization

The Yala swamp provides numerous products to the local indigenous communities. These include material for thatching and craft items from the macrophytes, brick-making soil, sand and domestic fuel. Others products included water for the animals and domestic use, vegetables, fish, and forage. Note, however, that wetland utilization is mainly for subsistence needs with minimal commercialization. This is geared mainly towards supplying food, shelter and subsistence income. Although these products were widely spread in their availability and utilization, there were some differences between the southern and the northern side of the swamp.

5.4.1 Macrophytes utilization

Although the Yala swamp has several species of macrophytes, the local communities have a strong preferential use of some species (Figure 5.5). The most commonly used species include *C. papyrus* L., *P. mauritianus* Kunth, *C. dives* syn. *Immensus* Del, *C. distans* L.f., *E. haploclada* (Stapf) Stapf, *T. domingensis* Forst, *Phoenix reclinata* (Schum.& Thonn. syn; *Phoenix spinosa Phoenix leonensis)* and *S. sesban* L. *Phoenix reclinata* was only found on the northern side towards the western section of the swamp. The preferential use of these species was based on their availability in terms of biomass. Other considerations were sourcing distances, ecological occurrence, intended final use and whether it could be purchased from the harvesters. Although no fees were levied for the use of the swamp, not all the households were able to harvest macrophytes. The greatest limitations were found in the households with old persons and young families. For example, the use of *Phragmites* in spite of its durability especially for thatching house was limited as it mainly occurred deep in the wetland and along the fridges of water bodies. On average, the sourcing distance varied between 50 and 500 m with a slight increase in the dry season to approximately 800 m, depending on the species and the side of the swamp.

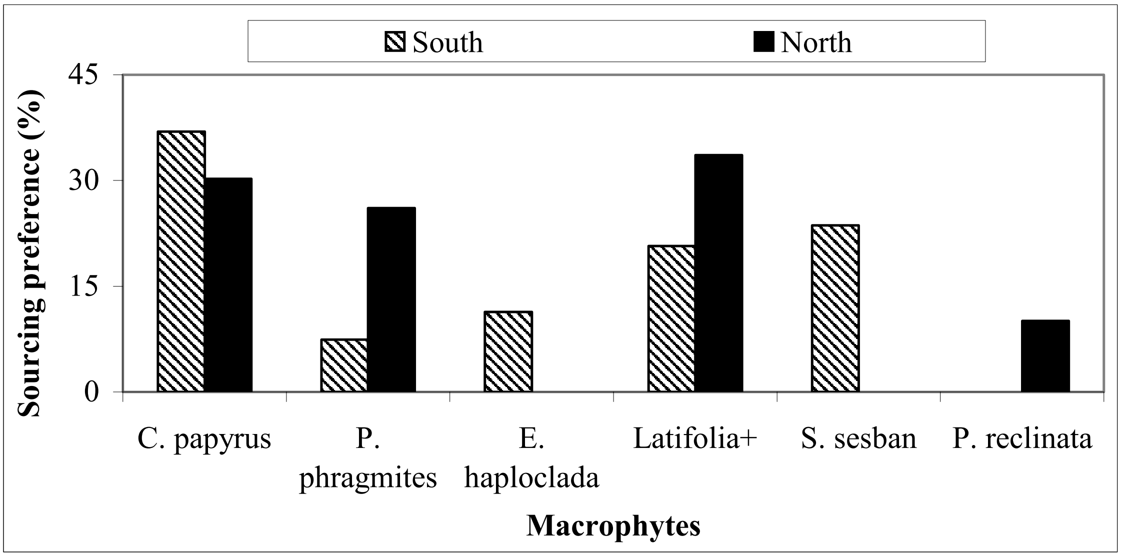

Figure 5.5: Preferential sourcing of the macrophytes in the Yala swamp

A large proportion of the harvested macrophyte were used at the domestic level on both sides of the swamp, mainly for making crafts, thatching and domestic fuel (Table 5.1). The macrophytes that were mainly used for domestic fuel included *C. papyrus, S. sesban* and *P. mauritianus*. However, due to the light density of the above-ground biomass of *Cyperus* species because of the presence of "aerynchyma", the rhizomes provided a much better source of fuel. All the dominant macrophytes provided some form of biomass fuel with *Cyperus* species providing the largest proportion. However, thatching and housing in general took the bulk of the macrophyte utilization. Some of the mats made from *C. papyrus* were used in building as ceiling material, window covers and doors.

Table 5.1: Various forms of macrophytes utilization

	Allocation of macrophytes-type of use %				Where used %			
Species	**Firewood**	**Ropes and Mats**	**Thatching Material**	**Not indicated**	**home**	**Sold**	**Both**	**Not indicated**
S. sesban	76	22	0	2	64	1	14	21
Latifolia +	21	12	17	50	64		22	24
C. papyrus	29	5	40	26	53	4	31	22
P. mauritianus	3	55	23	19	34		12	54
E. haploclada	0	33	21	46	53		29	18

Latifolia+ includes C. dives, C. distans and *C. exaltatus*

5.4.2 Construction material

Macrophyte provides an important source of thatch material for the local indigenous communities, where most of the houses were semi-permanent on both sides of the swamp. In the south 42% were thatched, 57% having iron sheet roof and only 1% were roofed with tiles. The walls were mainly made of earth (72%) and only 30% had a combination of cement, bricks and stones. The northern side only differed slightly with 55% of the houses having thatched roofs, 44% iron sheets and only 1%, of the houses surveyed had tiled roof. Slightly more (79%) of the houses had earth walls, 19% a combination of cement, bricks and stones while 2% were made of timber (Figure 5.6). The small numbers of houses constructed with bricks in the north in spite of brick making activities in the north was attributed to purchasing costs, since not all households were engaged in brick-making activities, as it was a labor-intensive procedure.

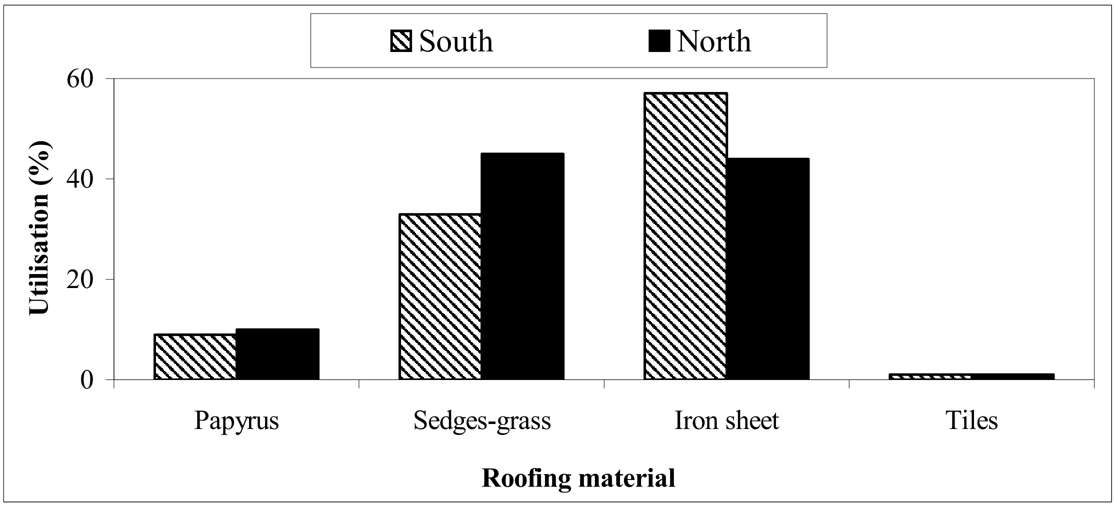

Figure 5.6: Types of roofing material in the study area

Various combinations of macrophyte species were used for thatching, which included *Cyperus papyrus* sedges like latifolia *(Cyperus distans* and *exaltatus)*, hippo grass (*Phragmites* spp.) and *Haploclada* spp. This was in contrast to the much-published use of papyrus alone as dominant thatching material relative to the other macrophytes such as latifolia (*Cyperus distans* and *exaltatus*). Both in the south and north *C. papyrus* constituted only 10% of the thatch material, while 33% in the south and 45% in the north consisted of other macrophyte species. It was common to see houses completely thatched with sedges like *C. distans* and *C. exaltatus*. However, although *P. mauritianus* offers much more durable roofing material than the other macrophytes, its utilization was limited by the availability of adequate biomass. In addition, it was also expensive to buy from the harvesters relative to the other macrophytes. Availability was complicated further by the fact that the species occurred mainly along water bodies and water canals, which made it more difficult to harvest than the widely distributed *Cyperus* species.

Most houses were thatched with a combination of macrophytes in different layers beginning with Phragmites at the bottom followed by papyrus, latifolia and haploclada. The procedure of roofing a grass or sedge-roofed house was usually as follows: Bundles of senescent *C. papyrus* culms were tied together and laid all round the roof to form a waterproof base. Where Phragmites was available it was used, since this species forms a much tougher foundation than papyrus. On top of this foundation layer, leafy material of either *C. distans* or *C. exaltatus* were laid followed by bundles of grasses such as *E. haploclada* as a top dressing to produce a heavy and compact roof.

All bundles were laid in sequence from the lower side of the roof towards the apex making it completely waterproof. A house constructed this way lasts for approximately 10 years before any repair needs to be done and is also cool during the hot months. However, only those families that were able to provide labor for the macrophyte harvesting and transportation or those able to buy the material managed to construct such houses. Often, cheap and short-lived houses were thatched with latifolia species like *C. distans* and *C. exaltatus* in combination with grasses like *E. haploclada*.

The analysis of the roofing material on both sides of the swamp indicates a strong relationship between the type of roofing and the education level of both the husband ($x^2_{(20)}$ 50.12 > 37.57, p = 0.000, α = 0.01) and the wife ($x^2_{(20)}$ 118.84 > 37.57, p = α = 0.01; Table 5.2). The results imply that the prevalence of low education level in the area (Figure 5.2) has a link to the presence of a high percentage of semi-permanent houses. Low education also mean very few alternatives sources of income hence the households are unlikely to devote their small income acquired to shelter provision in consideration of other needs like education and clothing.

Table 5.2: Wetland utilization and socio-economic status

Status and wetland use	**Calcula-ted Value x^2**	**d. f.**	**Sign. (2-tailed)**	**α 0.05**	**α 0.01**	**Sign**	**Determinant**
Roofing material	50.12	20	0.000	31.41	37.57	Y*	Husband education level
Roofing material	118.84	20	0.000	31.41	37.57	Y*	Wife education level
Roofing material	8.27	12	0.763	21.03		N	Nature of land tenure
Roofing material	28.37	24	0.245	36.41		N	Household type
Income long rains	53.77	35	0.022	49.8	57.34	Y	Husband education level
Income long rains	78.45	35	0.000	49.8	57.34	Y*	Wife education level
Income long rains	70.60	21	0.000	32.67	38.93	Y*	Nature of land tenure
Income long rains	102.62	42	0.000	55.76	63.69	Y*	Household type
Income dry seasons	44.75	40	0.279	55.76	63.69	N	Husband education level
Income dry seasons	95.77	45	0.000	61.65	69.95	Y*	Wife education level
Income dry seasons	48.09	27	0.008	40.11	46.96	Y*	Nature of land tenure
Income dry seasons	97.79	50	0.000	67.5	76.42	Y*	Household type
Wetland income Vs other sources	25.49	10	0.004	18.3	23.2	Y*	Husband education level
Wetland income Vs other sources	7.73	8	0.460	15.51		N	Wife education level

Table 5.2: Continued

Status and wetland use	Calculated Value x^2	d. f.	Sign. (2-tailed)	α 0.05	α 0.01	Sign	Determinant
Wetland income Vs other sources	10.41	6	0.108	12.59		N	Nature of land tenure
Wetland income Vs other sources	15.15	12	0.233	21.02		N	Household type
Ownership of wetland	4.84	5	0.436	11.07		N	Husband education level
Ownership of wetland	10.01	5	0.075	11.07		N	Wife education level
Ownership of wetland	1.72	3	0.632	7.81		N	Nature of land tenure
Ownership of wetland	13.40	6	0.037	12.59		Y	Household type
Wetland contribution to domestic food	26.99	20	0.136	31.41		N	Education level
Wetland contribution to domestic food	25.07	20	0.199	31.410		N	Wife education level
Wetland contribution to domestic food	13.15	12	0.358	21.02		N	Nature of land tenure
Wetland contribution to domestic food	28.02	20	0.109	31.41		N	Household type

N= not significant, Y=significant at both α 0.05 and 0.01, d.f. degree of freedom

5.4.3 Wetland products and marketing

Various products from the wetland were available on sale at the local markets but only in small quantities. These included mats of various sizes, fish, food crops and thatching material. The latter was only sold in the markets near the swamp such as the Ratuoro near the LBDA farm offices in the south due to its bulkiness. Although most of the households harvested their own thatch material, some had limited manpower e.g. old age, hence they had to buy from harvesters, forming a source of income for other people (Table 5.3). Furthermore macrophyte harvesting was a labor intensive process that was mostly done by men and transportation was not motorized necessitating more labor input. The major means of transportation both to the market and domestic level included bicycles (49%) and backloads (35%) with the vehicles usage (16%), which involve additional labor input. The low proportion of motorized transport was attributed to the poor infrastructure, small quantities or low prices that made it uneconomical to hire a vehicle. However, transportation of wetland products by middlemen for resale to distant and larger markets in Busia and Kisumu was through public service vehicles.

Products on sale at the markets were limited to fish, mats, papyrus ropes, and baskets. This low diversity was attributed to the effect of low products demand and lack of market information. Apart from the trade in the local markets, informal sales also took place at the households level. Trade at the household level covered all products including fish, papyrus ropes, thatch material, mats and baskets, but the sales were scattered and difficulty to quantify. Hence, the figures presented here may not reflect the real incomes, which were more likely to be on the lower side. Fish at the local markets and at the household level included fish from both the swamp and Lake Victoria. Swamp fish was mainly mudfish *Protopterus aethiopicus* while those from Lake Victoria and the satellite lakes included a combination of omena -*Rastrineobola argentea*, Nile perch –*Lates niloticus* (L) and tilapia. Tilapia was the most commonly traded fish in the local markets followed by omena and then mudfish. Nile perch was only sold in the market centers close to the Busia highway like Siaya and Ngyia but not at the local markets near the swamp, because it was mainly a commercial fish and sales were geared towards the larger urban centers such as Busia. Therefore, the swamp direct contribution to the sale of fish was low, although it provides crucial ecosystem functions related to the lakes like filter functions, hence indirectly supporting the fishing industry. When the income from Lake Victoria and the satellite lakes fishery was, factored in, this rose to USD207.79 per month, which was above the income from the fish obtained in the swamp.

Table 5.3: Average household income per month from swamp products

Product	Vegetables	Soil for brick making	Fishing (swamp)	Thatch	Craft items material	Fuel wood	Sand	Harvesting forage	Poles
South	20.84	0.07	27.86	8.88	15.57	10.28	17.04	rare	4.63
North	25.99	19.47	16.53	23.08	22.53	12.14	10.12	7.89	5.26

Exch.1USD = Ksh 76/-

The income at household levels could actually be higher since the figures do not include the sale of farm produce from the wetland or inter household sales. It was hard to ascertain the sources of wetland or off-wetland crops without introducing high biases in income levels, since differentiating them was difficult. Trade in most of these products from the swamp took place in the local markets near the swamp such as Ratuoro, Ngyia, Boro and Usenge in the south and Nyandorera, Port Victoria and Musoma in the north. Some of these products were later traded in bigger distant markets away from the swamp area such as in Umala, Siaya, Rangola, Ugunja, Busia, with only a small percentage going to the larger town of Kisumu. The low percentage of products going to Kisumu was because of the distant and since wetlands near the town could provide these products as well. Overall, with good marketing, organized groups and diversification of wetlands products, local income levels could be higher.

Commercialization of the macrophyte products was relatively higher on the northern side of the swamp due to the comparatively more developed infrastructure than on the southern side (Table 5.3) such as good commuter connections to the bigger towns like Busia and Kisumu. However, incomes were still low even by local standards. Incomes varied between the different macrophyte species both in the south and in the north (Table 5.4). Other important business centers on the northern side and close to the swamp included Nyandorera, Musoma, Ndekwe Island and Port Victoria. The latter two had busy trading routes with Uganda through the Lake Victoria. These trading outlets have great potential that could be tapped through improved marketing and flow of market information.

Table 5.4: Average household income (USD) per month from macrophytes

species	***C. papyrus***	***P. phragmites***	***E. haploclada***	***Latifolia+***	***S. sesban***	***P. reclinata***
South	8.68	4.21	9.74	9.57	7.79	
North	5.74	8.11	0.00	7.21	0.00	11.14

1USD = Ksh 76/- (Latifolia includes C. dives, C. distans and C. exaltatus)

All surveyed businesses were operated by individuals having commenced around 1961, but with most having came up relatively recently between 1996 and 2000. This contemporary increase maybe attributed to the macro-economic changes in the country, which have resulted in an upsurge of informal sector business (Jua Kali). In more than 60% of the businesses surveyed, start-up capital was mobilized from personal savings (40%), followed by merry-go-round savings group or from other businesses like the sale of charcoal, bananas and sugarcane. There was only one organized business group trading in macrophytes near the Nyandorera market in the north, which was initiated by LVEMP. The group had a relatively good income even by local standards (ca. 389.61 USD per month). The income could have been higher, but members were exploited by middlemen who bought the products at low prices from the group and sold them to other markets offering better prices such as Busia, Kisumu and Nairobi. This was due to the lack of market information reaching the local people, which would have enabled them to penetrate markets that were more lucrative. To be able to take advantage of the available market information, there is need to have organized groups, which can act as recipient for such information.

5.4.4 Dynamics of income sources

Subsistence sources and levels of income from the wetland vary widely on both sides of the swamp across the seasons. This was determined by several factors among them education, household type and land tenure (Table 5.2). The latter was important with regard to farming since the ownership of a farm in the swamp increases chances of income from the wetland during the dry season. However, the amount and sources of income varies a lot depending on season and side of the swamp. In the south 80% of the income was from farming, fishing making up 4%, business 3%, local employment contributing up to 5% and hunting only 3% of the total sources of income in the long rains. During the short rains the figures were similar but while farming was lower with 60%, business went up to 15%, local employment remained at the same level and fishing went up from 4% to 9%. Hunting remained at the same level, but a small contribution from relatives' comes in at 1% (Figure 5.7a). However, in the dry season there is a drastic change with farming dropping to 43% from 80%, business picking up to 21% mostly from macrophytes products, fishing up to 11%, while employment remains the same. Hunting increase to 6% as well as remittance from relatives moving up to 2%, which are shown under auxiliary sources in Figure 5.7 (a). The increase of the last two sources as well as business is due to the low returns from farming in the dry season.

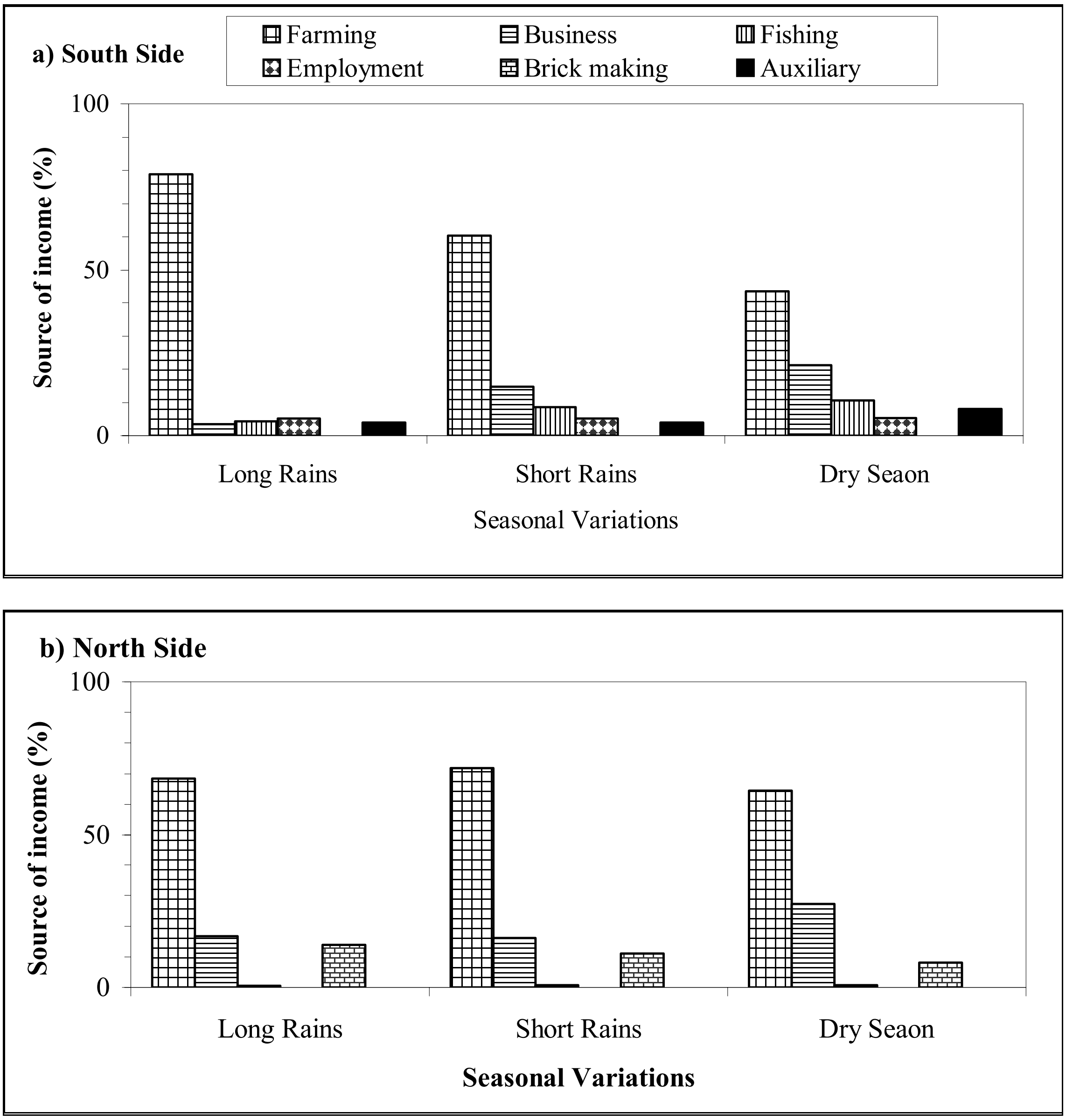

Figure 5.7: Major sources of income in (a) south (b) north

A slightly different scenario emerges in the north with farming contributing a slightly lower 68%, fishing making up 1%, business 17%, with brick making contributing 14% in the long rains (Figure 5.7b). During the short rains, business and brick-making dropped to 16% and 11%, respectively. Fishing remained at a low level of 1%, while farming rose to 72%. In contrast, in the dry season, business shot up to 27% while the bricking-making dropped from 14% to 8%. Brick-making and farming are water dependent activities, which dropped when water level went down. Fishing remained at the same level, but farming dropped to 64%. The small drop in farming in the north is due to the large converted areas that are convenient for dry season farming as the water recedes and macrophytes become easily available, hence the increase in business activities. In total, the overall average income in the Yala swamp in the wet season was ca. USD 24.94 ± 2.01 and in the dry season ca. USD 18.29 ± 1.82 on both sides. Thus, in spite of the rise in business in the dry season the overall income was still low due to the lower wetland products availability in spite of more people engaged in business activities.

Various types of crops were grown in the wetland across the seasons on both sides of the swamps. These included bananas, maize, millet, yams, sugarcane, kales, cowpea, onions and cassava, which are common in the LVB. However, there did not seem to be a clear distinction between crops grown in a specific season, neither in the dry nor the wet season. The annual cycle encompasses three distinct seasons, namely long rains (March to May), short rains (Oct. to Nov.) and the dry season (Dec. to Feb.). However, cultivation took place throughout the year, because the wetland has a constant supply of water from the high rainfall catchment area in the upper reaches of Mount Elgon and the Chelengany hills. Note, however, that the distribution of the dry season water is not uniform in the swamp due to the topographical limitations and the effect of reduced water volume from the catchments. This limits the utilization of the swamp during the dry season.

Several business undertakings were used to supplement the local income, especially in the dry season. These included sale of farm crops like potatoes, cassava, yams, oil crops (groundnuts, simsim), vegetables, millet and fruits (e.g. pawpaw, oranges, and passion), game meat, fish, mats, thatch material, local brews like chang'a, poles, pots and milk. Other activities included boat making, water vending and kiosk operation. These activities were supplemented by casual jobs like security guards, and working on other people's farms for wages. While the long rains season was characterized by minimal business activities, these picked up in the short rains and during the dry season to supplement the low returns from farming. This implies that the sales in the short rains and during the dry season are crops that are grown during the long rains in addition to the macrophyte products.

In terms of wetland, contribution verses other sources of income; the scenario was almost the same on both sides of the swamp. In the south 52% of the local respondents acknowledged that, activities within the wetland provide more opportunities than off-wetland farming activity (26%). While 22% indicated that, both provided the same. The survey also established that 82% of the households interviewed had farming land in the Yala swamp, which emphasizes the importance of wetland opportunities. The education level of the husband was important in determining contribution of income from the wetland $x^2_{(10)}$ 25.49 > 23.2, p = 0.004, α = 0.01 (Table 5.2). Wetland activities are labor intensive and require a large input from men relative to women contribution to realize benefits. It is likely that men with low education devoted more of their time in working in the wetland since they had limited chances of finding employment elsewhere. The ownership of the swampland unit had also a significant relationship with household type, $x^2_{(6)}$ 13.40 > 12.59, p = 0.037, α = 0.05. This outcome emphasizes the significance of men in wetland utilization. In addition, majority of the household are male head and land is held at household level, which again emphasizes the importance of household type in land ownership in the swamp. Most of the land around the Yala swamp is acquired through inheritance, which emphasizes the relationship between swamp utilization, local land ownership and household type.

This aspect was further supported by the income data discussed above, which indicates that wetland farming and products provided a higher income. In the north, 55% of the respondents acknowledged that the wetland provided a higher income than could be gained from outside the wetland (31% of the respondents). Only a moderate 14% had the feeling that both contribute the same. The importance of wetland activities was further emphasized by the fact that 90% on the northern side had farming land in the swamp. Overall, this means that more than 50% of income was related to wetland activities. The average landholding unit in the swamp was 2.42 ha ± 0.163, which was slightly lower than those outside the swamp (ca. 4 ha). Although the swampland units are small, they are more productive due to higher fertility and water availability than the adjacent dry land.

5.4.5 Wetland ownership, utilization and farming trends

The process of acquiring swampland varies slightly on both sides of the swamp. In the south, a relatively high 56% of the land had been acquired through self-allocation and only 25% had been bought, while 16% had been acquired through inheritance with a moderate 3% having been allocated by an undisclosed authority. In contrast, in the north, a large proportion (82%) was acquired through self-allocation, 9% was acquired through purchasing, 8% through inheritance and 25% had been allocated by again undisclosed authority. Since there was no clear management authority in the Yala swamp, all land had initially been acquired through self-allocation. Later, the same land may have changed hand through either sale or inheritance. Farming activities took a high 95% of swampland utilization, while the other land uses, i.e., grazing, fallowing and sand harvesting were equally distributed in small areas on both sides of the swamp.

Swampland ownership was bequeathed through the initial process of land clearing for farming, which involved slashing and burning. On both sides of the swamp, this was significantly correlated to the nature of land tenure ($r = -0.282$, $\alpha = 0.01$; $r = -0.179$, $\alpha = 0.05$) and the year of settlement ($r = -0.290$, $\alpha = 0.01$; $r = 0.240$, $\alpha = 0.05$). Since land is utilized by the local people, it is likely that early settlers who also own land near the swamp are most probably also engaged in farming activities in the wetland. The negative relationship means that those without land are unlikely to have land in the swamp; the same applies to the recent settlers. These relationships are weak, meaning that other factors determined the ownership of swampland. In the chi-square calculations, only household type had a significant relationship with the ownership of farm in the wetland $x^2_{(6)}$ 13.40 >12.59, $p = 0.037$, $\alpha = 0.05$ (Table 5.2). The process of acquiring land was based at the household rather than at individual level, hence the importance in determining the acquisition of land in the swamp.

According to 70% of the respondents, farming locations in the wetland change in the course of the year for a number of reasons. These include flooding (70%) especially in the north, normal shifting cultivation (5%) and the compelling need to increase crop production (10%). On the northern side of the swamp, crop destruction by wild animals was an additional factor.

There has been a gradual rise in the wetland farming over time, which dates back to the 1920's, when the percentage was only small (1%) due to the low population level. This rose in the 1960s to 10% on the southern side of the swamp. On the northern side, farming was introduced much later in the 1930s at a low rate of 1%, increasing in the 1970s and 1980s to 30%. Farming began in the wetland for varied reasons, which were similar on both sides of the swamp, the most important being for subsistence purposes. People were also attracted to the wetland by its water availability, high crop yields, and favourable farming climate (70% in the south, 90% in the north). The need to raise subsistence income was only stated by 30% of the people in the south and 10% in the north, indicating that farming was mainly geared towards the domestic food supply with income raising only as a secondary activity. Most of this farming took place along the edge of the swamp.

There was a feeling among the local communities (56%) on both sides of the swamp that the area under cultivation in the swamp had decreased. The reasons stated were varied, ranging from floods taking more land; crop destruction through wild animals discouraging cultivation plus a decline in soil fertility. The 1962 *El Nino* was alleged to have lead to excessive flooding and submergence of former farming land, especially on the northern side. In addition, the breakdown of the dike on the River Yala, which was constructed in the 1970s for drainage, was stated as a reason for the increased excessive flooding on the northern part of the swamp. Although excessive rainfall in East Africa in 1962 has been recorded (Sene *et al.,* 1994), the claims of the swamp expansion are hard to quantify due to the inadequacies of remote sensing data at the time. However, multi-temporal satellite data shows a different picture with more land opening between the 1970s and 2001 as presented in the land-cover change analysis (chapter 7). This correlates well with the data on settling pattern around the swamp, which shows a gradual increase but high settlement after the 1970s. While a loss in the previous farming land could have occurred through flooding in some areas as a result of the broken dike, other areas were most likely opened up along the front of the newly flooded zone. The flooding could only have reduced access to the inner part of the swamp or other parts of the swamp.

5.4.6 Grazing and forage

The area around the Yala swamp is semi-arid, and the wetland offers an important dry season grazing area. Grazing normally takes place along the edges of the swamp, since deep inside the wetland, the ground is unstable and the concentration of grass biomass and other palatable species is low. In particular, the southern and eastern part of the swamp, including the section that is currently leased out to a large-scale farming company (Dominion), are important grazing areas. Furthermore, the Luos in the southern and the eastern side are agropastoralists, while the Luhyas in the north are more agrarians. Furthermore, the relatively lower flooding levels on the southern side relative to the northern side of the swamp have made grazing there more favourable. Occasionally, grass is harvested from the swamp for livestock, but forage harvesting was only for young goats and calves. *Cyperus* species like papyrus are only edible when very young and such shoots are at times harvested as forage.

5.5 Swamp utilization constrains and future development

Sustainable utilization of the Yala swamp is faced with numerous challenges, which range from low returns on wetland products, poor infrastructure and high demand for farming land. Apart from these limitations, wetland utilization has been further complicated by flood-related problems. Households near the swamp suffered high incidences of diseases such as bilharzia and malaria (46%), threats of attack by wild animals (20%) and flooding (34%), although the first two were a result of the lack of preventive measure such as footwear and mosquito nets, due to the low standard of living. Other problems included crop raids by wild animals from the swamp such as wild pigs. The effect of floods in the hilly south was relatively low compared to the gentle sloping northern side, where floods temporarily displaced a significant proportion of the population each year. This problem was much more severe in the western part of the swamp, which was attributed to the increased floodwater from the broken dike on the River Yala.

However, in this rather desperate situation, the communities have devised several ways to cope with the floods. This included digging trenches/dikes (70%), shifting the cultivation areas or moving to higher grounds (20%). On the northern side of the swamp, which is characterized by frequent floods, some community members stay on their land throughout the flooding period (41%). They attributed this to the widespread flooding and that higher grounds were far. Other mechanisms included internal assistance from members of the community (80%). This assistance included provision of food, transport, clothing, accommodation and transportation of household goods to higher grounds. Note, however, that the assistance from the members of the community (55%) was low, especially on the northern side, since almost all of the community members were affected. However, apart from the limited assistance from the local communities, the government in collaboration with non-governmental organizations (NGOs) assists the displaced people by providing food and accommodation.

Although numerous products could be obtained from the swamp, the community was quite strongly inclined towards farming. According to the survey, the most highly prioritized future development was draining the swamp for farming, while fishing and conservation took a low priority. Fishing in the Yala swamp was more associated with the open waters of the Lake Victoria and the satellite Lakes Sare, Kanyaboli and Namboyo. This outcome was not surprising for two reasons. First, the study was carried out at a time when large-scale farming activities by the Dominion Company were commencing in the Yala swamp. This could have influenced the outcome to some extent. Second, field results indicate that allocation of swampland to cultivation, relative to other uses, and dependency on the wetland for subsistence food supplies and income were high. However, this preferred option overlooked other numerous benefits from the swamp like grazing, thatch material, fishing as well as ecosystem services like filter functions, carbon sequestration and species conservation.

5.6 Discussion

The socio-economic survey indicates that the Yala swamp provides numerous products and support to the local indigenous community, mainly at the subsistence level but with substantial commercialization. The need to supply domestic food and to raise incomes for cash economy needs form an important part of the swamp activities. Income was generated mainly through the sale of food crops grown in the swamp, macrophyte products, as well as through fishing, sand harvesting and brick-making. Indirect sources included the sale of the livestock that are partly dependent on the swamp.

Increased exploitation of the wetland resources for commercial purposes outside the traditional domains have been on the increase in the developing countries. For example, Kiwazi *et al. (*2001) and Maclean *et al. (*2003) note that in Uganda, increased papyrus harvesting is geared towards meeting education-related expenses. Similarly, the shift from traditional fishing in the Tana delta wetland in Kenya is due to the need to meet cash economy transaction requirements (Terer *et al*., 2004). Likewise, the increased wetland conversion in Uganda from the 1970s has also been attributed to population increase together with socio-economic changes like cash economy transactions such as payment of school fees. Similar observations have been made in the Uasin Gishu District wetlands (Kareri, 1992; Odongo, 1996) and the Yala swamp (Abila, 2002). The Yala swamp is located within a high population density area, where the living standards are low and livelihood means are limited; hence, the swamp provides an ideal source of income. Although actual income values are hard to compare due to methodological differences, most studies shows that the levels of income accruing to the local communities is low (Katondo, 2001; Kisusu *et al*., 2001). This compares well with observation in the Yala swamp. Exploitation by middlemen was also common in most cases a contributory factor to low income.

However, since business is normally not the primary reason for harvesting or farming the macrophytes, only a small proportion is sold and most products are used at the domestic level. This phenomenon was not restricted to the Yala swamp, where only a modest 30% of the macrophytes and food was used to raise income. Similarly, according to Katondo (2001), only about 40% of all the mats that are made in the Simiyu wetland in Tanzania are sold to the outside markets through intermediaries. However, income level remains too low to promote sustainable use. Furthermore, the sale of other swamp products like fish and crops attract equally low prices, which are not adequate to raise the living standard. The constraints regarding the marketing of the wetland products in the Yala swamp can be attributed to poor infrastructure. These structures keep the prices at low levels, which encourage more farming and suppress diversification of swamp utilization.

Wetland cultivation in Africa has been documented as an old tradition of the communities living next to these wet ecosystems and has posed no major threat to them (Kiwazi *et al.,* 2001; Thenya, 2001; Wood *et al.,* 2002; Maclean *et al.,* 2003; Terer *et al.,* 2004), and studies in the LVB indicate that land is an important asset and a significant source of income and food (Kiwazi *et al*., 2001; Mugo *et al*., 2001). However, there is a heavy and rising reliance on the Yala swamp as a source of subsistence food for the local communities, which is threatening other diverse and sustainable uses. This is due to several factors, among them a high population density (ICRAF, 2000) and small landholding size (ca. 4 ha) around the swamp. In addition, the low rainfall around the Yala swamp (ca. 760 mm/ per annum) limits rainfed farming, forcing the community to seek alternative farming land in the swamp. The need to feed the growing population, to raise income to meet other cash transactions increases the need for more farming land. This leads to large-scale conversions or several small-scale conversions, which deviates from indigenous sustainable utilization and threatens ecosystem functions.

Apart from the pressure that is generated by the increasing cash economy needs and food demand, there is also heavy reliance on the macrophyte biomass as a source of domestic fuel. Similar observations have been recorded by several researchers in the tropics (Odak, 1987; Gichuki *et al.,* 2001; Katondo, 2001; Kiwazi *et al.,* 2001; Thenya, 2001; Abila, 2002). While this can be attributed to their high biomass availability and spatial extent, poverty and the low income levels at the household level, especially in the Yala swamp area, limit other alternatives like electricity or gas. This means that reliance on the macrophytes as an important source of domestic fuel in the Yala swamp will continue. Although the biomass used was not quantified due to the regenerative ability of the macrophytes (Chapter 6), extraction at the domestic level does not pose a major threat to the ecosystem. However, use of macrophyte raw material for fuel and building does not provide a longtime viable source due to the current pressure to convert the swamp into farming area. Hence, there is need especially for more research on the possibility of making briquettes from the macrophytes to enhance the domestic energy supply from these plants. Due to the low socio-economic status in the area around Yala swamp, a coordinated approach in harvesting of macrophyte for building is necessary as well.

To facilitate sustainable use of the Yala swamp under the current scenario of increasing population pressure, an organized marketing system is essential. This would enable the local communities to realize tangible benefits and encourage conservation as well as sustainable use of the wetland resources. As it is, the low returns discourage investment of adequate time in wetland products, which has also been observed elsewhere (Thenya, 2001) and is major challenge to conservation and sustainable use. However, sustainable use of the swamp is complicated further by the question of property ownership and management, which is not clear. Although, most wetlands are reserved as government property under either the local authority or the central government, free access and utilization over time lead to over exploitation or degradation. In Uganda, Kiwazi *et al. (*2001) and Maclean *et al. (*2003) highlight the considerable ambiguity that surrounds the concept of the government or the local authority holding wetland "in trust for the people". They further note the confusion over rights and obligations of ownership on the one hand and management on the other. The situation is not different in the Yala swamp, where land is mostly self-allocated.

This scenario revolves around Hardin's 1968 "free-rider" assertion, where degradation and over-use is linked to a common property regime (CPR). Communities are unlikely to invest resources and time in land that has no security of tenure or where ownership is not clear. Likewise, the Yala swamp is seen as having free access for farming, grazing, fishing and macrophyte harvesting, and land is also acquired through self-allocation and/or from quasi-family inheritance. Swampland ownership is vaguely perceived as being in government hands but with free access. This means that the awareness of a need to develop local institutions is low and investment in such property is insecure, since ownership could be denied any time. The entry of a private large-scale farming company on the eastern side is one such case, and will mostly likely lead to increased exploitation pressure in a scenario of poor resources governance.

To develop a secure wetland management system, a clear institutional arrangement has to be established that fits within the current local situation. A local management plan that takes into consideration the current reliance of the communities on the ecosystem and ecosystem services is necessary. A participatory management approach would deliver numerous benefits to the local community (Terer *et al*., 2004), although precautionary measures are necessary to limit drawbacks (Allison and Badjeck, 2004; Stoll-Kleemann, 2004). This is important, since a set of rules suitable for specific socio-ecological conditions, e.g., leasing land for large-scale farming in the Yala swamp, can erode social welfare and lead to increasingly negative human impacts on the ecosystem. Under the current utilization arrangement, there is little motivation by the local community to engage in long-time infrastructure development for sustainable natural resources management. Hence, the will to achieve immediate benefits in wide rage of activities through, for example, conversion for farming, has high priority. Maclean *et al*. (2003) made similar observation in Uganda wetlands, where ownership ambiguity discourages sustainable utilization. Unfortunately, increasing mono-utilization such as farming will eventually lead to a decrease in diverse ecosystem use including fishing, water supplies, macrophyte harvesting and species habitat provision. The failure to maintain ecosystem diversity will lead to several detrimental effects, among them are ecosystem degradation, siltation of water systems, loss of habitats and a weak base for macrophyte products. Some of these impacts, such as siltation, are clearly visible in the 2001 satellite image analysis (Chapter 7).

However, there is limited experience to draw from on successful active wetland management under the current cash economy, since this is a recent phenomenon, as traditional use has prevailed to date (Kiwazi *et al.,* 2001). Allison and Badjeck, (2004), Terer *et al. (*2004) and Stoll-Kleemann (2004) provide valuable lessons on the emerging neo-management issues. One of the highlights is the need to trend carefully on participatory management due to some inherent drawbacks of communal management, like time-consuming decision-making process but acknowledges the benefit of more inclusive management. However, data on traditional uses like grazing, fishing, farming and macrophyte harvesting could provide valuable lessons on the management under cash economy (Wood *et al.,* 2002; Dietz *et al.,* 2003). Therefore, there is need to integrate the traditional roles with modern management so as to address the question of emerging needs like new income sources and increased food demand. A call for further research in the emerging institutional arrangement and changing dynamics in livelihood support from the wetland is necessary. This would help to formulate a balanced management plan, i.e., "wise use", which takes into consideration ecosystem services, habitat protection and livelihood support for the local communities.

5.6.1 Conclusions

The Yala swamp ecosystem is very important for the livelihoods of the local communities throughout the year. In spite of the ecological and social differences between the northern and the southern side, the swamp provides numerous beneficial products to both areas. These include water, thatch material and raw material for craft items. Other uses include farming, grazing and fishing. Farming was identified as the most important wetland utilization, which can be attributed to high population density, low precipitation (approximately 760 mm) and declining soil fertility outside the swamp. Like the other wetland utilization, farming was mainly geared towards supplying domestic food, as well as to raising modest incomes. Swampland holdings were often self-allocated or inherited along kinship lines, with such land mainly serving the local communities that have land nearby to the swamp, but not the landless.

The use of macrophytes was diverse and included thatching, domestic energy supply and making of craft items. Although *C. papyrus* is widely documented as the main thatching material, other species are equally important, and thatching includes a combination of several species and often other species such as *C. dives* and *C distans* are often used alone. However, the returns from the sale of wetland products were often low mainly due to the marketing constraints. These include lack of market information, poor transport network and exploitation by intermediaries. This in turn has acted as major hindrance to sustainable wetland utilization due to the reduced benefits and serves largely to promote the mono-use of wetland farming.

Therefore, to promote sustainable use, there is need to increase the direct benefits to the local communities including cash benefits. In addition, a clear ecosystem management that clarifies ownership would help to promote sustainable use. This could be achieved through participatory wetland planning and management. However, research on the emerging challenges like increasing wetland farming and cash economy transactions, which present a strong deviation from the tradition uses, would help to boost sustainable management of the ecosystem. Other studies that might help to promote participatory management include understanding of traditional methods of resource utilization and governance against the changing dynamics like land privatization. Also important is the value attached to the Yala swamp by the local community and the control measures exercised in its utilization by the local community.

6 MACROPHYTE GROWTH CHARACTERISTICS ACROSS DIFFERENT ECO-TYPES AND ASSOCIATED ECOLOGICAL DYNAMICS

6.1 Introduction

Wetland vegetation composition and ecological productivity are highly influenced by the flooding patterns as well as the ecological status. Therefore, although *Cyperus papyrus* is the most dominant emergent sedge in the tropical swamp, there are wide varieties of other sedges especially of the *Cyperus* genera. In the Yala swamp these species were distributed in different eco-types and ranged from the high water-emergent *C. papyrus* to low water species such as *C. dives, C. distans* and *Phragmites mauritianus*. Other species, such as *Phragmites*, occupied the disturbed ecological sites as well as water canals. Hence, some species were only found in one eco-type like *Phragmites* in highly disturbed ecotypes. These factors affected regeneration in certain ways

Human activities in the swamp such as burning, farming and grazing resulted in alteration of the ecological status of the wetland, especially nutrient circulation, which indirectly affected primary productivity. Hence, the Yala swamp can be referred to as semi-natural, especially along the outer zones. Even sites bearing tall pure stand of papyrus showed sign of having been converted sometime, but recovered due to heavy and extensive flooding. These changes had a strong bearing on the ecological dynamics of the Yala swamp. Occasional damage to the study plots were recorded, which increased towards the dry season, as human activities increased in the swamp. Therefore, there were variations in the monitoring weeks, with some of the study plots becoming damaged before the end of the 14 weeks, especially in the dry season.

The post-harvest growth characteristics of the six species showed high intra-species variability, but some common trends were observed. In all three eco-types, i.e., less disturbed, transitional and highly disturbed, a fast growth rate was observed in the first 3-4 weeks, followed by reduced growth in the next ten weeks. Growth after the 14th week was on average highly diminished in all species and across the eco-types. This growth pattern was maintained even in the dry season and across the highly disturbed eco-types, although correspondingly lower growth rates were measured. Macrophytes that were not harvested in the 14th week gained minimal height compared to the harvested macrophytes of the same species. Again, growth rate and biomass gain were high both in the wet season and the less disturbed eco-types, which had a favorable ecological environment for macrophyte growth. Comparatively, relatively more nitrogen and phosphorous amount were observed in the macrophyte biomass relative to the soil subsystem, which was also high in the wet season compared to the dry season.

6.2 Post harvest macrophytes dynamics

6.2.1 Stratum 1- highly disturbed eco-type

All species showed simultaneous fast growth from the first week gradually leveling off in the 7th week. This was followed by a relatively slow gain in height (Figure 6.1). However, there was high variability in height depending on the physiognomic structure of the species. *T. domingensis* gained ca. 400 cm in 14 weeks, while *P. mauritianus* gained ca. 270 cm in 12 weeks. *Cyprus distans* had gained ca. 190 cm by the 14th week, and since it does not generally grow very tall, on average a relatively low height was expected. In the 14th week, all species were harvested and the dry biomass weight recorded. The overall height gained in the next 14 weeks (post harvest) was comparatively lower by between 37% and 10% on all the three species. This was followed by the third harvesting in the 29th week, with the post-harvest period showing a much lower gain in height and growth rate. Full data are given in Appendix 3.

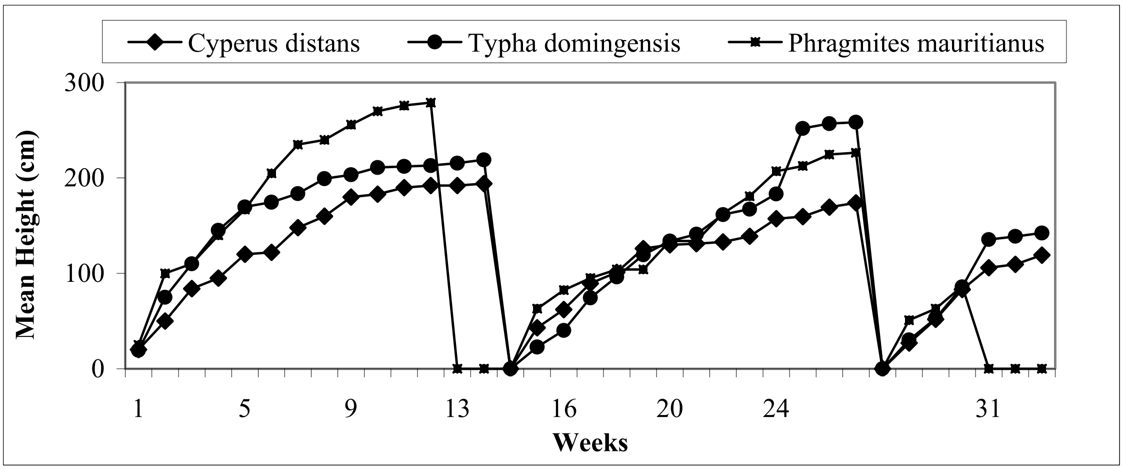

Figure 6.1: Natural growth of macrophytes in the highly disturbed eco-type in stratum_1

The highest growth rate was achieved in the first 3-4 weeks and ranged between 15 and 300 % (Appendix 4). There was then a strong drop in the growth rate, which was maintained on average between 1 and 12% for the next 10 weeks. In terms of the specific species, *T. domingensis* had the highest average post-harvest growth rate

(37 %) followed by *P. mauritianus* (32 %) and *C. distans* (24 %) for the first 14-week period. However, the overall growth rate slowed down significantly by the 11th week. The subsequent post-harvest growth rate in the 2nd and 3rd post-harvest period dropped by between 30% and 90% (Appendix 4).

6.2.2 Stratum 1- medium disturbed (MD) / transition environment eco-type

In the transitional environment eco-type, *T. domingensis* showed the highest post-harvest height gain of ca. 450 cm in the first 14 weeks. This was followed by *C. papyrus*, which reached ca. 350 cm over the same period. In this eco-type, *C. distans* was relatively taller at 340 cm compared to the highly disturbed eco-type, where it attained only ca. 190 cm. However, after the second harvesting session, the overall height attained by the three species dropped by an average 50%. This was slightly more than the drop recorded in the highly disturbed eco-type, and *C. distans* actually failed to regenerate after harvesting due to submergence (Figure 6.2).

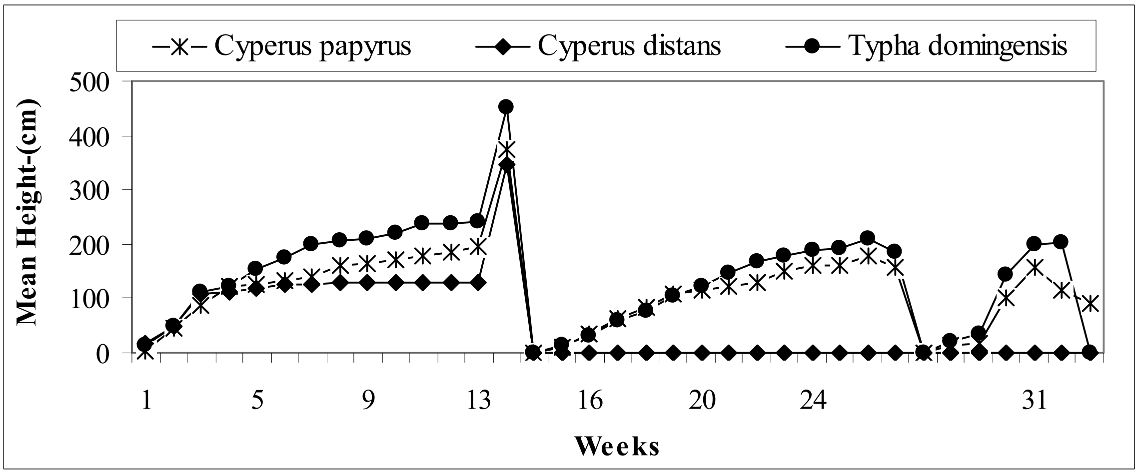

Figure 6.2: Natural growth of macrophytes in the transitional eco-type in stratum_1

The highest rate of growth was achieved in the first 2 weeks (100 – 2000% in *C. papyrus*) followed by a moderate drop in the 3rd and 4th week (5 – 100%) in all three species. This was followed by a fast drop in the growth rate, which was maintained for the next 10 weeks, ranging between 1 and 15%. However, the growth rate after the 2nd and 3rd post-harvest period dropped significantly and was maintained at below 10% in stratum 1.

Comparing species performance, in both the highly disturbed and transitional eco-types, the fastest growth rate was recorded in *C. papyrus* in the transitional eco-type followed by *T. domingensis* in the highly disturbed eco-type. Both species gained height fast between the 1st and 2nd week. However, *C. distans* in both of these eco-types maintained a relatively low rate of post-harvest growth. It was observed that *C. distans* commenced growth immediately after harvesting but showed a peak in the first 4 weeks that was lower than that of the other two species. This was attributed to the fact that physiognomically it does not grow very tall like the other two species.

6.2.3 Stratum 1 - low disturbed (LD) eco-type

In stratum 1 in the low disturbed (LD) eco-type, *P. mauritianus* attained the highest post-harvest growth height of ca. 425 cm in the first 14 weeks. This was followed by *C. papyrus*, which attained a mean of 405 cm over the same period and *C. distans* attaining a lower height of ca. 150 cm in 13 weeks. All three species were characterized by a slow growth rate in the first two weeks after harvesting compared to the other two eco-types. However, growth picked up well in the third week (Figure 6.3). The period after the 2nd harvesting was characterized by a growth rate very similar to that in the first 14 weeks with only a small reduction in the overall height gain in *C. dives* and *P. mauritianus*. In the post-harvest period after the 3rd harvesting session in the 29th week, a much lower growth was recorded as observed in the other eco-types. The period after the 3rd harvesting session was characterized by an erratic growth pattern in all eco-types, probably due to the onset of the dry season and ecosystem disturbance.

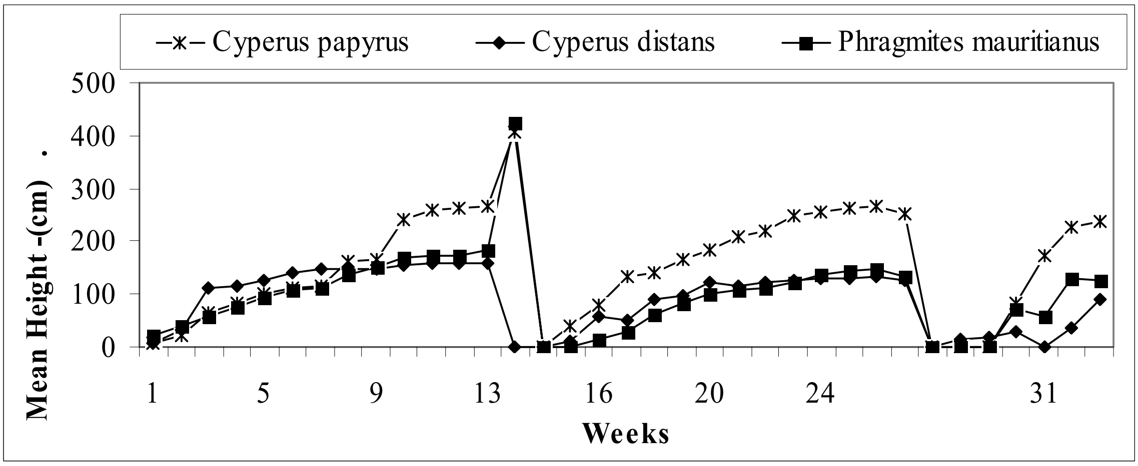

Figure 6.3: Natural growth of macrophyte in the low disturbed eco-type in stratum_1

There was a high shooting rate in the first 2-4 weeks in stratum 1, which ranged on average between 100 and 320%. However, this was slightly lower than in the transition eco-type, but almost the same as in the highly disturbed eco-type in the same stratum and in the stratum 2 below. A growth rate of between 10 and 30% was maintained for the next 3-10 weeks up to the 14th week. Note, however, that the period after the 2nd harvesting session was characterized by a lower growth rate, which dropped by between 5 and 100% as observed in stratum 1 in the HD eco-type. This phenomenon of reduction in the post-harvest growth rate was observed in all eco-types in stratum 1.

6.2.4 Stratum 2- transition environment eco-type

In stratum 2 (Figure 6.4), *C. dives* syn. *C. immensus* Del. attained an overall mean height of ca. 150 cm in 11 weeks, which was slightly below the height attained in stratum 1 over the same period. *E. haploclada* attained a mean height of ca. 130 cm in 11 weeks and showed the same growth pattern as *C. dives*. In contrast to stratum 1 in the highly disturbed eco-type, the growth rate in 2nd post-harvest period was remarkably high. Both species attained the same height as in the period after the 1st harvesting.

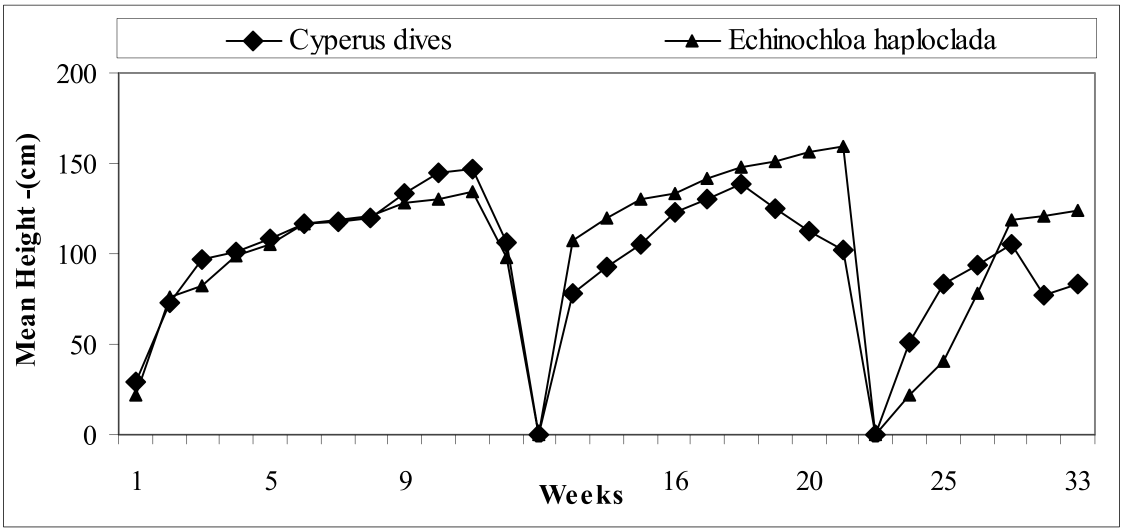

Figure 6.4: Natural growth of macrophyte in the transitional eco-type in stratum_2

In stratum 2, (Figure 6.4) the post-harvest growth rate was slightly lower than in the other strata ranging between 5 and 250% (Appendix 4). However, it was extended over a longer period beyond the 4 weeks before gradually leveling. Both species exhibited reduced growth vigor after the 3rd harvesting period as observed in the other strata.

6.2.5 Stratum 3- low disturbed eco-type

Similar post-harvest growth trends as observed in stratum 1 in the LD eco-type were recorded for *P. mauritianus,* which attained a mean height of ca. 350 cm in 12 weeks, followed by *T. domingensis* with a mean height of 250 cm over the same period, while *C. papyrus* attained a mean height of ca. 160 cm. All three species were characterized by a slow post-harvest growth rate in the first 4 weeks, which then gradually picked up and was maintained for the next 7 weeks; thereafter, the rate slowed down. Similarly, the period after the 2nd harvesting session was characterized by a slow growth in the first weeks as in stratum 1. However, these species attained almost the same height as in the period after the 1st harvest (Figure 6.5). Nevertheless, the LD eco-type in strata 1 and 3, showed almost the same post-harvest growth characteristics. This emphasizes the overriding effect of ecological status on macrophyte growth compared to harvesting.

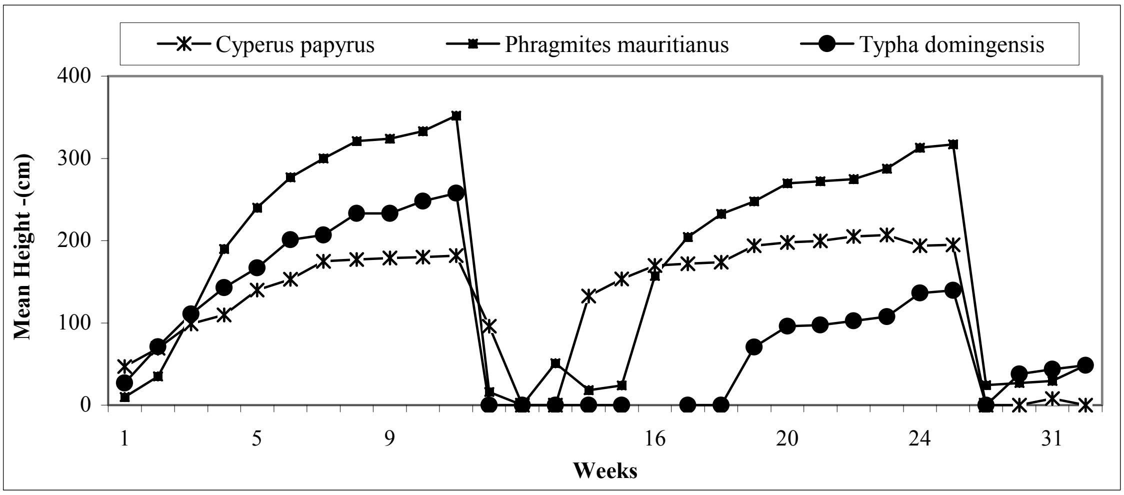

Figure 6.5: Natural growth of macrophyte in the low disturbed eco-type in stratum 3

There was high shooting rate in the first 4 weeks, which ranged between 50 and 250%. This was slightly lower than in the transitional eco-type but almost the same as the highly disturbed eco-type. Post-harvest growth of between 10 and 30% was maintained for the next 3 weeks, i.e., up to the 6th week. This was followed by a significant drop of between 1 and 10% as observed in the other strata and eco-types. Similar observations were made in the low disturbed eco-type in stratum 1.

6.2.6 Comparative effect of harvesting and non-harvesting

As a control experiment, some species were left standing for the entire period of the experiments. Growth data was collected from the 28th week (2nd post-harvesting session), which shows that macrophytes that were harvested after the 14th week grew much higher than species that were not harvested (Table 6.1).

Table 6.1: Comparative growth data on harvested and non-harvested macrophytes

	Height of harvested macrophyte (cm)						**Change**
Weeks	**28**	**29**	**30**	**31**	**32**	**33**	**cm**
C. distans	27	52	83	106	109.5	119	92
T. domingensis	30.33	52.83	85.83	135.5	138.83	142.5	112.17
P. mauritianus	51	63	86.5	0	0	0	35.5
C. papyrus	14	16	100.5	158.5	116.5*	91*	77
	Growth rate – (%)						
Weeks	**28**	**29**	**30**	**31**	**32**	**33**	**%**
C. distans	0	92.59	59.62	27.71	3.3	8.68	31.98
T. domingensis	0	74.18	62.46	57.86	2.46	2.64	33.27
P. mauritianus	0	23.53	37.3	0	0	0	10.14
C. papyrus	0	14.29	528.13	57.71	-26.5*	-21.89*	110.35
	Height of non-harvested macrophyte (cm)						
Weeks	**28**	**29**	**30**	**31**	**32**	**33**	**cm**
C. distans	157.5	157.5	159	159	161.5	162.5	5
T. domingensis	148.83	148.83	150.5	151.17	155.17	219.67	70.83
P. mauritianus	0	0	0	0	0	0	0
C. papyrus	191.25	191.25	199.5	207.25	221.5	221.5	30.25
	Growth rate – (%)						
Weeks	**28**	**29**	**30**	**31**	**32**	**33**	**%**
C. distans	0	0	0.95	0	1.57	0.62	0.52
T. domingensis	0	0	1.57	0.44	3.1	41.57	7.63
P. mauritianus	0	0	0	0	0	0	0
C. papyrus	0	0	4.31	3.88	6.88	0	2.51

*Source: field measurements, *, 0 –plants damaged in the plots (either slashing and grazing)*

For example, *C. distans* that was harvested gained 92 cm in 14 weeks after the 2nd harvesting, while those not harvested gained only 5 cm over the same period. The harvested plants achieved this gain in height despite the reduction in the flooding level in the swamp. The percentage rate of growth was similarly highly diminished after the 27th week for the non-harvested macrophyte species (Table 6.1). This implies that other factors like change of ecological parameters and plant nutrient uptake performance have a greater effect on growth than harvesting.

6.2.7 Above ground macrophytes biomass

Macrophytes biomass was only significantly influenced by the season ($p = 0.023$). The biomass amount decreased with season from the wet to the dry season, between May 2003 and March 2004 (Figure 6.6).

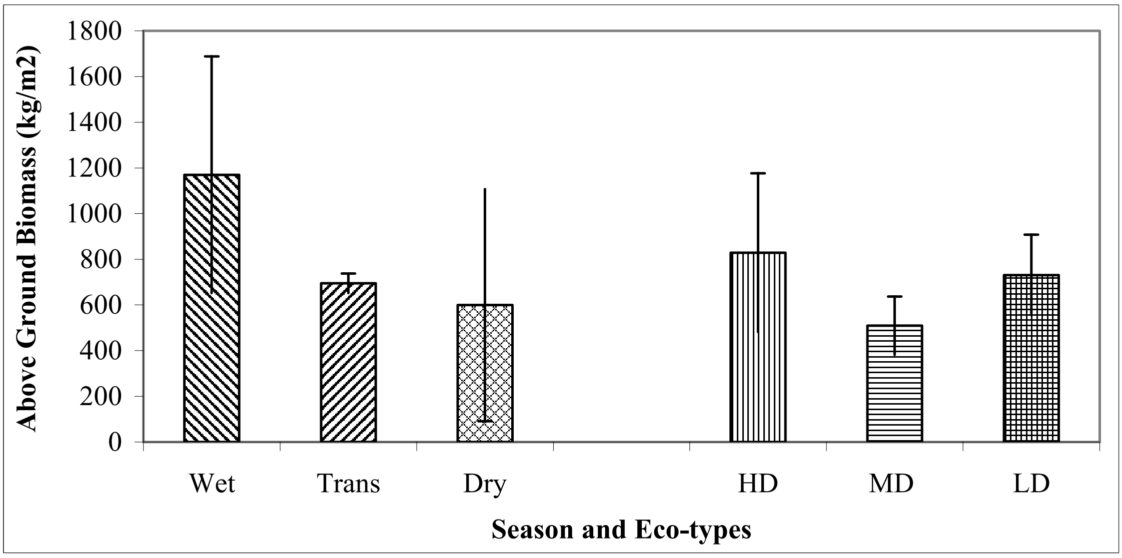

Figure 6.6: Above ground biomass variation with both seasons and eco-types

Across the eco-types, higher biomass values were observed in the highly disturbed eco-types than in the less disturbed eco-types (Figure 6.6, Appendix 5). The high value in the highly disturbed eco-types was due to the presence of *P. mauritianus,* which grows to a great height (ca. 2m). In contrast, the transitional eco-types were characterized by the presence of relatively low weight and height species such as *C. distans, C. exltataus* and *C. dives,* which had comparatively low biomass. On the other hand, the less disturbed eco-types were more highly dominated by *C. papyrus*, which has a relatively higher biomass than *C. distans, C. exaltatus, C. dives* but less than *P. mauritianus*.

In terms of specific species biomass production, *C. papyrus* had the highest at ca. 1,014 g per m^2 dry weight followed by *P. mauritianus* (Table 6.2), while *C. dives* and *C. exaltatus* had the lowest biomass*,* which was expected, since they are relatively small physiognomically.

Table 6.2: Above ground biomass production of macrophytes species

Macrophytes species	*Cyperus papyrus*	*Phragmites mauritianus*	*Cyperus dives*	*Echinochloa haploclada*	*Cyperus distans*	*Cyperus exaltatus*
Dry weight g per m^2	1,014.35	982.38	765	749.92	414.48	208.20
S.E ±	75.91	74.55	334.36	238.86	97.30	122.76

(full data given in appendix 5)

Nevertheless, both the different species (p = 0.508), species and eco-type interactions were not significant, (p = 0.181). Hence, it was not possible to explain the effect of their interaction.

6.2.8 Macrophytes nutrient content

Macrophyte nutrient content was only significantly influenced by seasonality, nitrogen being affected most strongly (p = <0.001) followed by phosphorous (p = 0.025; Table 6.3). The eco-types had only a weak influence on the nitrogen-phosphorous (N:P) ratio (p = 0.101), which was not significant. Again, the interactions between eco-types and seasons were weak. Post-hoc analysis did not register any differences between the means for those that were also significant at 0.05 and 0.01. The relationship of the interaction between macrophyte nutrient variability and eco-types plus seasonality is presented below (Figure 6.7).

Table 6.3: Analysis of variance of (ANOVA) of macrophyte nutrient content

n = 42	**Eco-type (d. f. 2, 49)**	**P value**	**Season (d. f. 1, 49)**	**P value**	**Eco-type/Season (d. f. 2, 49)**	**P value**
Nitrogen (N)	0.18	0.847	12.38	<0.001	1.00	0.374
Phosphorus(P)	0.74	0.484	5.36	0.025	1.60	0.213
N:P	2.41	0.101	1.15	0.288	0.49	0.013
F-critical values						
α 0.05	3.18		4.03		3.18	
α 0.01	5.06		7.17		5.06	

The nitrogen and phosphorous content in the macrophytes varied widely across seasons, eco-types and among the different species. In terms of seasonality, nutrient content in the wet season was relatively higher compared to the dry season (Figure 6.7). In addition, there was a marked difference between the wet and the dry season in both nitrogen and phosphorous content, which was also reflected in the analysis of variance (Table 6.3).

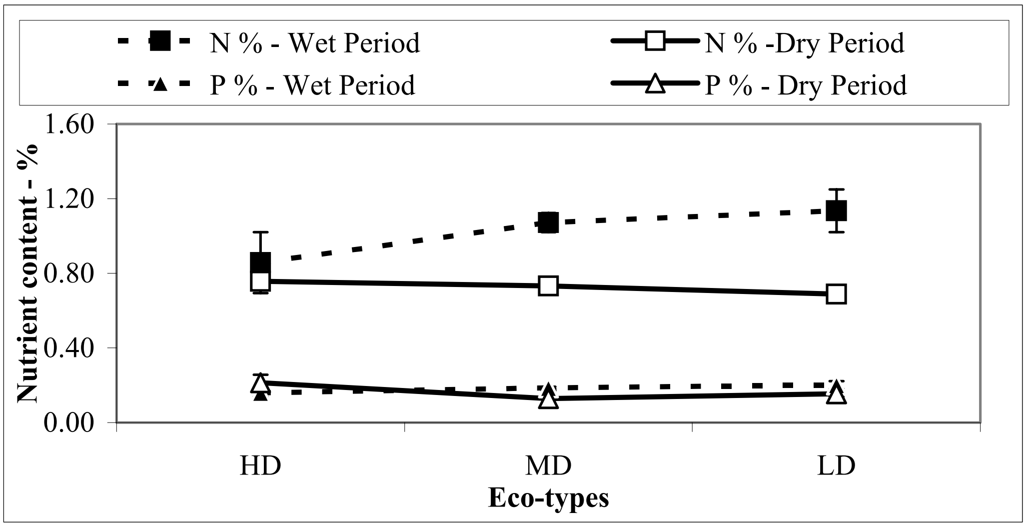

Figure 6.7: Macrophytes nutrient content across the eco-types and between the seasons

Across the eco-types, the macrophytes in the less disturbed eco-types had higher nitrogen and phosphorous contents, while these values were lower in the highly disturbed eco-types, although this was not significant (Figure 6.7, Table 6.3). In contrast, nitrogen content showed a clear pattern between the wet and dry season, which was also significant even at F = 0.01, while there was only a minimal difference in the phosphorous content across the eco-types and between the seasons. However, while there was an upward trend in the wet season across eco-types, there was only a minimal change in the dry season for both nitrogen and phosphorus.

A similar pattern was observed in the interactions between the macrophytes and season variables. Seasonality had a highly significant effect on nitrogen even at F-critical 0.01 (p = <0.001) (Table 6.4), and phosphorous was relatively affected (p = 0.030). However, the variability of both nitrogen and phosphorous was not significant among the different species and had low P values.

Table 6.4: Analysis of variance of (ANOVA) of macrophyte nutrient content

n = 42	**Plants spp. (d. f. 11, 42)**	**P values**	**Season (d. f. 1, 42)**	**P values**
Nitrogen (N)	1.16	0.343	14.67	<0.001
Phosphorus (P)	0.70	0.729	5.05	0.030
N:P	1.13	0.363	1.89	0.176
F-critical values				
α 0.05	2.04		4.08	
α 0.01	2.73		7.31	

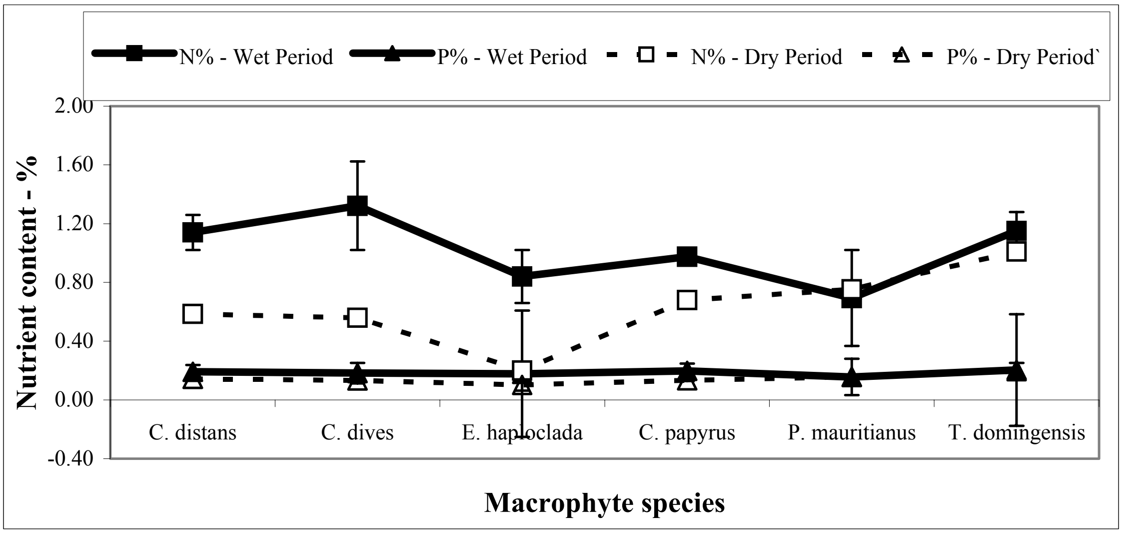

Figure 6.8: Macrophytes nutrient content among the different species

The same pattern of seasonal variability was repeated among the species, although this was not significant. All species showed high values in the wet season and correspondingly low values in the dry season. However, there were some differences among the species, with relatively high values observed in the transitional eco-type species such as *C. dives* and *C. distans*, while for *P. mauritianus* and *T. domingensis* differences between the wet and dry season in both total nitrogen and phosphorous content were minimal. In contrast to total nitrogen, total phosphorous showed only little variation between the wet and dry season, although both were statistically significant ($p = 0.001$ and $p = 0.030$, Figure 6.8, Table 6.4).

Although the N:P ratio showed no significant influence ($p = 0.176$), it exhibited some tendencies (Table 6.3, 6.4). Among the eco-types, relatively high average values were observed in the wet season (5.77±0.288) compared to the dry season (4.95±0.027; Figure 6.9). There was minimal variation across the eco-types, but relatively high values were observed in the transitional eco-types.

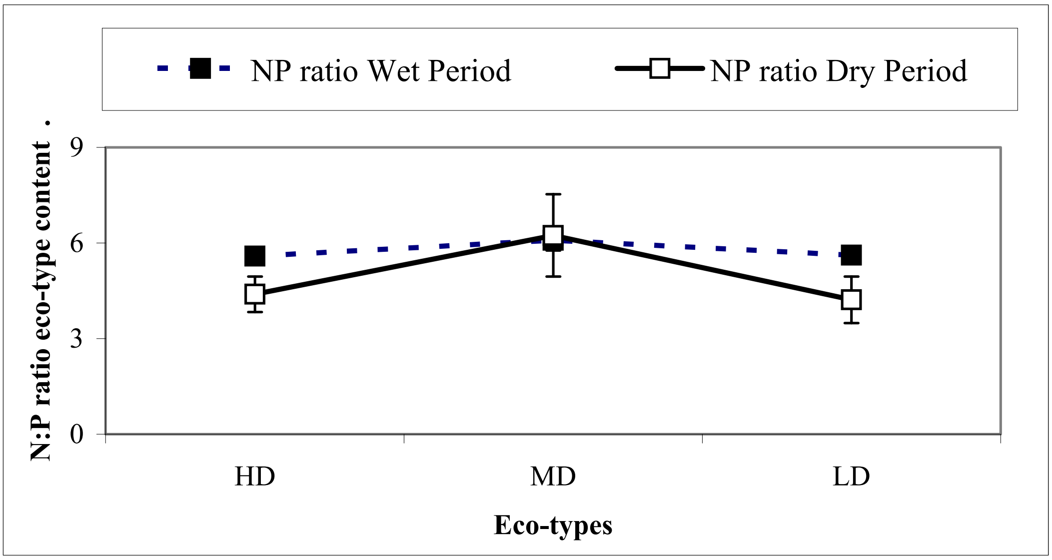

Figure 6.9: N: P ratio across the eco-types

Among the different macrophytes, the N:P values in the wet season were high compared to the dry season (Figure 6.10), however it was not significant (Table 6.4). On the other hand, relatively high values were observed in the transitional eco-type species, where there was a great difference between the wet and dry season. These variations could be attributed to other factors that were not considered in the experiment.

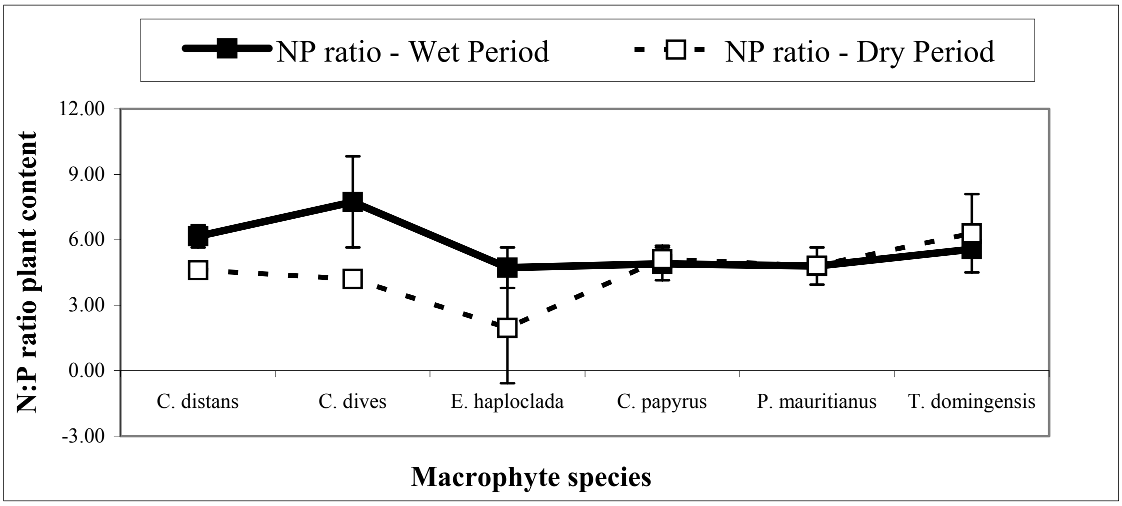

Figure 6.10: N: P ratio in macrophytes

Comparing the nitrogen and phosphorous content in the plant and in the soil subsystem, the macrophytes had a relatively higher nutrient content (Figure 6.11). However, only total nitrogen was significantly different ($p = 0.013$). Although phosphorous had a relatively high p value at 0.165, there was no significant influence. The relatively high values observed in the macrophytes were in spite of the fact that the dead biota and the underground macrophyte biomass were not considered in the nutrient analysis, which would have increased the biomass nutrient content. In both soil and plants, there was a gradual rise from the highly disturbed eco-types to the less disturbed eco-types. This relationship was also significant (p = <0.001).

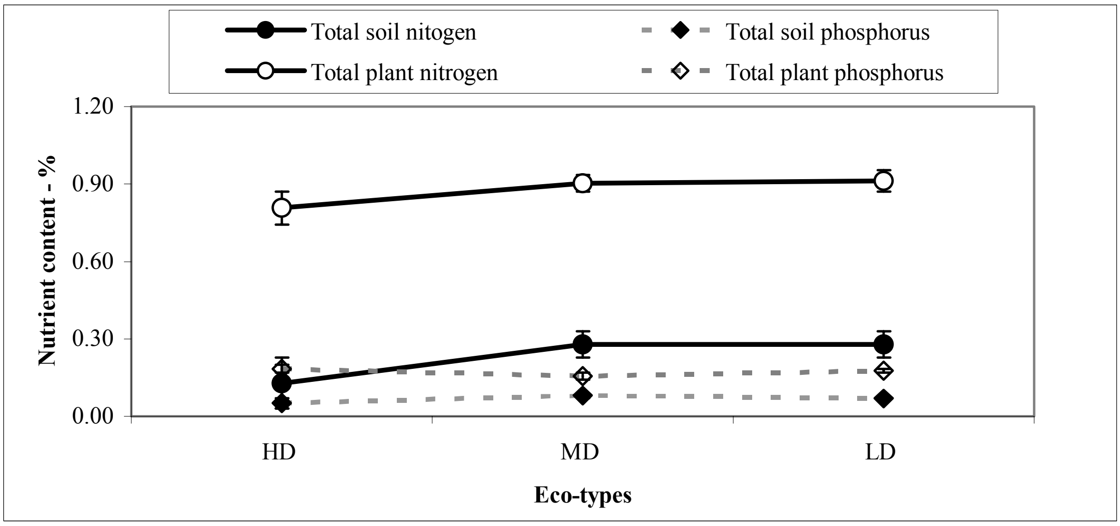

Figure 6.11: Nutrient content in soil and macrophytes

6.3 Ecological swamp dynamic

Wetland ecosystem ecology is largely dependent on the extent and duration of flooding, which in turn affect the spatial-temporal variability of the physico-chemical environment. The prevailing physico-chemical characteristics in a wetland ecosystem influence to a great extent the macrophyte species composition and occurrence depending on ecological zone. In this regard, selected ecological parameters were investigated in both soil and water. Soil parameters included pH, cation exchange capacity (CEC), total phosphorous (TP), extractable phosphorous (EXTRAC-P), total nitrogen (TN) and exchangeable potassium (EXCHK). Water parameters included pH, water-soluble carbon (WSC), electrical conductivity (Ec), TN and TP. These ecological parameters varied strongly in the swamp, which affected macrophyte growth both directly and indirectly. The following discussion is based on the results of these analyses.

6.3.1 Water characteristics

From the two-way ANOVA, all ecological parameters except pH and Ec varied significantly with either eco-types or seasons. The season dynamics emerged as having a greater influence on the water parameters than the eco-types. The water pH had high values in dry season and in the highly disturbed eco-type (Table 6.5). Correspondingly, high EC values were recorded in the dry season and in the highly disturbed eco-type.

Table 6.5: Mean and standard error values of water parameters in the Yala swamp

Ecological parameters	Grand Mean	Wet	Transitional	Dry	HD	MD	LD
pH	7.42	7.22 ±0.184	7.60 ±0.191	7.40 ±0.007	7.49 ±0.085	7.40 ±0.001	7.39 ±0.023
Ec (mS/cm)	0.64	0.596 ±0.11	0.397 ±0.21	0.828 ±0.220	0.89 ±0.281	0.58 ±0.022	0.54 ±0.059
Water soluble carbon–mg/l	2.46	2.94 ±0.75	2.75 ±0.280	1.72 ±0.47	2.17 ±0.298	2.93 ±0.455	2.22 ±0.254
Total phosphorus-mg/l	0.24	0.31 ±0.087	0.143 ±0.075	0.21 ±0.011	0.42 ±0.200	0.14 ±0.079	0.23 ±0.005
Total nitrogen-mg/l	2.79	3.73 ±0.876	2.81 ±0.038	2.01 ±0.84	2.36 ±0.48	2.85 ±0.003	2.98 ±0.131

HD- highly disturbed, MD- medium disturbed, LD- low disturbed

However, neither the eco-type nor the season had any significant effect on pH variability ($p = 0.856$ and 0.056 respectively, Table 6.6). The water pH was relatively more alkaline compared to the soil (5.5 - 6.2), with pH values increasing from the wet to the dry season, though slightly higher in the transitional period. This was in contrast to the pattern observed in the soil, where the transitional period showed low values. Spatially, the pH values dropped from the highly disturbed to the less disturbed eco-types (7.5 - 7.3), with similar trends for Ec and total water phosphorous.

Table 6.6: Analysis of variance of (ANOVA) of swamp water ecological parameters

Ecological parameters	Eco-type (d. f. 2, 81)	P value	Season (d. f. 2, 81)	P value	Eco-type /Season (d. f. 4, 81)	P value
pH	0.16	0.856	2.99	0.056	0.81	0.525
Electrical conductivity	0.70	0.490	1.74	0.182	1.35	0.260
Water soluble carbon	1.48	0.233	3.54	0.033	0.92	0.455
Total phosphorous	4.14	0.019	2.39	0.099	2.36	0.060
Total nitrogen	0.84	0.435	10.33	<0.001	1.53	0.210
F-critical values						
α 0.05	3.11		3.11		2.49	
α 0.01	4.88		4.88		3.56	

d. f. = degree of freedom

In the case of Ec (mean 0.51 ± 0.11), neither eco-types nor seasons were significant ($p = 0.490$ and $p = 0.182$, respectively; Table 6.6). However, Ec values increased from the wet to the dry season (Table 6.5), but with low values in the transitional period corresponding well with the shift in pH. In terms of spatial variation, Ec dropped from the highly disturbed to the less disturbed eco-types, which again correlated well with the pH variations across the eco-types.

Water-soluble carbon (WSC) (mean 2.45 ± 0.21; range 1.72 - 2.94 mg/l) was only significantly influenced by the season ($p = 0.033$, Table 6.6). Spatially, the WSC values increased from the highly disturbed to the less disturbed eco-type with values ranging between 2.2 – 2.9 mg/l (Figure 6.12), which was also closely related to the variability observed in pH.

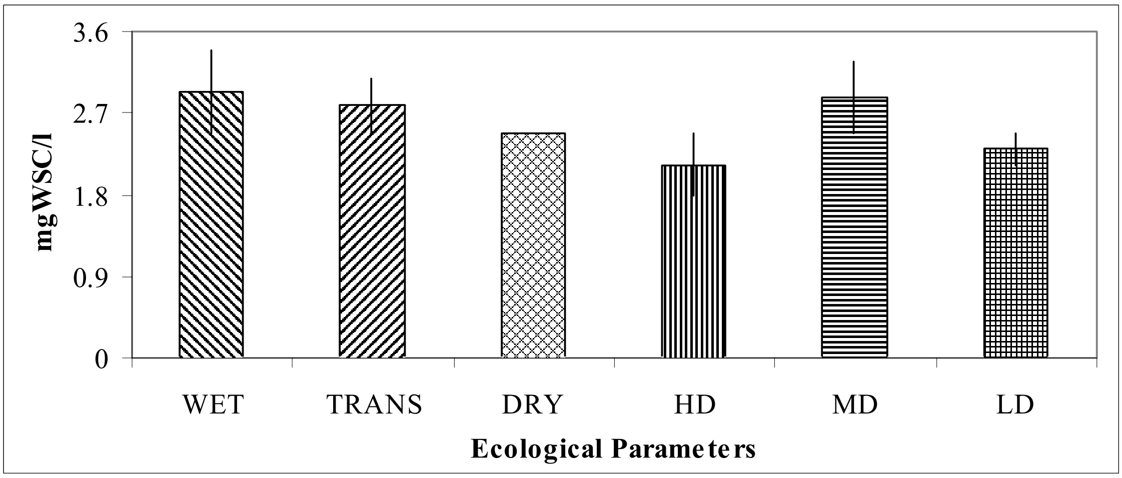

Figure 6.12: Variation of water-soluble carbon with eco-types and seasons

On the other hand, the total water phosphorous (TP) dropped from the highly disturbed to the less disturbed eco-type (0.14 - 0.4; Table 6.5, Figure 6.13), with the change from the wet to the dry season following the same trend. In addition, TP was influenced significantly by both eco-type and season variability ($p = 0.19$ and $p = 0.099$, Table 6.6).

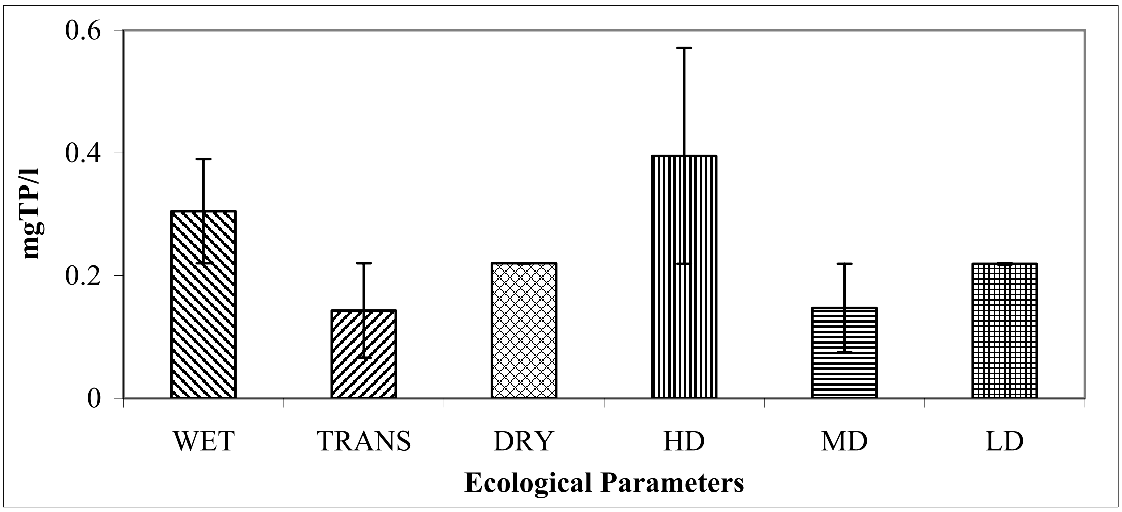

Figure 6.13: Variation of water total phosphorous with eco-types and seasons

However, only seasonality showed a significant influence on water total nitrogen (TN) ($p = <0.001$), which was also significant at $\alpha = 0.01$ (Table 6.6) with values ranging from 2.01 - 3.72 mg/l (mean 2.87 ± 0.17), decreasing from the wet to the dry season with the values across the eco-types increasing from the highly disturbed to the less disturbed eco-types (Table 6.5, Figure 6.14).

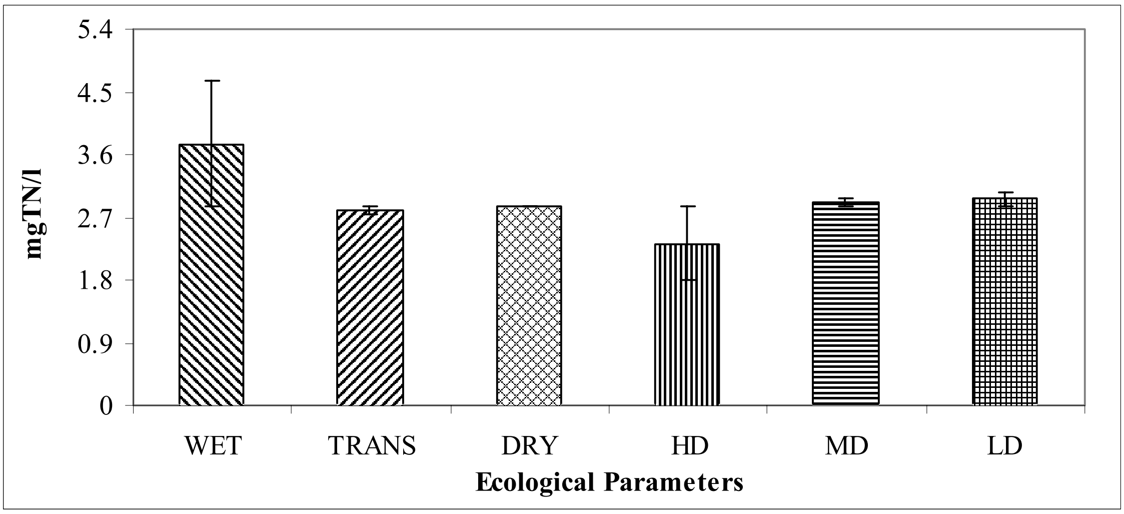

Figure 6.14: Variation of water total nitrogen with eco-types and seasons

6.3.2 Soil characteristics

The variability of ecological soil parameters was more strongly influenced by the eco-types than by seasonality. However, only CEC and TN indicated any significant effect of either eco-type or season. Variation of pH across the seasons and the eco-types was minimal (5.8 - 6.2), with slightly lower values in the wet season and in the less disturbed eco-type (Table 6.7). Correspondingly, high CEC values were observed in the wet season.

Table 6.7: Mean and standard error values of soil parameters in the Yala swamp

Soil Parameter n=45	**Grand Mean**	**Dry**	**Transitional**	**Wet**	**HD n=9**	**MD n=18**	**LD n=18**
pH	5.96	5.94± 0.02	6.15± 0.19	5.80± 0.17	6.92± 0.04	6.05± 0.09	5.90± 0.07
Cation exchange capacity-me/100g	3.17	2.34± 0.83	3.73± 0.56	3.45± 0.27	2.22± 0.95	3.47± 0.30	3.35± 0.18
Total phosphorus - %	0.07	0.07± 0.00	0.07± 0.00	0.07± 0.00	0.05± 0.02	0.08± 0.01	0.07± 0.00
EXTRACTP_M_ mg/kg	19.84	15.66± 4.18	25.19± 5.36	18.66± 1.17	23.17± 3.33	24.07±4.23	13.94±5.90
Total nitrogen - %	0.25	0.30± 0.05	0.18± 0.07	0.27± 0.02	0.13± 0.12	0.28± 0.03	0.28± 0.03
EXCHK_me/100g	0.46	0.41± 0.06	0.48± 0.02	0.50± 0.04	0.39± 0.07	0.49± 0.02	0.48± 0.01
Bulky density (BD)- g/cm^3 (dry season)	0.43	-	-	-	0.36± 0.12	0.37± 0.11	0.55± 0.07

HD- highly disturbed, MD- medium disturbed, LD- low disturbed

However, for soil pH (mean 5.96 ± 0.11), there was no significant variation with either eco-type ($p = 0.82$) or season ($p = 0.42$) at $\alpha = 0.05$ (Table 6.7, 6.8).

Table 6.8: Analysis of variance of (ANOVA) of swamp soil ecological parameters

Ecological parameters	**Eco-type (d. f 2, 36)**	**P values**	**Season (d. f 2, 36)**	**P values**	**Eco-type /Season (d. f 4, 36)**	**P values**
pH	0.20	0.818	0.87	0.428	0.17	0.875
Cation exchange capacity (CEC)	5.29	0.010	8.27	0.001	0.46	0.768
Total phosphorous	2.81	0.125	0.01	0.237	0.78	0.575
Extractable phosphorous	2.21	0.008	1.50	0.027	0.73	0.360
Total nitrogen	5.54	0.073	3.98	0.990	1.13	0.545
Exchangeable potassium	0.35	0.704	0.50	0.613	0.29	0.886
F-critical values						
α 0.05	3.27		3.27		2.64	
α 0.01	5.27		5.27		3.91	

d.f – degree of freedom

The CEC ranging from 2.2 - 3.2me/100g (mean 3.17 ± 0.18) was significantly influenced by both eco-type (p = 0.010) and season (p = 0.001; Table 6.8). The effects of eco-type and season were also significant at α = 0.01 (Table 6.8). However, combined eco-type and season interactions did not have a significant effect. When the means were subjected to post hoc least significance difference (LSD), significant changes with both eco-type (0.008) and season (0.009) were also recorded. In terms of spatial variability, low values were observed in the highly disturbed eco-type compared to the less disturbed eco-type (Figure 6.15).

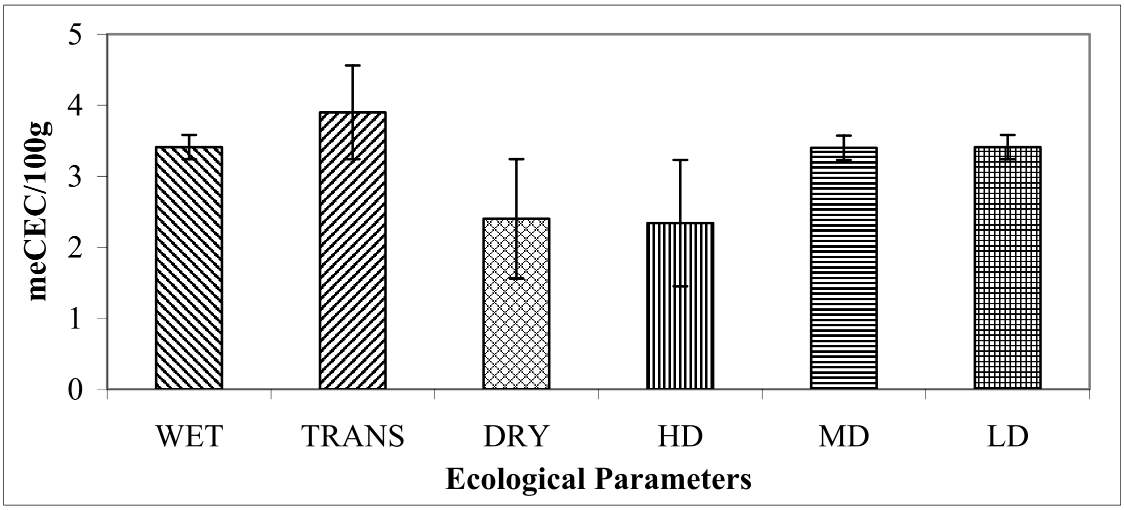

Figure 6.15: Variation of CEC with seasons and eco-types

In contrast, neither eco-type nor season had any significant influence (Table 6.8) on total soil phosphorous, which ranged from 0.04 to 0.07 (mean 0.07 ± 0.005). There was minimal variation across the season, but the values in the highly disturbed eco-type were lower than in the less disturbed (Table 6.7, Figure 6.16).

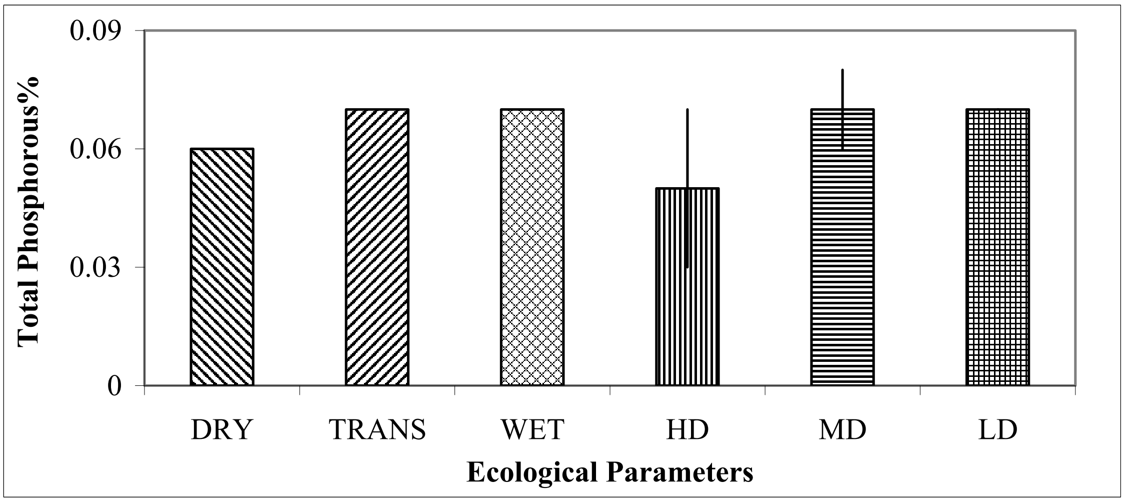

Figure 6.16: Variation of soil total phosphorous with seasons and eco-types

Extractable phosphorous ranging from 17 - 27 mg/Kg (mean 19.84 ± 2.36 mg/Kg) was also not significantly influenced by the seasons or eco-types ($p = 0.125$ and $p = 0.237$, Table 6.8). However, seasonal variability showed a drop from the wet to the dry season (Figure 6.17).

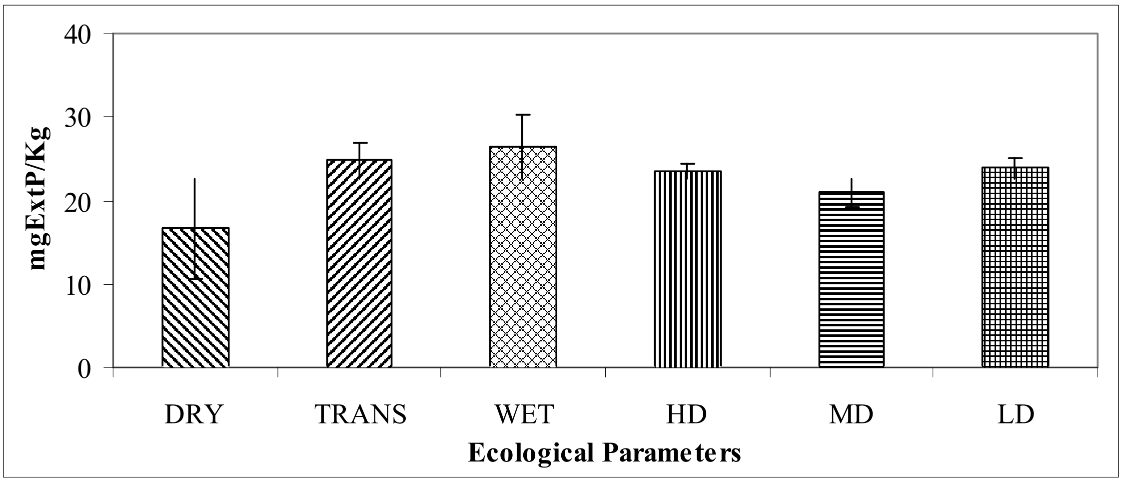

Figure 6.17: Variation of extractable phosphorous with seasons and eco-types

Total soil nitrogen (mean 0.25 ±0.02 and range 0.16-0.29) was significantly influenced by both the eco-types ($p = 0.008$) and seasons ($p = 0.027$) at $\alpha = 0.05$ (Table 6.8) with the eco-type having a significant influence even at $\alpha = 0.01$. Post hoc analysis was also significant with both the eco-types (0.021) and the seasons (0.024). Furthermore, relatively high values were observed during the dry season and in the less disturbed eco-type (Figure 6.18).

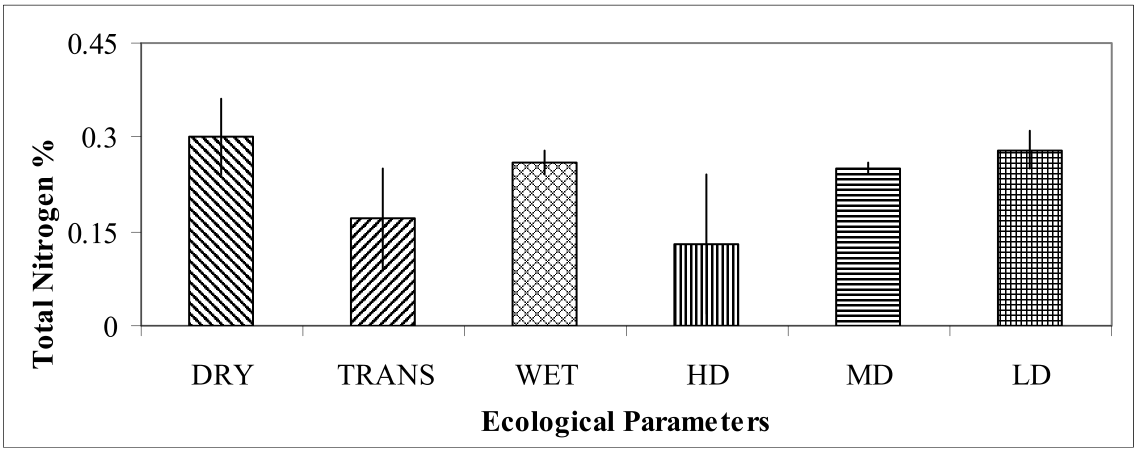

Figure 6.18: Variation of soil total nitrogen with seasons and eco-types

In contrast, there was no significant influence on exchangeable potassium either by eco-types or seasons ($p = 0.704$ and $p = 0.613$, Table 6.8). The eco-type value, range 0.39 –0.53 and mean 0.47 ± 0.039 me/100g, increased from the highly disturbed to the less disturbed eco-types with the same trend being superimposed across the seasons (dry to wet), (Table 6.7, Figure 6.19).

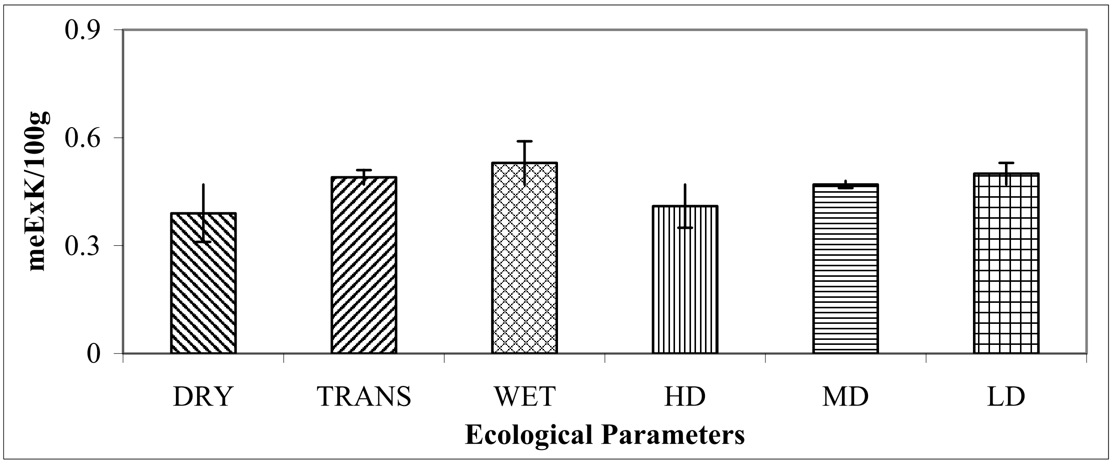

Figure 6.19: Variation of soil exchangeable potassium with seasons and eco-types

Soil bulk density values ranged between 0.36 – 0.55 g/cm3, across the eco-type increasing from the highly disturbed to the less disturbed eco-types (Table 6.7, Figure 6.20).

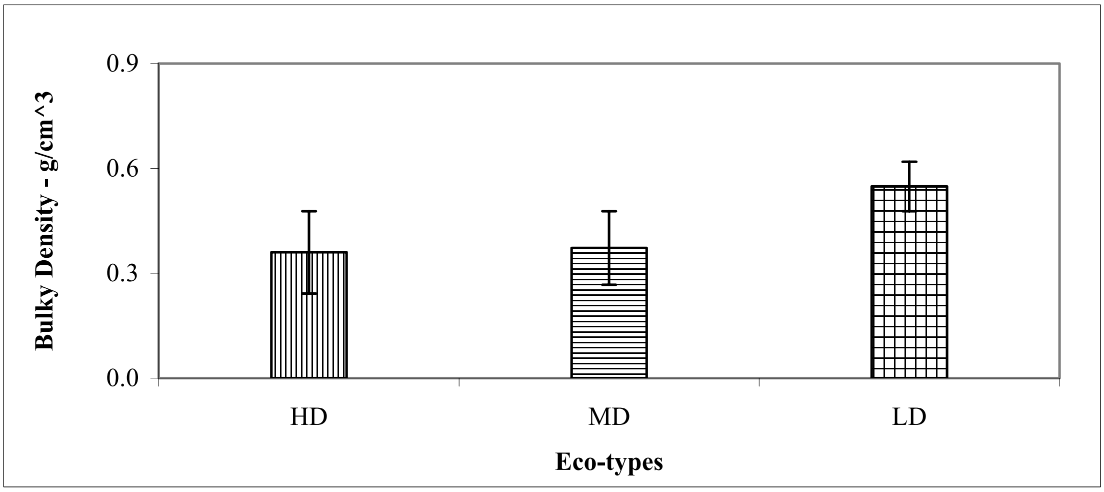

Figure 6.20: Average soil bulky density variation with eco-types

6.4 Discussion

Although ecological productivity is often expressed as the amount of biomass produced within a given time, the prevailing ecological parameters are also important. In wetland ecosystems, nitrogen and phosphorous dynamics in particular play a very important part in determining the overall productivity of macrophytes. Other important ecological parameters include flooding, pH and cation exchange capacity. These aspects are important in determining the variability in productivity. Ecological dynamics, especially in the tropical wetlands, are strongly tied to the seasonality of flooding and anthropogenic activities. Thus, amount of biomass and growth pattern are strongly influenced by the seasonal pattern of water input and the variations in water volumes (Gaudet, 1978). The Yala swamp ecosystem is characterized by heavy flooding in the wet season followed by increased human activities in the dry season. These activities include farming, grazing, macrophyte harvesting, and brick making in the dry season, which significantly alter the ecological set-up. Brick making in particular has the effect of removing soil including the top soil, which has most nutrients that are essential for ecological growth.

6.4.1 Water quality dynamics

The water-pH values recorded in the Yala swamp were similar to those recorded by Aloo (2003), which were within the alkaline range. The values also showed similar variability with soil pH, increasing from the wet to the dry season and the less disturbed to the highly disturbed eco-types. However, the water environment was more alkaline (7.6) because the water has the ability to dissolve solutes from the substrate, hence the ability to maintain pH values above those of the underlying acidic soils (Barnes *et al.,* 2002). The vigorous decomposition process within the wetland substrate is also known to lead to acidic conditions due to the enhanced oxidation-reduction process. However, the slightly lower values in the wet season and in the less disturbed eco-types were the result of the influence of the prevailing anaerobic conditions in the substrate. Although, more alkaline swamp water (pH 8) has been recorded in other swamps in East Africa, this was attributed to the highly volcanic geological formation of the catchments (Gaudet and Melack, 1981; Njuguna, 1982; Mbuvi and Mainga, 1991; Thenya, 1998). Lake Victoria Basin, however, has no significant volcanic influence since it was formed as a result of vertical up-warping (Bugenyi *et al*., 2001). Nevertheless, the local Yala swamp geology is alkaline, which contributes to the high alkalinity in the swamp water subsystem.

The electrical conductivity (Ec) values recorded in the Yala swamp water subsystem were within those recorded by Aloo (2003) in inland water systems. These values were more than fives times those reported for Lake Victoria (Njuru and Hecky, 2005). However, no study exists on the seasonal or spatial variability. High Ec values were maintained throughout the year in the swamp. As Ec is dependent on the concentration of solutes in an ecosystem, during the wet season, the water ions were probably highly diluted and this lowered conductivity. As the water amount reduces in the dry season, the solute concentration increases, shifting the pH towards alkalinity, which results in a rise in conductivity. In terms of ecological units, the less disturbed areas were more or less like the wet season with lower pH values. This had the effect of lowering conductivity due to the presence of high amounts of ions and organic acids.

There was high and wide variability in the Ec values observed in the Yala swamp. These high Ec values, ranging from 400 –900 µS/cm, were mainly due to the influence of the local geology with minimal ions coming from the catchments. This was a strong contrast to the observations reported from the Rift Valley Lakes (Gaudet and Melack, 1981; Njuguna, 1982; Mbuvi and Mainga, 1991) and Laikipia wetlands (Thenya, 1998), where the effect of catchments was significant in contributing solutes. Nevertheless, the values observed in the Yala swamp compares well with those wetland ecosystems that are highly influenced by the volcanic geological formation like the Rift Valley wetlands with values around 300 µS/cm. The local geological influence is strongly exhibited by the spatial variability of conductivity in the Yala swamp ecosystem. For example, although the area along the Lake Victoria shoreline had high Ec, the southern side of the swamp was more alkaline (1,310 µS/cm) compared to the northern section (520 µS/cm). In contrast, the satellite Lakes indicated a different scenario with high water conductance in the inland Lake Kanyaboli (190 µS/cm) and low values in the shoreline Lake Sare (100 µS/cm). The former could be due to the effect of reduced water inflow after the Yala River diversion in the early 1970s (GoK, 1994), while the latter experiences the benefit of macrophytes filtration, hence lower conductivity values. Okemwa (1981) made similar conductivity gradient between the satellite lakes although the range was slightly higher.

The unlikely effect of the catchment is emphasized by the low values in the rivers water. Both of the Rivers Yala and Nzoia had low Ec values at 80 µS/cm, which makes them unlikely sources of solutes to the swamp and the satellite Lakes. Njuru and Hecky (2005) attributed the source of solutes to the Lake Victoria from the inflowing rivers, which is unlikely. The swamp area especially the sandy and murram border as well as the cultivated sections along the Lake Victoria is most likely to be the net source of solutes to the Lake Victoria. This area is also characterized by numerous anthropogenic related disturbances, especially along the southern and northern side of the swamp, which are likely to trigger release of solutes into Lake Victoria. These solutes include both nutrients like nitrogen and phosphorous plus sediments.

The main source of the water-soluble carbon (WSC) in swamps is the autochthonous material from the decomposition of the macrophytes and the slow water movement. In this regard, high values were observed in the less disturbed and the transitional eco-types as well as during the wet season. This corresponds also to high amounts of phosphorous, nitrogen and macrophytes productivity that is, both the increase in the plant biomass and the high post-harvest growth. The presence of WSC affects the acid-base chemistry by shifting the pH towards acidity, which increases the availability of some nutrients like phosphorous and nitrogen (Keeland and Conner, 1999). WSC is also an important source of energy and nutrients to the microbial food chain, which promotes mineralization. Soils with high WSC also tend to have high phosphorous availability and subsequent high plants uptake according to Scott and Condron, (2005). Since the production of detritus material is higher than its decomposition in the natural wetlands, organic matter accumulates, which favors the reduction process that in turn promotes nutrient availability. Hence, the relatively higher growth rate of macrophytes in the less disturbed eco-types as compared to the highly disturbed and the dry season.

The high nitrogen values that were observed in the Yala swamp in the wet season as well as in the less disturbed ecological units were due to enhanced nitrogen fixation by macrophytes. This pattern of nitrogen variability corresponds well with other observations in East African wetlands, i.e., in Lake Naivasha by Gaudet and Melack (1981), Muthuri (1985), and Mwaura (1981) and in Uganda swamps by Lind and Visser (1962). This pattern is also associated with the catchments flushing effect during the rain season. In low redox potential environments such as in the less disturbed sites, organic nitrogen is converted to nitrate and ammonium nitrogen, which is available in the overlaying water (Jones, 1987). This pattern of variation also corresponds well with the increase in biomass and the observed high post-harvest growth, since nitrogen is useful in biomass accumulation. Note, however, that nitrogen values below 0.714 mg/l have been found to be limiting ecological productivity according to Viner (1973); however, the values observed in the Yala swamp were above this value even in the dry season.

Phosphorous availability was high in both the highly disturbed areas and during the wet season. The presence of high redox potential in the highly disturbed eco-types triggers the process of releasing phosphorous from the sediments, hence its availability in the overlying water. However, during the wet season, the relatively high phosphorous amounts in the water as observed in the Yala swamp is due to the additional discharge from the catchment areas as observed by other scientists (Njuguna, 1982). This has also been observed in the LVB as a result of phosphorous being washed down from the farming and the deforested areas in the catchments (ICRAF, 2001; Njuru and Hecky, 2005). The prevailing anaerobic conditions in the wet season promote phosphorous conservation by encouraging adsorption onto the soil particles in the presence of iron and manganese oxides (Gaudet, 1979, Njuguna, 1982; Thenya, 1998; Gilliam *et al.,* 1999). This increases chances of availability of phosphorous to the macrophytes, which corresponds well with the high post-harvest growth rate and the overall high biomass gain in the wet season.

In addition, to the catchment contribution, other likely phosphorous sources are dry-season specific and include decomposing organic matter, and excrements from livestock and wild animals like hippopotamus. Phosphorous input from livestock has been noted in the Lake Naivasha north swamp (Gaudet, 1979). In the Yala swamp, dry season grazing is an important socio-economic activity and the swamp also has numerous large herbivores like hippopotamus. Unfortunately, these phosphorous sources promote macrophyte growth only in the wet season due to the unfavourable environment for nutrient circulation in the dry season. Since the phosphorous sources in the Yala swamp, both exogenous and autochthonous, vary widely, further investigations are necessary to determine specific sources and their proportionate contributions. It is also possible to hypothesize that disturbed parts of the swamp are the likely source of phosphorous into the lake ecosystem, especially through pathways, where macrophytes filtration has been removed. This is in addition to the urban sewage discharge to the main Lake Victoria (Njuru and Hecky, 2005).

6.4.2 Soil chemistry dynamics

Since wetland soils are found in depressions or low-lying areas, their soil forming factors are strongly influenced by the presence of water, vegetation and drainage. This results in hydromorphic soils that are rich in humic acids and hemicelluloses. The soil characteristics also reflect the geology of the area and the prevailing human activities. For example, land-use pattern and vegetation cover have a strong influence on soil fertility variation in the swamp, with farming leading to reduced organic matter in the soil (Lung'ayia *et al.,* 2001), while the geological set-up influences soil composition.

The soil pH values in the Yala swamp were found to be slightly acidic (5.2 - 6.2). Similar observations have been made in wetland soils within East Africa, (Gaudet, 1977; Mavuti, 1989; Crafter *et al.*, 1992). The tendency towards acidity results from the reduction processes that release hydrogen ions in anaerobic reactions. The low pH in the wet season and in the less disturbed eco-types was due to the prevailing anaerobic conditions in the swamp, while the alkaline soil pH in the highly disturbed eco-type and in the dry season was due to the accumulation of carbonates of calcium and magnesium (Jones, 1987; Mbuvi and Mainga, 1991). This was because of the reduced anaerobic conditions and the high decomposition rates. These results are in line with swamp pH values observed in other parts of the country such as the Laikipia wetlands (Mbuvi and Mainga, 1991; Thenya, 1998). Note, however, that pH values below 4 have been observed to contribute to nutrient deficiency, but the values obtained in the Yala swamp were above this, even during the wet season.

Cation exchange capacity (CEC) is pH dependent with high exchange rates being associated with organic soils due to the presence of hydrophilic colloids mainly humic acids and hemicelluloses. The results obtained in the Yala swamp correspond to this argument, and values increased from 2.3me/100g in the highly disturbed eco-type to 3.4me/100g in the less disturbed. The CEC values obtained in the Yala swamp were within the range of other studies in the tropics (Mbuvi and Mainga, 1991; Thenya, 1998). This means that the soils are able to attract and retain positively charged elements as plant nutrients (FitzPatrick, 1988), especially in the less disturbed eco-types. The ability to retain nutrients decreases with ecological disturbance, resulting in leaching tendencies. Temporal changes from the wet to the dry season result in reduction of CEC, as organic matter and colloids levels drop. Similarly, the pH shifts to alkalinity reducing nutrient availability for plant growth, hence low ecological productivity.

The concentration of exchangeable potassium observed in the highly disturbed eco-type was lower than in the less disturbed eco-type. These variations closely followed CEC dynamics, which emphasized cation variability in the swamp with both seasonality and ecological aspects. In natural wetland, solutes like potassium and sodium get concentrated in the soil through plant transpiration processes (Barnes *et al.*, 2002). However, in the disturbed eco-types, the ions are dissolved and exported out of the ecosystem into the water and also depleted by the dry season farming, hence the low values. All values observed in the Yala swamp were below 0.5me/100g soil, which correspond to values recorded in other wetland studies in Kenya (Mbuvi and Mainga, 1991 and Thenya, 1998). This means that the converted wetland ecosystem units have a reduced capacity for macrophytes regeneration.

The Yala swamp is extensively cultivated and grazed during the dry season and, based on the vegetation composition alone, this could give an erroneous scenario of natural eco-types. In the dry season, large sections of the swamp, especially in high flooding areas, are opened up for farming and grazing by the local communities, leading to soil compaction, which again affects soil bulk density. The bulk density values in the swamp ranged between 0.36 g/cm^3 in the highly disturbed eco-types and 0.55 g/cm^3 in the less disturbed eco-types. This increase was unexpected, however, the variation can be attributed to the soil compaction during the intermittent dry season conversions and grazing (Andriesse, 1988). However, the values observed here were still lower than those recorded in the adjacent farms by Mfundisi (2005), which ranged between 0.6-1.3 gcm^3.

According to other wetland studies in the Ewaso Narok swamp, Kenya, (Thenya, 2001) and in Ethiopia (Abebe and Geheb, 2003), wetlands are able to reclaim large sections that are converted in the dry season through flooding in the wet season. In the process, a significant proportion of the original vegetation is re-established and a large amount of organic material is deposited. Although this results in increased nutrient availability, it is unlikely to alter the compaction level of the soil. It is also important to point out that large sections of the natural swamp in the Yala swamp area are not accessible due to the presence of thick macrophytes and flooding, therefore lower bulk density is likely much deeper within the swamp.

Nitrogen concentration in the swamp was relatively low with a maximum value of 0.30%±0.03 during the wet season. Mfundisi (2005) found average total nitrogen of 0.40%±0.29 in the Yala swamp, which was within the range of the values found in this study. Mitsch and Gossenlink (1993) reported similar total nitrogen values of between 0.35 and 0.66% in the freshwater marsh of the Atchafalaya Delta, USA. In the flooded soils, nitrogen occurs in high percentages in form of ammonium nitrogen, nitrates, and undergoes conversion into nitrogen gas through denitrification, due to the low prevailing redox potential (Jones, 1987). Low nitrogen values in the Yala swamp during the wet season were attributed to the accelerated denitrification that was favored by the prevailing low redox potential. These findings also correlate well with observations made in other tropical swamps (Thenya, 1998). As the flooding levels goes down in the dry season, nitrogen fixation and denitrification reduced on the overall. Thus, although the amount of total nitrogen in the wetland during the dry season is high, it is in forms not useful to the macrophytes, due to the reduced nutrient transformation. Verhoeven and Schmitz (1991) observed that, since nitrogen is important in promoting vegetative growth, reduction during the dry season and in the disturbed eco-types has an overall effect of hampering vegetative growth. Similar observations were made in the Yala swamp with regard to macrophyte post-harvest growth.

In the case of both total phosphorous and extractable phosphorous, the high values in the wet season and in the less disturbed eco-types were due to the low redox potential. This corresponds well to the effect of anaerobic conditions on phosphorous availability (Kyambadde *et al.,* 2004). These conditions promote phosphorous adsorption onto the soil particles in the presence of iron and manganese oxides (Thenya, 1998; Gilliam *et al.,* 1999). The low amounts of phosphorous in the highly disturbed eco-types and in the dry season occurred because, in the presence of a high redox potential, phosphorous is sorbed away and gets lost from the ecosystem. Therefore, the wet season and the less disturbed eco-types had more ecologically favourable conditions for macrophytes growth since phosphorous was more readily available. This corresponds well with high post-harvest growth rate and overall high biomass gain in the two scenarios.

6.4.3 Macrophytes nutrient storage

The increase in the critical nutrients nitrogen and phosphorous in the plant biomass is mainly due to the response from outside stimuli (U.S EPA, 2002; Kyambadde *et al.,* 2004). For example, according to Kansiime *et al*. (2003) passing of raw sewage through *C. papyrus* under natural conditions increased macrophyte above-ground biomass nitrogen and phosphorous from 0.98% N and 0.18% P to 1.6% N and 0.23% P (dry weight) in the Nakivubo wetland, Uganda (Kansiime *et al.,* 2003). This also similarly increased the N:P ratio from 5.44 to 6.95.

The values obtained in the Yala swamp ecosystem were well within the range of the other studies in the Yala swamp. In 2005 (Mfundisi, 2005) observed a value of total nitrogen 1.32±0.6% which was within the findings in this study (1.2±0.5%). The macropyhte nutrient values in the Yala swamp were also within Nakivubo natural swamp level (Kansiime *et al*., 2003) and were also above ecological limiting levels in wetlands. The Yala swamp is surrounded by small-scale farms with a fertilizer input too low to act as a source of nutrients. Again, nutrients flushed from the catchments are transported mainly along the rivers canal directly to Lake Victoria, and input into the swamp is minimal and widely spread. These two scenarios minimize chances of swamp nutrient enrichment. The variability observed in the Yala swamp eco-types was attributed to the flooding dynamics as well as to the anthropogenic effect. The higher macrophytes nutrient content in the less disturbed eco-types was due to the high nutrient transformation to assimilatable form by plants, which results in more uptake. The amount of macrophytes nutrient level reduced in the dry season as less nutrients transformation took place. Several authors among them Kansiime *et al.* (2003) and Kyambadde *et al.* (2004), observed that uptake of nutrients corresponds to availability, with luxuriant uptake where nutrients occur in high amounts as observed in the Yala swamp. Thus, the plant nutrient uptake is not triggered by negative temporal variation in the ecological set up such as the reduced flooding in the wetland ecosystem, but by the favourable wet conditions. In the low flooding and dry periods, a large proportion of the nutrients are locked in the dead macrophyte biomass, hence it is unavailable to the growing macrophytes. Therefore, a high plant nutrient content in the living macrophyte biomass reflects healthy ecosystem functioning, with high availability of nutrients.

Comparing the values of both nitrogen and phosphorous in the soil and in the macrophytes in the Yala swamp, relatively more nutrients were stored in the plants compared to the soil. Similar observations were made by Silvan and Laine (2004) on studies in wetlands nutrients. Mfundisi (2005) observed similarly higher nutrient content in plants as compared to the soil subsystem. This could be due to the frequent changes in the water level in the swamp, which affect nutrient availability. The high nutrient availability in the wet season, triggers high nutrient conservation in macrophytes, as a crucial ecological survival technique. Due to the high rate of decomposition and strong leaching tendency in the tropics, plant biomass normally has a higher nutrient content than soil, which was also observed in the Yala swamp. Further studies on the nutrient off-take with the macrophyte harvesting are necessary, especially with the likelihood of higher macrophytes harvesting with local population increase.

6.4.4 Macrophytes post harvest growth and biomass dynamics

Wetland vegetation is known to respond to nutrient availability by increased primary production (Craft *et al.,* 1992). This increase is reflected in increased above-ground biomass and increased phosphorous and nitrogen content in the macrophyte biomass (Kansiime *et al.,* 2003; Kyambadde *et al.,* 2004). Similar observations were made in the Yala swamp across both seasons and the eco-types. For example, post-harvest macrophyte growth and increase in the above-ground biomass were closely related to the changes in the environmental parameters both in the soil and water. All macrophyte species were characterized by relatively high growth rate in the post-harvest period, both in the less disturbed eco-types and during the wet season. Those eco-types characterized by heavy flooding were also found to have an overall high average height compared to areas that had low flooding. This was attributed to the prevailing favourable ecological environment for high primary productivity, which included high amounts of water-soluble carbon. According to Gilliam *et al.,* (1999) water soluble carbon facilitates mineralization, which results in high nutrient availability. The prolonged hydro-period favored accumulation of colloids and together with the associated slightly acidic pH environment favored high cations exchange that was also favourable for high post-harvest macrophyte growth.

As the wet period reduced and the swamp was opened for farming, the ideal ecological set-up for macrophyte growth was reversed. In natural wetlands, production of detritus is higher than its decomposition resulting in accumulation, which favors reduction process that in turn promotes nutrients availability (Davis, 1991). However, in the transformed eco-types there is less organic matter accumulation that in turn results in relatively lower CEC, which together with other unfavourable ecological conditions suppress macrophyte growth. The reduction of the organic material in the highly disturbed eco-types caused a shift of the pH to alkalinity, which was unfavourable for cation exchange. In addition, the presence of a high redox potential also in the highly disturbed eco-types led to phosphorous being easily sorbed away from the ecosystem coupled with lower nitrogen fixation. These factors, combined with less flooding, were detrimental to macrophyte growth resulting in less biomass and height gain overall. According to Verhoeven and Schmitz (1991), nitrogen is important in promoting vegetative growth, thus a reduction in the dry season and in the disturbed eco-types has an overall effect of slowing down vegetative growth.

According to Nalubega and Nakawude (1995), nutrient uptake by macrophytes is high in the first four weeks of growth and thereafter reduces, with macrophyte biomass change following the same trend. Similar growth characteristics were made in the Yala swamp, across both the seasons and different eco-types. Despite the unfavourable changes in the ecological conditions during the dry season, macrophyte growth in the first four weeks was still fast. The relatively lower rate of macrophyte growth in the subsequent post-harvest sessions (2nd and 3rd) as the flooding reduced was due to low nutrient availability as nutrients were held up in the dead plant biomass. According to Keeland and Conner (1999), the recycling of nutrients through dead biota reduces nitrogen and phosphorous availability, which are critical in plant growth. Thus, although, the values obtained in the Yala swamp were above ecological limiting levels, even in the dry season, reduction in circulation still put a strain on macrophyte growth. These results indicate that the reduction in height gain and the lower biomass gain were not the effect of continuous harvesting. It was the change in ecological status like flooding, which had a negative effect on nutrient circulation. Similarly, variability of macrophyte growth with nutrient dynamics have been observed before (Nalubega and Nakawude, 1995; Keeland and Conner, 1999).

The shift in the macrophyte biomass across both seasons and eco-types was found to be closely linked to the changes in nutrient levels. Similarly, in an experimental design where sewage was discharged through macrophytes in the Nakivubo wetland Uganda, the above-ground biomass increased from 1,983g dry wt m^2 to 3,973g dry wt m^2, which was a 50% change (Kipkemboi *et al.*, 2002). Thus, although these values in the Yala swamp were lower than in the Nakivubo wetland, there was a 50% change between the wet and dry season from 969g dry wt m^2 to 694g dry wt m^2. These changes corresponded to the Nakivubo observations, where the wet season simulated sewage nutrient enrichment. Using the average macrophytes productivity of 880g dry wt m^2 and the total macrophytes coverage of 15,482 ha, less converted areas, water and bushes coverage. Then the approximate Yala biomass productivity is about 1.4 $x10^8$ tonnes dry weight per fourteen week period on average.

In spite of these temporal changes, two important ecological observations were made with regard to macrophyte submergence after harvesting. In case of *C. papyrus*, when the plants were submerged immediately after harvesting, there was delayed shooting compared to non-submerged shoots, but thereafter growth was normal. In contrast, the *C. dives* completely failed to regenerate when submerged immediately after harvesting before shooting took place. This was attributed to the fact that *C. dives* thrives in the less flooded eco-types, but is able to withstand flooding once the shoots are above the water submergence level. Depressed shoot development in submerged areas has been observed in other wetland research as a part of combined multiple stressors like reduced light penetration (Sager *et al*., 1998). In some cases, it has also been observed to affect aboveground biomass. It was concluded that this behaviour was species specific, and different species could respond differently to submergence.

Another notable observation in this study was that, in spite of the effect of temporal variability (wet-dry) in the growth rate and biomass gain, the macrophytes retained the 14-week growth cycle in all eco-types and across the seasons. Growth was fast in the first 4 weeks after harvesting both in the wet and dry season, followed by reduced growth rate in the next 10 weeks, after which growth was minimal. Those macrophytes that were not harvested showed a minimal height gain after the 14th week, while the harvested plants grew fast in the first 14 weeks in spite of the reduced flooding in the wetland as the dry season set in. Therefore, 14-week intervals could be optimal for macrophyte harvesting. Most studies have monitored macrophyte growth for 6-8 weeks (Nalubega and Nakawude, 1995; Keeland and Conner, 1999, Kansiime *et al.,* 2003; Kyambadde *et al.,* 2004). In these studies reduction in nutrient uptake have been associated with reduction in macrophyte growth. Hence, the results in Yala swamp present a longer monitoring period in natural settings. This implies that other factors such as ecological parameters, seasonal variability and plant nutrient uptake have a greater effect on growth than the effect of harvesting as demonstrated above.

6.4.5 Conclusions

Environmental dynamics in the Yala swamp vary widely, both spatially and temporally. The spatial distribution of the various types of ecological units is influenced by wetland transformation through utilization by the indigenous communities, mainly through small-scale farming and macrophyte harvesting. In addition, the bi-annual flooding adds a significant temporal variable. For example, conducive environmental conditions for macrophyte growth reduce from the wet season to the dry season, which was also superimposed across the less disturbed to the highly disturbed eco-types.

In spite of the dry season conversions, the Yala swamp is able to spring back to high ecological productivity in the wet season due to heavy flooding. In addition to allowing the deposit of nutrients from the catchments, the wet season allows macrophytes to regenerate in previously cultivated areas through improved ecological conditions. Nutrients are also released from the dead biomass as flooding increases. This is important, since a high percentage of nutrients are concentrated in the macrophyte biomass relative to the soil subsystem. However, the swamp does not suffer from nutrient limiting levels. Due to the extensive conversion of the swamp in the dry season, especially along the edges at times extending for over a hundred meters, bulk density is highly variable around the swamp

Significant macrophyte growth was limited to the first 14 weeks, with fast growth being recorded in the first 4 weeks, thereafter greatly reducing. This cycle corresponds to the macrophyte nutrient uptake, which have been recorded in other studies. However, the seasonal ecological variations slowed down the growth rate more strongly than harvesting, especially in the dry season due to the reduced nutrient circulation level. In addition, ecological disturbance, especially conversion to farming, had a significant negative effect on macrophyte growth.

These results indicate that it is possible to manage macrophyte harvesting based on the 14-week interval with a slightly prolonged harvesting interval in the dry season due to the overall reduced ecological productivity. However, this should be accompanied by studies on the effect of nutrient off-take with macrophyte harvesting, which was not evaluated in this study.

7 SPATIAL AND TEMPORAL ANALYSIS OF LAND-COVER TYPES

7.1 Introduction

The observed variability of land cover in the Yala swamp was attributed to both anthropogenic activities as well as natural processes like flooding. These land covers indicated that a significant portion of the swamp was still, under macrophyte cover in spite of the expansion of the human influenced land-cover changes between 1973 and the year 2001. These changes included both agricultural areas as well as the disturbed ecological sites. The most prominent change was the increase in agricultural land at the expense of sedges-papyrus communities. The influence of human activities on land cover was related to the proximity causes like subsistence farming or policy initiatives. The pressure to convert the swamp emanates from high dependence on the Yala swamp by the local communities. Macrophyte harvesting, grazing and farming exert high pressure on the land cover. Particular hot spots of land-cover change were identified along the edges, but with a higher proportion on the northern side relative to the other part of the swamp.

7.2 Land-cover analysis

7.2.1 Distribution of vegetation communities

The vegetation species collected in the Yala swamp (Appendix 7) were grouped into five major formations based on species association and location of occurrence. Since wetland vegetation formations are strongly influenced by combination of flooding, landscape and ecological disturbances, these factors were considered in the grouping of the species and the formulation of vegetation communities. The vegetation communities were classified according to Pratt and Gwynne (1978), which is the vegetation classification commonly used in East Africa. A total of 68 plant species were collected, which were represented in 27 families (Appendix 7). The communities were as follows: (1) *Cropland complex (conversion),* (2) *Phoenix reclinata-Brachiaria brizantha-Eucalyptus*, (3) *Cyperus papyrus-Phragmites mauritianus-Typha*, (4) *Cyperus dives C. papyrus Phragmites*, and (5) *C. dives-Sesbania sesban.* These vegetation formations were later overlaid with the satellite-derived land cover with the assistance of the GPS points taken at each vegetation transect (Figure 3.2). The details of each vegetation formation are presented below with the shorter version of the vegetation communities names in parenthesis, which is used in land-cover maps.

Cropland-complex (conversion) **community (<u>Conversion – cropland-settlement complex)</u>**

This coverage represented areas that had undergone widespread conversion all around the swamp, especially along the edges. It had wide coverage in the northern and north-western section of the swamp, to the south of Lake Kanyaboli and in the south-eastern section (Figure 7.1 and 7.2). The details of transformation are given in Figure 7.4-7.6. Scattered macrophytes were found along the rivers and lakes, but much of the land had been colonized by annuals like *Tagetes minuta* Linn. J. Essen, while the water canals and small water pools were colonized by *Azolla Africana* Desv., *Senna obtusifolia* L. Irwin and Barneby with Onagraceae *Ludwigia stolonifera*-(Guill. & Perr.) Raven on flooded farms.

The canal banks were occupied by compositae *Melanthera scandens* (Schumanch and Horn) Roberty, grass *Digitaria velutina* (Schweinf) Chiov and *Hyparrhenia rufa* plus the introduced legume *Mimosa pigra* L. The area along the swamp edges had an assemblage of compositae *Sphaeranthus gomphrenoides* O. Hoffm, *Vernonia purpurea* (*E. dummeri, V. dummeri*), gramineae *Leersia hexandra* Sw. (Rice) and *Sporobolus pellucidus*. The regrowth in the cultivated areas was comprised of *Amaranthus spinosa*-(L.) R. Brown ex. DC., *Gomphocarpus seulunatus*, composite *Enydra fluctuans* Lour., Leguminaceae *Sesbania sesban* L, *Clitoria tarnate* L and *Senna occidentalis* L. All species together formed thick bushes in the wet season. Crops grown here included maize, beans, cabbages, sugarcane and bananas, among others. Due to the high flooding in the wet season from May to August, most of the converted land had been abandoned. This gave a good chance for the species to briefly re-establish prior to sampling. Hence, a good representation of the species composition in this zone was captured.

Phoenix reclinata-Brachiaria brizanthae-Eucalyptus **community (<u>Bushes-I– Eucalyptus- Phoenix –Hibiscus)</u>**

This vegetation community was widely spread along the ecotone and the drier sections of the swamp. It had wide coverage in the south-western part of the swamp but sparse coverage on the northern side. Phanerophytes in the area included *Eucalyptus* spp. and *Phoenix reclinata* (Schum. & Thonn.), (syn; *Phoenix spinosa Phoenix leonensis),* with the latter only being found on the northern side. In addition, there was a widespread coverage of gramineae with both swamp edge species like *Eriochloa meyerana*- Kunth*,* *Brachiaria brizantha* (A. Rich) A. camus and ecotone species like *Chloris gayana*-Kunth. Cattle grazing was heavy in this eco-type due to the relatively reduced flooding. Some of the herb species found in this vegetation formation included Umbelliferae *Oenanthe palustris* Lum and *Cycnium tubulosum* (L.f.) ssp Montana (N.E.Br) O. J. Hansen. In contrast to the other formations, there was notable settlement both on the south-western and north-western part of the swamp due to the relatively low flooding conditions. This vegetation formation also had relatively minimal macrophyte coverage, with sand harvesting and rocky sections being prevalent in the south-west part. Thus, this vegetation formation was more like an ecotone.

Cyperus papyrus-Phragmites mauritianus-Typha **community (S edges-I – Papyrus Phragmites Typha)**

This vegetation formation was prevalent in areas that had experienced minimal disturbance and were heavily flooded. Undisturbed eco-types in the Yala swamp were restricted to areas deep inside the swamp, along the riverine areas and water bodies like lakes. *Cyprus papyrus* L. was the most dominant emergent macrophyte, forming an almost monotypic stand. The formation was found on the western part of Lake Kanyaboli, in the riverine area of the River Yala and around the Lakes Namboyo and Sare in the south. On the northern side, it was restricted to small patches, most of these being along the shore of Lake Victoria and inside the Island of Ndekwe both in the Musoma area. Plant species found in association with *C. papyrus* especially on the outer edges of papyrus stands included compositae such as *Ageratum conyzoides* L., Cyperaceae like *C. dives* syn. *Immensus* and *C. articulatus*-Linn. Others were Typaceae *Typha domingensis* Forst, climbers such as convolvulaceae – *Hewittia sublobata* (Lf) Kuntze and Malvaceae *Hibiscus diversofolius.* Also present were cucurbitaceae *Mukia maderaspatana* (L.) MJ. Roem, gramineae *Phragmites karka* (Retz.) Trin. ex Steud *Phragmites mauritianus* Kunth and polygonaceae *Polygonum pulchrum* Blume.

Cyperus dives –C. papyrus Phragmites **community (Sedges-II – Dives, Papyrus, Phragmites)**

This vegetation community had a wide coverage all along the swamp drawdown areas and was characterized by frequent disturbances like fire, farming and grazing activities, especially in the dry season. This vegetation formation was found around Lake

Kanyaboli, and was extensive on the northern side, in the Nyandorera area and to the north of Lake Sare. It was dominated by sedges such as *C. dives* in the wetter sections plus *C. exaltatus, C. brevifolius*-Rotta *(Kyllinga brevofolius)* and *C. distans,* with *C. papyrus* scattered along the inner sections that experienced prolonged flooding period. Gramineae species present included *Eragrostis exasperata* Peter and *Eriochloa meyerana* (Nees) Pilg, compositeae *Solanum anguivi* Lam and *Vernonia purpurea* (*E.dummeri, V. dummeria*). However, due to the low flooding, the formation was also characterized by a high presence of phanerophytes along the edges. Species that appeared as regrowth in cultivated areas included Tiliaceae *Corchorus olitorius* L. (murenda-*Luo*), Leguminoseae *Clitoria ternata* and Thelypteridaceae, *Cyclosus striatus* (Schum.) Ching. On the northern side, the sedge zone was intermixed with *Phoenix reclinata*, (Schum. & Thonn.), (syn; *Phoenix spinosa Phoenix leonensis),* which was restricted to this side of the swamp. This community was rich in species, which was attributed to the annual ecological disturbance followed by heavy flooding.

Cyperus dives-Sesbania sesban **community (Bushes-II – Dives Sesbania interface)**

This was a rather small community emerging from the converted areas, which comprised vegetation species of the converted areas, ecotone and sedges zones. It formed an interface between the sedges and the cropland complex all around the swamp and was characterized by numerous bushes. The Cyperaceae included *C. distans* and *C. exaltatus* with gramineae including swamp-edge species like *Leersia hexandra*-SW and *Sporobolus pellucidus* Hochst. Ecotone species included *Hyparrhenia rufa*-(Nees) Stapf and *Paspalum carmmersonii*-Lam and the drier eco-type species such as *Panicum maximum* Jacq. Herbs included *Gomphocarpus semilunatus* A. Rich., and the climber *Gloriosa* simplex L. of the Liliaceae family, both in the regrowth area. Leguminosae included *S. sesban*, *Crotalaria pallida* (var obovata) (G. Don) Polhill and *Acacia macrothyrsa*-(syn.-*(A. buchanaii* Harms., *A. dalzielii* Craib. *A. prorsipinnata* Stapf) Harms with Verbenaceae *Lantana camara* L. on the edges. This section was also frequently cultivated during the dry season, but due to the high water level in the wet season, the species were able to re-establish at relatively high levels.

7.2.2 Satellite remote sensing data

The use of remote sensing techniques to analyze changes in land cover is a very useful especially in large ecosystems like wetlands, which present big challenges in terms of ground mapping due to inaccessibility (Van der Kwast, 2002). Collection of ground data is important in change detection, but accessibility in the Yala swamp was restricted to the area along the edges. However, this data was still useful in land-cover discrimination. Land-cover analysis was achieved through the combined use of 1973 MSS and 2001 ETM images, both of which were recorded in the dry month of February, plus aerial photographs as ancillary data. Seven broad land-cover classes were identified in the Yala swamp, covering both vegetation and water systems (Table 7.1). Through loading the GPS points collected along the vegetation transects, the five grouped vegetation communities were overlaid with the satellite-derived land-cover classes (Figure 7.1 and 7.2). This approach was necessary, since direct discrimination of vegetation species from Landsat is limited due to both spatial and spectral limitations.

Table 7.1: Land-cover classes

No.	**Signature – Land-cover Type**	**Abbreviations**
1	Water –Lakes, Open water	Open water
2	River –River and stagnant water, silt	Silt water
3	Conversion –Cropland-settlement complex	Conversions
4	Bushes I –Phoenix-Eucalyptus-Hibiscus	Bushes-phoenix
5	Sedges I –Papyrus-Phragmites-Typha	Sedges-papyrus
6	Sedges II –Dives-Papyrus- Phragmites	Sedges-dives
7	Bushes II –Dives Sesbania interface	Bushes-sesbania

7.2.3 Land-cover signatures separability

Land-cover signature separability was done using the transformed divergence (TD) method. The statistical separability of the signatures used to classify the two images was significantly high. For 1973, the average was 1863, which was above the critical value of 1700 with a minimum average of 1469 (Table 7.2). The signatures with low TD values in the 1973 were attributed to the close spectral signatures as a result of the close similarity in the composition of vegetation. These land covers (Table 7.1) with low TD values were characterized by the presence of a significantly high proportion of sedges like *Cyperus dives* and *C. distans*; hence separability was low due to spectral overlap. However, they were located in different ecological units within the ecosystem with unique species composition. This is elaborated further in the land-cover classification and the description of vegetation communities in the discussion.

Table 7.2: 1973 MSS signatures evaluation

Land-cover classes	**average 1863**	**minimum- 1469**					
	1	2	3	4	5	6	7
1- Open water	0	2000	2000	2000	2000	2000	2000
2- Silt water		0	2000	2000	1967	*1469	1756
3- Conversions			0	1717	1652	1999	1898
4- Bushes-phoenix				0	1763	1980	1994
5- Sedges-papyrus					0	*1654	1705
6- Sedges-dives						0	*1568
7- Bushes-sesbania							0

** Low TD values*

The average TD value for the year 2001 was slightly higher at 1911 with a minimum average of 1419 (Table 7.3). Whereas most of the signatures had good separability, a few lay below 1700. Those signature classes that recorded low separation values were 5 and 6 (Table 7.1, Table 7.3), both of which were also characterized by strong dominance of sedges in the family cyperaceae, hence the overlap in signatures.

Table 7.3: 2001 ETM signatures evaluations

Land-cover Classes	**average 1911**	**minimum 1419**					
	1	2	3	4	5	6	7
1- Open water	0	1998	2000	2000	2000	2000	2000
2- Silt water		0	2000	1974	2000	2000	2000
3- Conversions			0	1956	1892	*1419	1992
4- Bushes-phoenix				0	*1599	1848	1996
5- Sedges-papyrus					0	*1474	1977
6- Sedges-dives						0	2000
7- Bushes-sesbania							

** Low TD values*

7.2.4 Change detection and land-cover dynamics

Several changes were observed after comparing the 1973 and 2001 images,. The most prominent coverage in both images was sedges mainly Cyperaceae family, which was favored by the prolonged presence of water in the floodplain (Figure 7.1 and 7.2).

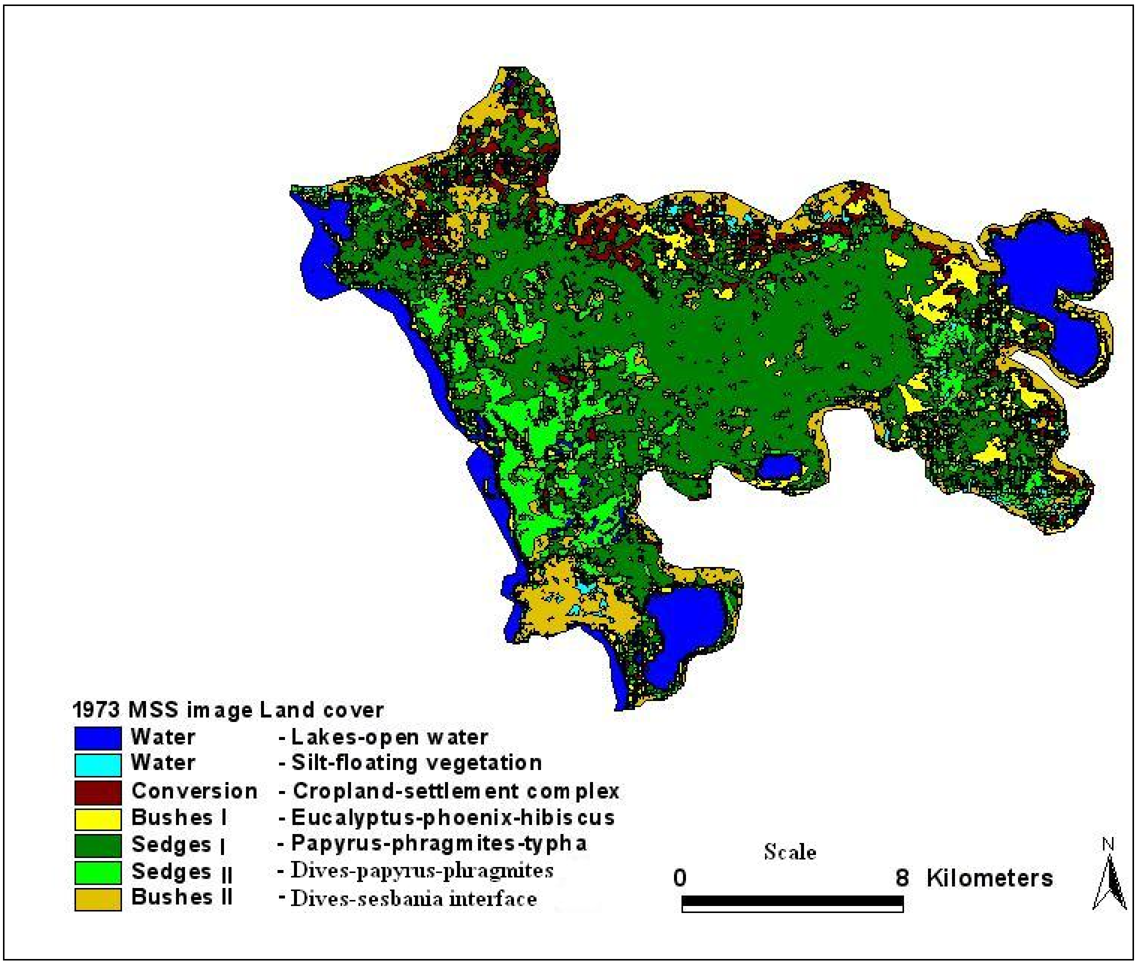

Figure 7.1: Land-cover classes in Year 1973

The water bodies especially along Lake Victoria recorded some significant changes in terms of increased siltation (Figure 7.1 and 7.2). This change was most pronounced at the mouth of River Yala, which was attributed to the reduced macrophytes coverage. This area had also experienced extensive expansion of farming activities.

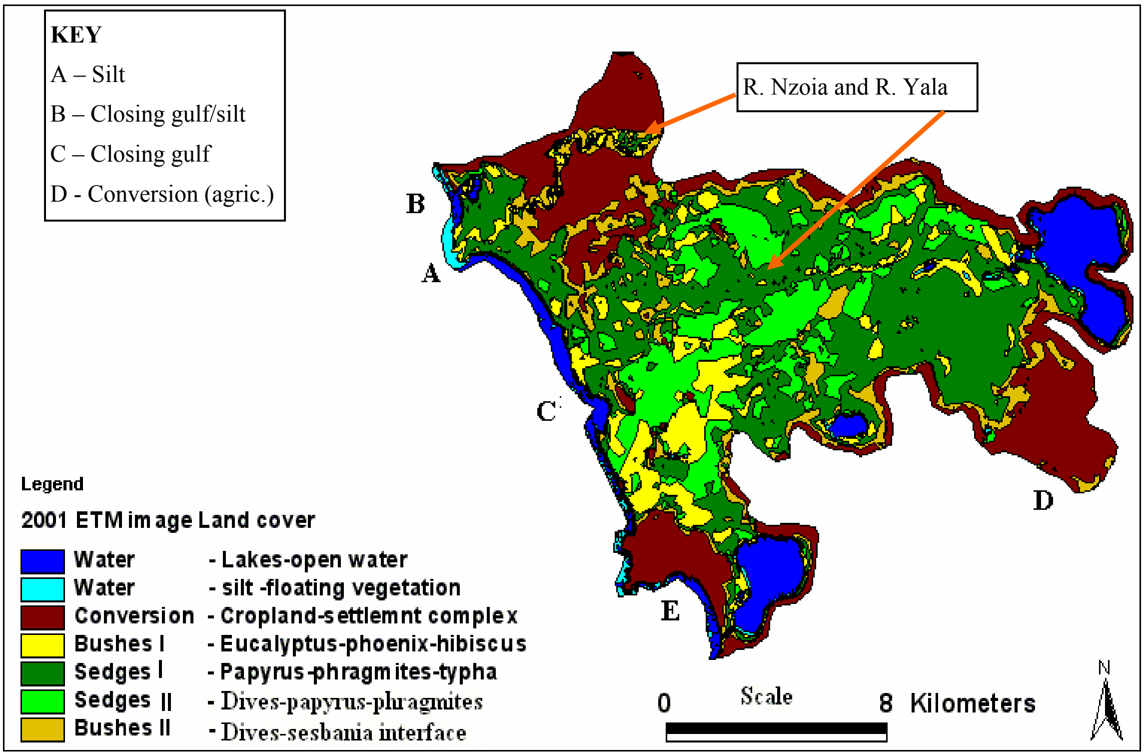

Figure 7.2: Land-cover classes in Year 2001

Comparing the 1973 and 2001 images, the most prominent changes were noted in the increase of conversions of wetland agriculture area and the decrease in the *Papyrus-Phragmites-Typha* communities (sedges-papyrus). More areas had been opened up for farming (conversion) with a three-fold increase in converted areas from 1,564 ha to 5,939 ha (Figure 7.3). Using the 1973 image as the base, the rate of conversion translated to 156.25 ha per year. Also noted was an increase in the *Cyperus dives -phragmites* community (sedges-dives), which often appears in the low flooded and disturbed areas.

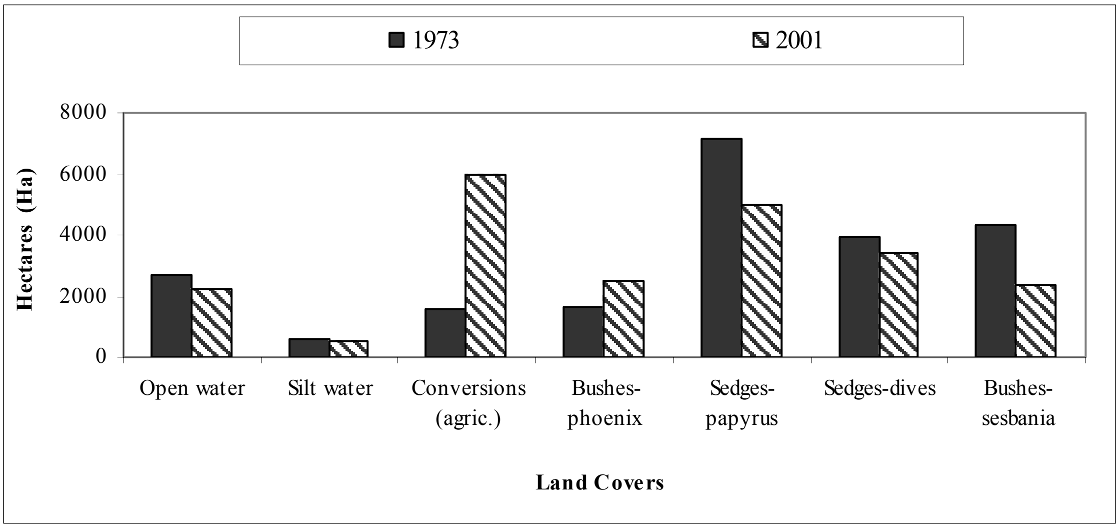

Figure 7.3: Land-cover dynamics between 1973 and 2001

Most of these changes had occurred around Lake Kanyaboli, along the River Nzoia and in the Lake Sare area (Figure 7.2). These areas offered good accessibility to the swamp. In addition, the northern side of the swamp, including along the River Nzoia, had experienced more conversions than the other areas in the swamp. This was facilitated by the convenient gentle landscape compared to the hilly southern side. Specific details of the land-cover changes are presented below.

7.2.5 Land-cover changes in specific zones

Some sections of the swamp had experienced relatively strong changes in land cover, mainly as a result of anthropogenic activities. However, natural processes such as catchment degradation were also important in influencing land-cover changes in the swamp, especially through the deposition of silt in the water systems. The areas most affected by these changes included the north-western section along the River Nzoia and the south-eastern side of the swamp.

North-western side of the Yala swamp and along River Nzoia

Major changes had also occurred on the north-west side and along the Lake Victoria shoreline both in terms of vegetation degradation as well as siltation. Much of the land along the river had been converted into small-scale agricultural land (2001 image), with subsequent reduction of the macrophyte coverage that was present in 1973 (Figure 7.4, see Figure 7.1/7.2 for key).

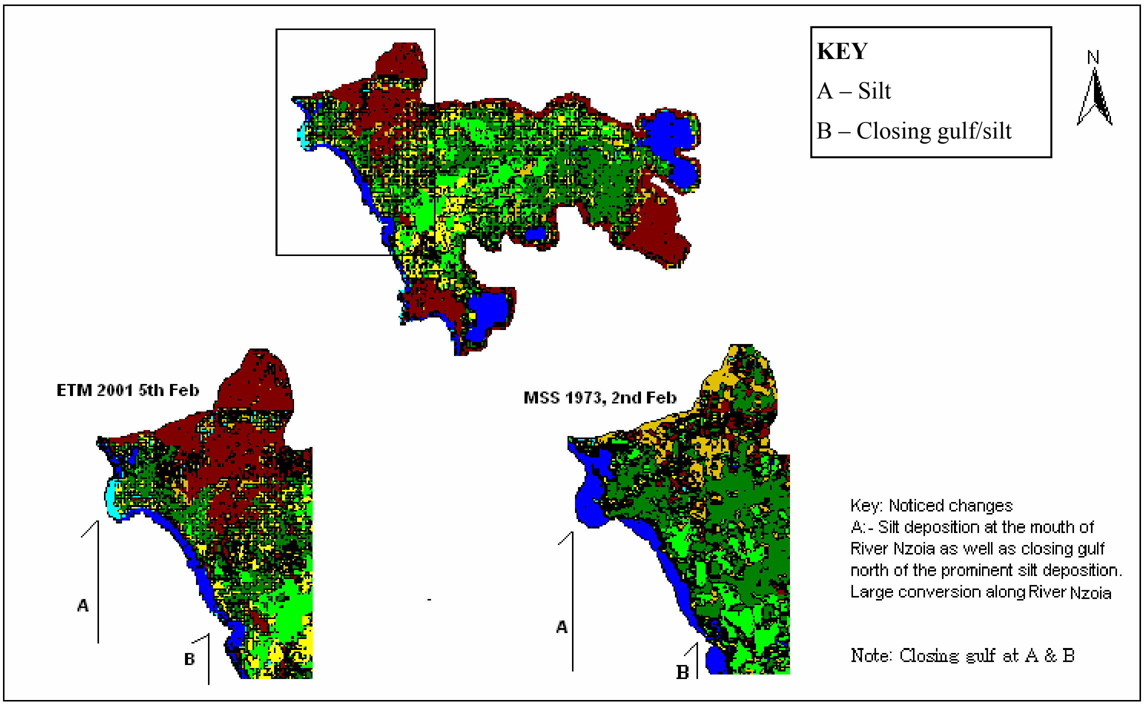

Figure 7.4: Land-cover changes in the northern part of Yala swamp

Further up to the north of the River Nzoia, the lake gulf, which was prominent in 1973, was almost cut off from the main lake by vegetation encroachment and silt deposition (Figure 7.4). Similar changes were also noted along the Lake Victoria shoreline, mainly in form of silt deposition (*see arrow B*). The presence of the water hyacinth (*Eichhornia crapssipes* (Mart.) Solms) might also have contributed to the accumulation of silt, due to the low dispersion by water especially in the sheltered areas along the shoreline. No such plume was observed at the mouth of the River Yala, which flows through the swamp.

This region of the swamp, including part of the River Nzoia, encompass part of the Budalangi area, which experiences heavy flooding during the wet season contributing to heavy soil erosion. The silt is mainly from denudated land in the catchment area and along riparian areas of the River Nzoia. The River Nzoia channel had also shifted northward, probably due to the accumulation of silt as it meanders to the Lake Victoria (*see arrow C*) (Figure 7.5). This corresponds well with the silt deposition observed along the lakeshore (*see arrow A,* Figure 7.4; arrow *C,* Figure 7.5 see Figure 7.1/7.2 for key).

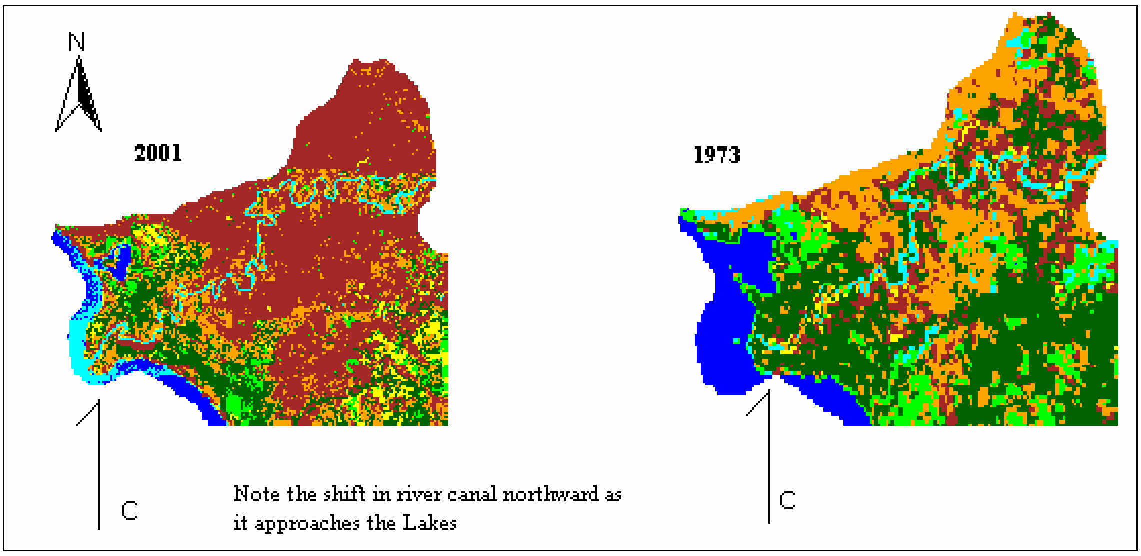

Figure 7.5: Land-cover changes near the mouth of River Nzoia

South-western side

Other significant land-cover changes were noted on the south-eastern side of the Yala swamp (Figure 7.6; see Figure 7.1/7.2 for key). This area was initially opened up by the LBDA for small-scale farming and seed production in the 1970s. However, the scheme malfunctioned and much of the land was later taken up by small-scale farmers both for food production and grazing.

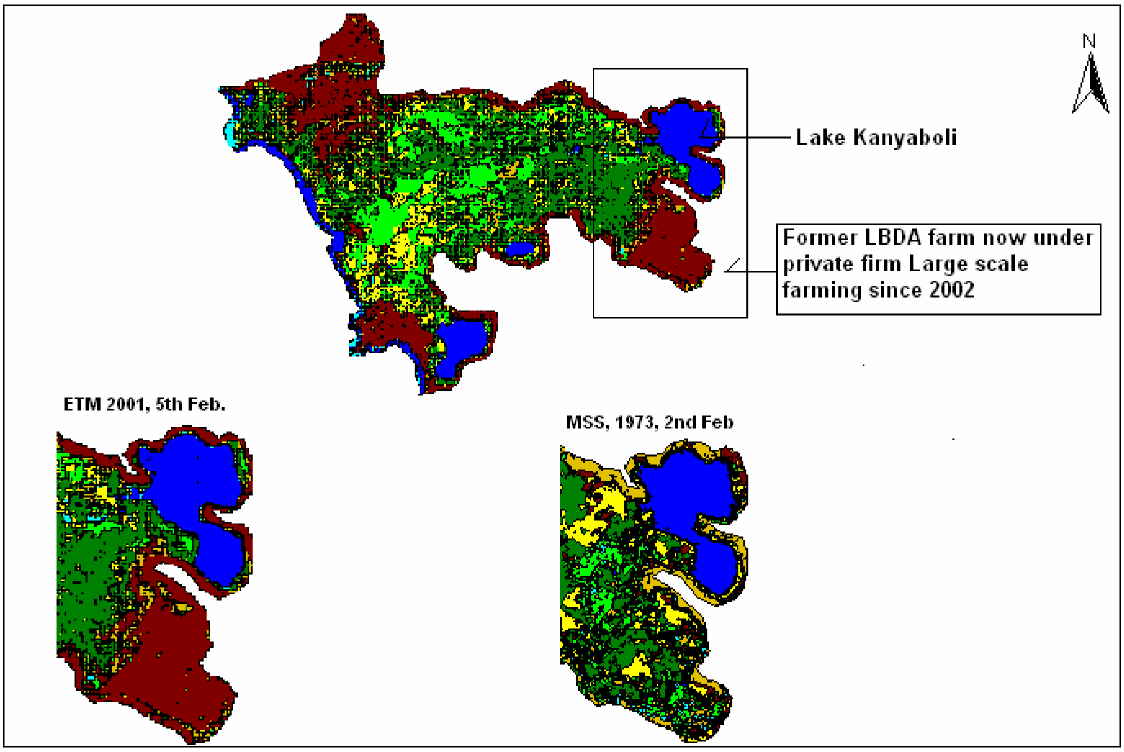

Figure 7.6: Land-cover changes south-east of Lake Kanyaboli

Recently in year 2002, this part of the swamp was leased out to a private company for large-scale rice production; this development was not included in this analysis. The change recorded in the year 2001 of a large conversion was mainly part of the LBDA area under use by the small-scale farmers. In contrast, only a few converted patches were visible in the 1973 image. When the wetland was opened up in the early 1970s (GoK, 1994), the River Yala was canalized, reducing flooding, which facilitated continuous farming activities by the small-scale farmers. In addition to these changes, numerous other changes were noted both in the 1973 and the 2001 images. These were mainly concentrated along the swamp edges, where the swamp was easily accessible especially to the farming community.

7.2.6 Post classification

Error (confusion) matrix

The greatest confusion was observed between sedges-papyrus with sedges-*dives* and bushes-*sesbania* in both the 1973 and the 2001 images. In addition, other classification confusion was observed between cultivation areas and bushes-*Phoenix* in the 1973 image and sedges-*papyrus* with bushes-*Phoenix* in the 2001 (Appendix 7). Sedges-

Papyrus also showed the lowest Kappa statistics at 50% in 2001 (Table 7.4). The low values for the sedges-*papyrus* can be attributed to the wide distribution in the swamp ecosystem and intermixing with other macrophyte communities, thus reducing separability. Again, the low value of silt-water in the 1973 image is due to extensive vegetation coverage and low siltation at the time

Accuracy report

In general, the accuracy assessment was high in terms of both the overall accuracy values and the Kappa statistics in the 2001 image compared to the 1973 image. The overall accuracy in the 2001 image was 75% with Kappa accuracy being 5% lower, although still high at 70% (Table 7.4). In contrast, the 1973 image had relatively low overall accuracy at 50 % and Kappa statistics also 5% lower at 45%.

Table 7.4: Accuracy assessment report for 1973 and 2001 images

Class Name	**Reference totals**		**Classified totals**		**Number correct**		**Producer accuracy (%)**		**Users accuracy (%)**		**Kappa statistics K^%**	
	1973	2001	1973	2001	1973	2001	1973	2001	1973	2001	1973	2001
1-Open water	13	29	9	33	9	28	69	97	100	84.85	1.00	.82
2- Silt, water	7	19	13	9	5	8	71	42	38	88.89	0.37	00.88
3-Conversions (agriculture)	22	31	31	35	19	28	86	90	61	80.00	0.57	0.76
4-Bushes-phoenix	14	33	11	36	7	24	50	73	64	66.67	0.61	0.60
5-Sedges-papyrus	42	34	44	53	33	31	79	91	75	58.49	0.70	0.50
6-Sedges-dives	19	29	15	18	10	17	53	59	67	94.44	0.64	0.94
7-Bushes-sesbania	38	27	32	18	25	16	66	60	78	88.89	0.74	0.87
Total	236	102	236	202	119	152						
Overall accuracy							**50.4**	**75.3**			**0.45**	**0.7**

In the 2001 image, classification of the sedges-*dives* (0.94) and silt (0.88) was the most reliable with high overall Kappa statistics, followed by bushes-*sesbania* (0.87) and open water (0.82) (Table 7.4). Kappa statistics were the lowest for the classification of the sedges-*papyrus* (0.50) and bushes-*phoenix* community (0.60), while in 1973 image, the open water had the highest Kappa values followed by bushes-*sesbania* community with silt-water having the lowest (Table 7.4). The clear water in the 1973 image was easily discriminated from the other land covers.

Land-use change matrix

All land covers showed a change in coverage between 1973 and 2001. The most significant changes were a three-fold increase in the converted areas to agriculture, mainly at the expense of the bushes-*sesbania* community, which contributed 2,701.9 ha and sedges-*papyrus* 1,335.07 ha (Table 7.5).

Table 7.5: Land-use change matrix 1973 and 2001 (57 metre pixel) in ha

Land covers	Open water	Silt, water	Conver-sions (agricul-ture)	Bushes-phoenix	Sedges-papyrus	Sedges-dives	Bushes-sesbania	**Total - 1973**
Open water	1914.3	305.4	65.9	110.8	159.5	75.7	40.3	2672.1
Silt, water	2.6	4.2	346.1	25.0	101.1	12.7	77.7	569.3
Conversions (agriculture)	9.4	13.3	640.1	135.8	335.0	178.7	251.8	1564.2
Bushes-phoenix	70.8	58.8	308.4	192.0	624.8	183.3	214.5	1652.6
Sedges-papyrus	52.6	62.4	1335.1	898.1	1914.4	1871.5	1046.2	7180.2
Sedges-dives	115.4	63.1	542.3	783.7	1255.8	833.4	366.2	3959.9
Bushes-sesbania	35.8	35.8	2701.9	317.2	609.3	280.4	363.3	4343.6
Total - 2001	2200.9	543.0	5939.8	2462.6	4999.9	3435.6	2359.9	21942.0

Also noted was a reduction in the sedges-*dives* coverage zone with a shift mainly to sedges-*papyrus* community of 1,871.45 ha. Likewise, the open water area also decreased due to vegetation encroachment. Whereas the bushes-*phoenix* community, which often appears as a colonizer in the disturbed areas or the less flooded eco-types, showed an increase in 2001. This was mainly at the expense of sedges-*papyrus* (898 ha) and sedges-*dives* (783 ha).

7.2.7 Normalized difference vegetation index

The 1973 image had overall higher normalized difference vegetation index (NDVI) values compared to the 2001 image (Figure 7.7). These changes were noted in terms of the reduction of the positive values in the 2001 relative to the 1973 values. The shift in NDVI values between the two dates supports the changes recorded in the coverage of the vegetation communities in the two images, where several changes were noted in vegetation coverage.

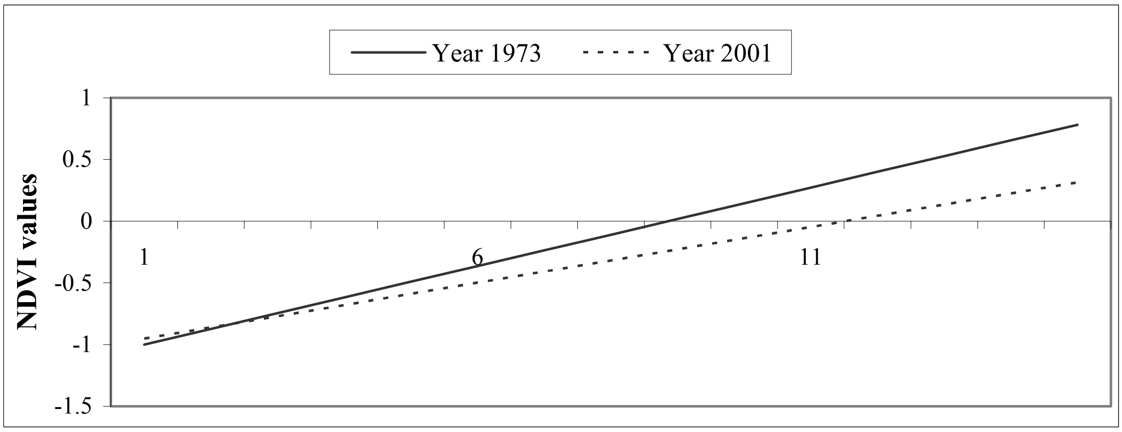

Figure 7.7: Comparison of NDVI values of 1973 and 2001

The 1973 MSS NDVI values ranged between –1.0 and +0.909 (Figure 7.8). These values indicate high positive values meaning an extensive coverage of vegetation compared to the 2001 NDVI values. The high negative values were due to the high transparency of water, which reflects more at Near Infrared (NIR).

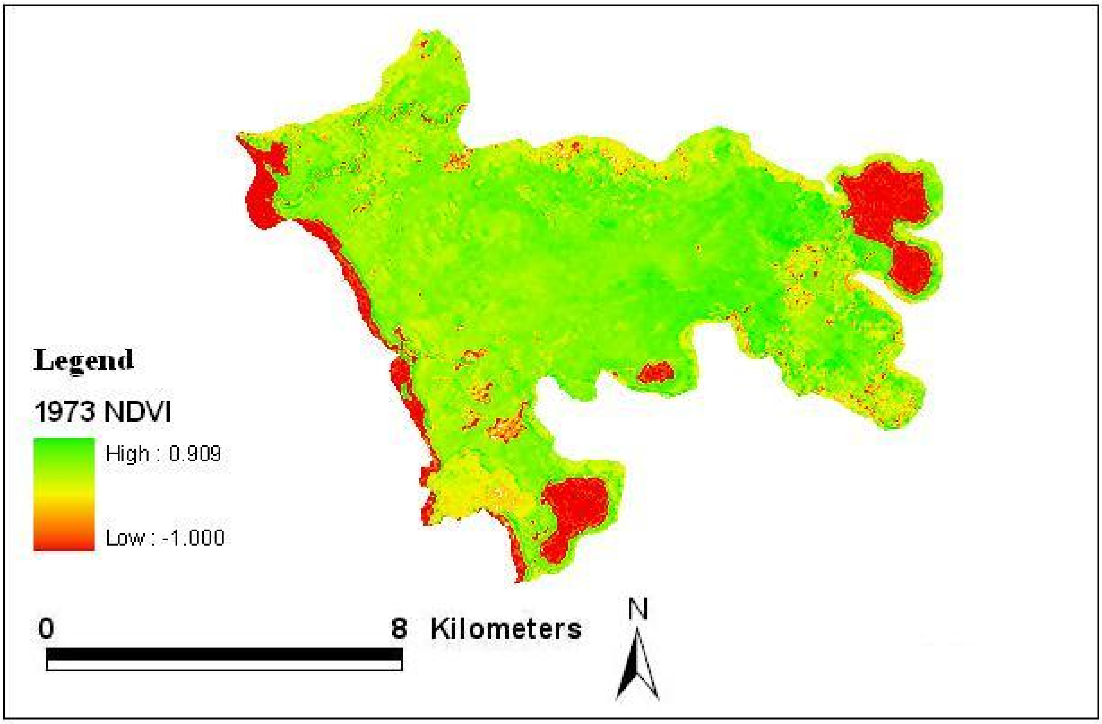

Figure 7.8: NDVI for Year 1973

In 2001 (Figure 7.9), the NDVI values ranged between –0.952 and +0.405 and there was a slight decrease of the negative values and a significant reduction of the positive values, indicating overall reduction in the vegetation cover in the whole swamp (Figure 7.9). The two images were taken around the same time in the dry month of February, which gives the differences a much greater significance. The observed reduction of the negative values was due to the siltation of water bodies and the subsequent reduction in transparency, which results in absorption of NIR, while the lower positive values were due to the reduced vegetation biomass cover.

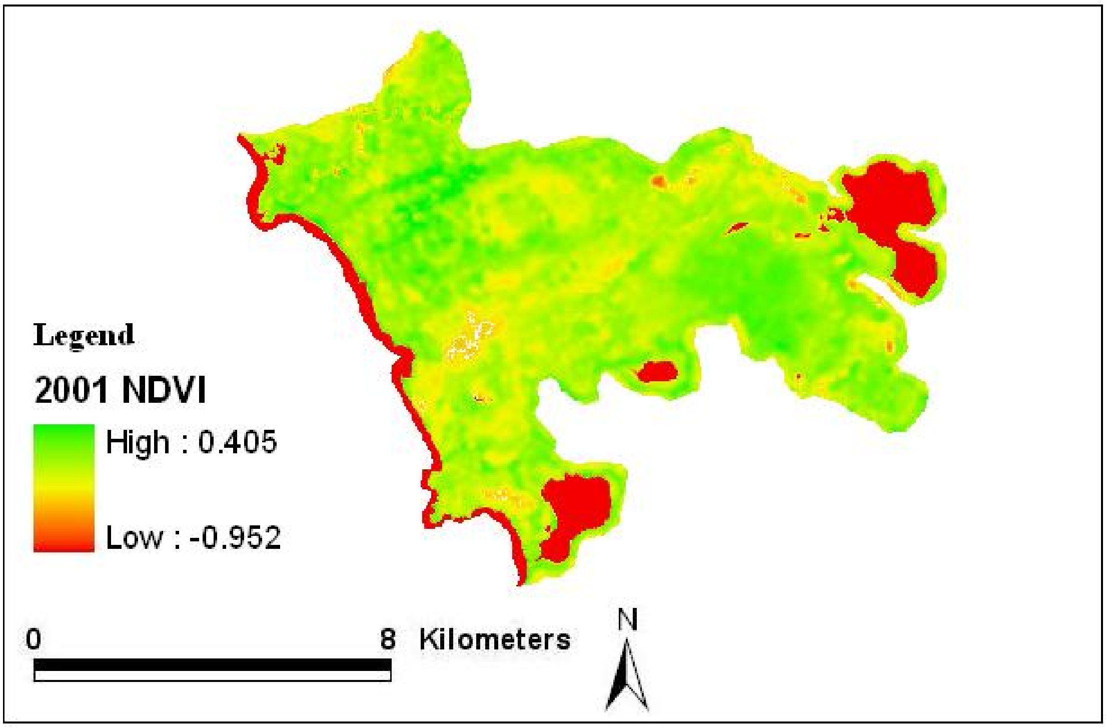

Figure 7.9: NDVI for year 2001

The differences between the NDVI values (1973, 2001) indicate a high decrease in vegetation biomass both inside the swamp and along the edges of the swamp. Overall, there was a decrease in vegetation cover in the swamp. A slight increase in the NDVI values was recorded mostly along the swamp edges and along the water bodies (Figure 7.10). These two areas have experienced more changes relative to the other sections of the swamp.

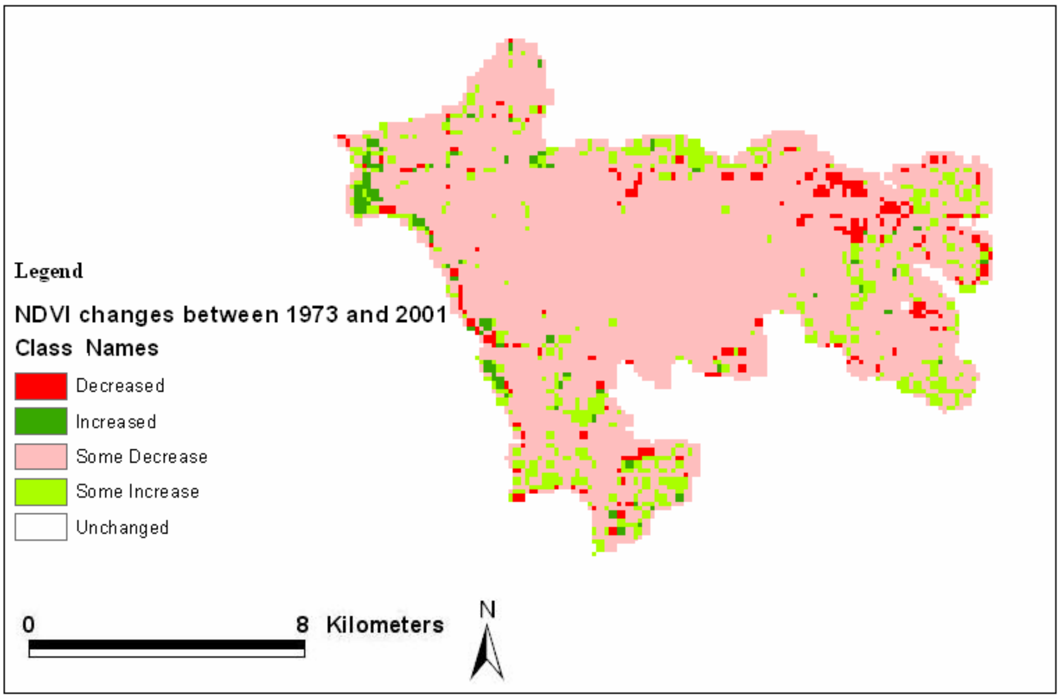

Figure 7.10: NDVI change between 1973 and 2001 images

The increase in the NDVI values in water bodies and riverine areas like along the River Nzoia was attributed to the increase in floating vegetation and siltation, while the minimal increase along the edge of the swamp could be due to the emerging vegetation or crops in the converted areas. Some of these increases, especially along the edges of the swamp and water bodies, could also be due to geometric correction errors in the southern part of the swamp carried over from the original image. However, this was minimal and does not disqualify the changes observed, both in the NDVI values as well as in the land cover in the swamp. Since the two images were already geometrically corrected, the error in the southern part of the swamp could not be rectified further. However, the northern part of the swamp was not affected by this error.

7.3 Discussion

By the use of combined hybrid classification and vegetation spatial distribution, it was possible to identify vegetation community distribution as well as other land covers in the Yala swamp. The results obtained compared well with other studies in the Yala swamp (Otieno *et al*., 2001). Synthesis of wetland classification studies by Ozesmi and Bauer (2002) observes that most studies on remote sensing of the wetlands ecosystem have used unsupervised classification or clustering due to the difficulties of separating spectral signatures. However, the use of the hybrid classification approach results in much higher accuracy and better results. Complete separation of vegetation classes, especially where there has been heavy disturbance in wetlands is highly limited due to the overlap of signatures in the Landsat (Van der Kwast, 2002). Similarly, in the Yala swamp, some confusion in classes was noted especially those with high composition of cyperaceae species, although use of macrophytes inventory minimize this confusion. Tropical wetlands are often characterized by high plant diversity, especially along the edges, with disturbances interrupting even monotypic papyrus stands. Gathering of ground truthing data is limited in wetlands through inaccessibility of the wetlands due to unstable ground. Ozesmi and Bauer (2002) observed that confusion between spectral signatures is often high where there is limited ancillary data. However, in the Yala swamp, availability of ancillary data, including aerial photographs, topographical maps and vegetation data was relatively good.

Ecological disturbance in the Yala swamp triggered a change in vegetation communities between 1973 and 2001. The main vegetation change was from the papyrus in shallow water to sedges-*dives* and bushes as observed in the 2001 image. However, the papyrus community still had a wide coverage in spite of the increase in bushes and conversion for farming. Disturbance in the Yala swamp stems from annual semi-permanent cultivation, bi-annual flooding and grazing. The importance of subsistence agriculture in land-cover change is indicated by three fold increase between 1973 (1564 ha) and 2001 (5639 ha). This represents an average conversion of 156 ha/yr over 28 years period, using 1973 as the base. Comparatively, Mfundisi (2005) reported the overall converted agricultural land at 6,333 ha by the year 2001, which corresponds to the figures observed here. Using the 1984 as the base the rate of conversion was 375.5 ha/yr, over 17 years period (1984-2001), which indicate that, the rate of conversion have almost doubled compared with the period (1973 – 2001). The LVB wetlands are important farming areas (Mugo and Shikuku, 2000; Gichuki *et al.,* 2001; Abila, 2002), which contribute to vegetation change.

In addition, the effects of both the swamp conversion for subsistence livelihood and the repeated macrophytes harvesting was clearly reflected in the accumulation of silt along the water bodies in particular along Lake Victoria shoreline. Previous records on the water quality in the Lake Victoria including the shoreline areas indicate that the Secchi transparency index has generally declined by about 50%

between 1930 and 2005. In 1930, Worthington recorded a variation between 0.5 and 7.9 m; this declined to 1.5-2.8 m by 1992 (Mavuti and Litterick, 1992) 0.6-2.3 m in 1995 (Calamari *et al*., 1995) and to 0.6-2.8 m in 2001 (Njuru and Hecky, 2005). The shoreline has an approximate 0.7 m secchi disc index compared to the open lake of 2.9 m (Njuru and Hecky, 2005). This can be attributed to the effect of catchment degradation, with a subsequent increase in river discharge and soil erosion (ICRAF, 2000; Sangale *et al*., 2001).

The reduction of macrophytes especially along the water bodies, including the Lake Victoria shoreline, has contributed to more turbidity as less water filtration takes place. This is again reflected in the vegetation-cover changes with the reduction of NDVI positive values between 1973 and 2001 by about 50%. This can also be attributed to the combined effect of the annual conversion of the swamp for subsistence livelihood and repeated macrophyte harvesting. Using the tasseled cap transformation greenness (vegetation) index on 1984 and 2001 images, Mfundisi (2005) recorded a decrease in vegetation by an almost similar margin. Analysis of the wetness indices between the two dates indicated no changes in swamp moisture content. This means that the vegetation-cover changes were due to local effects like swamp conversion mainly through subsistence agriculture.

Two aspects of the variations observed in the NDVI values for the Yala swamp are significant in two ways. First, wider NIR bands like in MSS images tend to produce lower NDVI values, while higher centre wavelength NIR bands like in ETM images implicate higher NDVI values (Saura, 2003). As a result, only small differences would be expected between the 1973 and the 2001 images, but in this case large difference were recorded. Second, the presence of water in the wet season conceals vegetation, thus lowering NDVI values (Narumalani *et al*., 1999). However, the images were taken in the month of February, which falls within a dry period. This presented a much more conducive condition, since much of the vegetation was exposed and the wetland has less water after the short rains in October to November. Thus, the NDVI values reflect to a great extent the effect of localized disturbance like conversions, which leads to lower biomass coverage.

Land-cover changes in the Yala swamp can be attributed mainly to the demographic dynamics as well as policy arrangement. Socio-economic data indicate that wetland farming is an important source of domestic food supply as well as for income provision in the Yala swamp. This phenomenon had also been observed in other wetlands within the LVB (Mugo and Shikuku, 2000; Gichuki *et al*., 2001). Farming has also been identified in other parts of Kenya as an important factor in wetland conversion mainly to agriculture in both humid (Mohamed, 2002) and arid and semi-arid wetlands (Thenya, 2001, Githaiga *et al.*, 2003) but detailed studies are still lacking. The areas that have experienced high land-cover changes have combined high accessibility, high population and household density, especially in the northern side of the swamp. Wetland accessibility is high on the southern side of Lake Kanyaboli, north of Lake Namboyo, along the River Nzoia and generally along the edges of the swamp. Farming activities along the River Nzoia were not deterred by flooding, since this is seasonal and receding floods leave fertile soils for farming, which encourage cultivation. Note, however, that the land south of Lake Kanyaboli was initially drained by the government of Kenya (GoK, 1994; Aloo, 2003) and later taken over by small-scale farmers.

The observed accumulation of silt at the mouth of the River Nzoia, which was not observed at the mouth of the River Yala, was also noted by Otieno *et al.* (2001). This was attributed to two processes. First, accumulation of the silt was due to the effect of the catchment degradation according to observations by JICA, (1980), ICRAF, (2000) and Sangale *et al*., (2001). The silt also deposits nutrients, mainly nitrogen and phosphorous, from catchment farming and the deforested areas, which encourages the proliferation of the water hyacinth among other floating macrophytes (ICRAF, 2000). These floating macrophytes in turn reduce the dispersion of the silted water from the shoreline and sheltered areas as observed at the mouth of the River Nzoia. Second, the clearing of the macrophytes along the River Nzoia make the water filtration process ineffective. The River Yala, which flows through the swamp, has no such plume at its mouth. Macrophyte clearing is mainly linked to farming. This combined cultivation and deposition of silt from the catchment to the floodplain of the River Nzoia has also contributed to a shift in the river canal as it approaches the lake. In addition to the human activities mentioned above, the Kenya river basins have a higher mean annual rainfall and average slopes as well as higher sediment transport capacity than the other sub-basins of the LVB (Odada, *et al*., 2004). This contributes to high sediment transport, especially where the vegetation cover is reduced or sparse.

7.3.1 Conclusions

Remote sensing and use of GIS techniques provided useful information on the spatial and temporal land-cover changes, including variation on macrophyte coverage and aquatic systems in the Yala swamp. The two images allowed identification of long-term (from 1973 to 2001) changes including the magnitude of change over 28 years period. Field inventory of vegetation combined with satellite images enabled identification of the vegetation communities distribution over the whole ecosystem including areas, which were inaccessible. The changes observed in the Yala swamp were attributed to the localized activities of wetland farming. Areas with large conversions natural vegetation to agricultural land also fell in high population densities areas. Although some sections like the south-eastern was a combination of policy aided conversion initially by the government, which was later taken up by small-scale farmers.

These changes have significant implications towards the wetland ecosystem conservation and sustainable use. One, the progressive expansion of farming area means that pressure to open up the wetland for farming is high, which is likely to slow down. Secondly the adjacent Lake Victoria is likely to loose more benefit of swamp ecosystem services of water filtration. These impacts are already evident with significant siltation on the north western side of the swamp at the mouth of river Nzoia. The observed increased siltation was attributed to the combined effect of catchment degradation as well the localized action of removing macrophyte along water bodies. Since the ecosystem have not conservation or utilization plan, these changes are expected to become more pronounced in the swamp and subsequently both in Lake Victoria and Yala swamp satellite lakes like Lake Kanyaboli.

The interpretation of the observed land-cover changes relied significantly also on the socio-economic data as well to explain the variability. These results show the applicability as well as the usefulness of remote sensing and GIS techniques in change detection, and the tools can be recommended for other similar types of study. This approach can be used to monitor land-cover changes in the Yala swamp including the water system that are recipient of land degradation effects. For example, the use of historical images enables quantification of long-term changes in aquatic vegetation even in areas that are inaccessible for ground data collection or where no data exist at all as was the case for 1973.

8 DYNAMICS OF LAND-USE CHANGE AND LAND-USE CHANGE DRIVERS

8.1 Introduction

Land-use changes are often associated with anthropogenic activities, but this varies from place to place depending on the general situation. Nevertheless, subsistence agriculture has been isolated as a major factor in land-use changes in Africa. The high dependence on the Yala swamp for farming and macrophyte harvesting in a high population density area generates a high pressure for land-use change. This high dependence emerges clearly in the socio-economic analysis. Due to the small land size and declining soil fertility, the swamp offers good possibilities for farming and income generation. This is also made convenient by the easy accessibility, since there are no controls with respect to swamp use, which also means that land can be acquired through self-allocation. The high population and household densities are important drivers, and act as proxy for proximity causes of land-cover change like cultivation. Administrative Locations with high population densities also showed high conversion indices. The approach of integrating remote sensing and socio-economic data in the Yala swamp helped in understanding further the relationship between land-use change drivers and the underlying causes.

8.2 Wetland land-use change drivers

8.2.1 Land-use change indices

To find out the statistical relationship between household, census and spatial data, two computation approaches were employed. The first involved combining the census and the spatial data to generate demographic indices as presented in (Table 8.1), while the second step involved computing the wetland land requirements and utilization data. This was achieved through combining household and spatial data to generate the indices of land requirement and utilization (Table 8.2).

8.2.2 Wetland demographic indices

Wetland demographic indices such as swamp population density per location were computed by combining census and swamp spatial data as presented in Table 8.1.

Table 8.1: Wetland demographic indices (Source: Computed from 1999 population and household census, GoK)

LOCNAME	Loc_total _area (ha)	Loc_wet_ area (%)	Loc_wet_ area (ha)	New_pop _No.	New_pop _density- km^2	New_hse hold_No.	New_hseho ld_density – km^2
Bunyala Central	3,918.03	81	3,167.75	5,052	160	1,342	43
Bunyala East	1,501.49	16	238.72	55	23	134	56
Bunyala North	1,224.78	46	559.11	2,498	447	571	102
Bunyala South	3,664.90	93	3,422.18	4,647	136	1,173	34
Bunyala West	1,363.14	67	910.91	8,461	929	2,018	222
Central Alego	652.48	6	58.11	247	608	63	156
Khajula	1,837.95	96	1,757.42	5,574	317	1,404	80
South Central Alego	3,323.72	23	1,242.29	2,639	341	689	89
South West Alego	2,624.08	15	885.78	985	252	248	64
South Alego	1,422.88	42	590.52	985	167	242	41
Usonga	7,149.00	76	5,446.58	5,694	105	1,513	28
Central Yimbo	5,223.00	23	1,499.85	1,646	135	384	32
East Yimbo	2,707.40	8	221.44	311	141	76	34
North Yimbo	5,502.86	47	2,629.06	3,394	130	804	31
West Yimbo	2,995.13	44	1,655.33	7,837	591	1,975	149
Total	**45,110.84**		**24,285.05**	**50,025**		**12,636**	

Variable	Explanation
1. Loc_total_area	= Location total area
2. Loc_wet_area %	= Percentage of Location in the wetland area
3. Loc_wet_area	= Location area in the wetland coverage
4. New_pop_No.	= New population number – proportionate number in swamp area
5. New_pop_density	= New population density – based on swamp area per Location
6. New_hsehold_No.	= New household number -proportionate number in swamp area
7. New_hsehold_density	= New household density –based on swamp are per Location

8.2.3 Wetland land requirements

Based on the demographic indices obtained in (Table 8.1), wetland land-use data such as the swamp household land demand were computed per location (Table 8.2) as outlined in section 4.8.

Table 8.2: Wetland land-use data (Source: Computed from field socio-economic data and 1999 census data)

LOCNAME	Conver_Fct (ha)	Access_area (ha)	Hsehold-demad (ha)	HseHold_share (ha)	Perc_in_use (%)	Area_under use (ha)	Use_intsy (ratio)
Bunyala central	2.73	3,167.75	3,668.46	0.86	8.54	313.16	9.89
Bunyala east	2.62	238.72	350.73	0.68	20.00	70.15	29.38
Bunyala north	2.62	559.11	1,495.03	0.37	20.00	299.01	53.48
Bunyala south	2.49	3,422.18	2,917.00	1.17	27.32	796.91	23.29
Bunyala west	2.62	910.91	5,287.40	0.17	11.70	618.74	67.93
Central Alego	1.15	40.55	104.36	0.39	23.91	24.96	61.55
Khajula	2.59	1,757.42	3,635.52	0.48	18.09	657.49	37.41
South Central Alego	2.70	774.79	2,981.06	0.26	20.37	607.25	78.38
South West Alego	1.8	390.68	1,012.88	0.39	20.21	204.73	52.40
South Alego	2.85	590.52	688.39	0.86	52.63	362.31	61.35
Usonga	4.29	5,431.53	6,507.89	0.83	13.53	880.77	16.22
Central Yimbo	1.96	1,215.51	927.17	1.31	68.06	631.06	51.92
East Yimbo	1.90	221.44	144.68	1.53	56.25	81.38	36.75
North Yimbo	2.02	2,602.30	1,637.29	1.59	74.47	1219.33	46.86
West Yimbo	2.00	1,326.67	4,928.77	0.27	100.00	4928.77	371.52
Summation		**22,650.7**	**36,286.63**			**11,696**	

Variable	Explanation
1. Conver_Fct	= Conversion factor - average swamp unit held per household
2. Access_area	= Accessible area - swamp area less water
3. Hsehold_demad	= Household demand - function of conver-fct and new population
4. Hsehold_share	= Household share - unit per household based on 1999 census
5. Perc_in_use	= Percentage in use- portion of the unit held that is in use
6. Area_underuse	= Area under use - coverage under use in the swamp
7. Use_intsy	= Use intensity - utilization intensity of the swamp land

The computation of wetland land requirements (Table 8.2) shows that, although the average conversion factor (Conver_Fct) was 2.4 ha ± 0.163, some household units were smaller, while others were larger than average. Using the average for the respective administrative locations, the total household land demand (hsehold_demad) was 36,286.63 ha against an accessible area (Access_area) of 22,650.07 ha. This implies that since the computed demand area was larger than the available land area, conversion pressure is bound to increase over time. However, it is important to note that not all households are simultaneously engaged in farming in the wetland as implied by the calculation, since some landholdings in the wetlands are idle. Furthermore, households only cultivate part of the land they claim. This is given by the sum of the percentage of land under use (perc_in_use; 11,696 ha), which is 50% of the accessible land. Again, due to the temporal variation in the use of the swamp by the households, these 11, 696 ha are not all in use at the same time. This means that the total area under use at any particular time is less than this figure. Therefore, the high household demand (hsehold_demad; 36,286.63 ha) gives an indication of the pressure that is likely to be exerted in the near future. This pressure will result in the opening up of additional wetland areas as the household number and the relative proportion of the farming household communities in the wetland increase.

8.2.4 Wetland-use change drivers

Correlations

Land-use correlations were done in SPSS using the population indices as explanatory factors and the swamp-use indices as the response factor (Table 8.3). In general, the correlations were relatively high. Household share had a negative relationship with household density (r = -0.745) implying that a rise in household density would result in a decrease in swampland shareholding *y = 1.216 – 0.006x, where x= density*. Similarly, population density (r = -0.691) had a similar negative relationship. Household demand for swampland and conversion factor had a positive relationship with accessible area/available land minus water. Therefore, the two variables that is household demand and conversion factor are likely to be high in areas with relatively high availability of land. This trend is likely since land availability is also likely to attract a higher number of the farming communities. This is important, since conversions are also likely to be small in areas with relatively low land availability coupled with decreasing shareholding (r = -0.745) as population and household density rises. Demand also rises with increase in the population variable (r = 0.666) under the current socio-economic settings.

Table 8.3: Correlations of wetland land-use change drivers

Dependent - Y		**New _hsehold density**	**New _pop -density**	**Access _area**	**Loc _total _pop**	**New _total _pop**
		Independent - X				
Area_underuse		0.275	0.283	0.157	**0.770(**)**	**0.584(*)**
	Sig.	0.322	0.306	0.576	0.001	0.022
Use_intsy		0.455	0.443	-0.183	**0.742(**)**	0.402
	Sig.	0.089	0.098	0.514	0.002	0.138
Perc_in_use		-0.100	-0.063	-0.133	0.342	0.010
	Sig.	0.723	0.822	0.637	0.212	0.971
Hse_hold share		**-0.745(**)**	**-0.691(**)**	0.303	-0.410	-0.301
	Sig.	0.001	0.004	0.272	0.129	0.276
Hsehold_demand		0.279	0.322	**0.674(**)**	**0.666(**)**	**0.917(**)**
	Sig.	0.315	0.242	0.006	0.007	0.000
Conver_fct		-0.158	-0.169	**0.552(*)**	-0.025	0.389
	Sig.	0.573	0.548	0.033	0.930	0.152

Pearson correlation –
***sign. at the 0.01 level (2-tailed) and * sign. at the 0.05 level (2-tailed).*

The area under use and utilization intensity also increases with population increase, r = 0.770 and 0.584 respectively. The most important variable in this relationship is household density followed by population density; the former is important, since swampland holdings are at the household level. This means that as both densities increase, the landholding unit per household decreases, thus increasing utilization intensity.

Regression analysis

The coefficients of determination of the four drivers that is new household density, new population density, access area and total population were significantly high, especially household density, total and new population (Table 8.4) with r^2 around 0.550. Household density (r = 0.555) was important in determining shareholding, since wetland holdings are at the household level. While the areas under use and utilization intensification were significantly influenced by the Location population number. Population growth is bound to increase the overall area under use, while reducing shareholding. Alternatively, a high density is bound to increase the intensity of utilization of the land held in the swamp.

Table 8.4: Coefficient of determination and R^2 for selected wetland change drivers

Dependent-Y	**New_hsehold _density**	**New_pop _density**	**Access_area**	*****Loc_total _pop**	**New_pop _No.**	**R^2 value**
	Independent Var-X					
Conver_fct	0.072	0.017	**0.000** (0.033)	-0.094	0.140	0.304
Hsehold_demand	-0.141	-0.159	**0.363** (0.029)	0.024	**0.679** (0.000)	0.895/0.841
Hsehold_share	**-0.006** (0.001)	0.754	0.010	-0.008	0.023	0.555
Area_underuse	-0.203	-0.279	0.063	**0.214** (0.001)	0.033	0.593
Use_intsy	0.074	-0.003	-0.278	**0.015** (0.002)	0.322	0.550

Sign. P value of coefficients indicated in parenthesis for the relevant predictors

Swamp conversion and household demand are dependent on the availability of land, that is accessible land coverage per Location (r^2 = 0.304, r^2 = 0.363) (Table 8.4). While demand is determined by two prominent factors that is, access land and the computed proportionate swamp population numbers. However, it is acknowledged that other factors complicate this relationship. These include variability in soil, household and population densities, and economic as well as social infrastructures like roads. This outcome indicates that household densities, population numbers and swampland accessibility factors are important proxies of population as drivers of land-use change in the Yala swamp. The socio-economic survey provided valuable explanation of the underlying factors related to these demographic variables.

8.2.5 Spatial wetland modifications scenario and administrative Location conversion indices

The household variable was important in determining the overall conversion of the natural swamp to agricultural land, since households rather than individuals acquire land in the swamp and make the decision for farming. With respect to accessibility, those administrative Locations with large spatial swamp coverage are likely to show a higher demand resulting in more conversions to agricultural land compared to smaller areas due to the larger number of people attracted to the land, since land availability is the limiting factor. This is clearly illustrated in Figure 8.1 showing the relationship between household demand for land and population variables. These areas constitute hotspots of land-cover change in such areas as the southeast and north western part of the swamp (Figure 8.2).

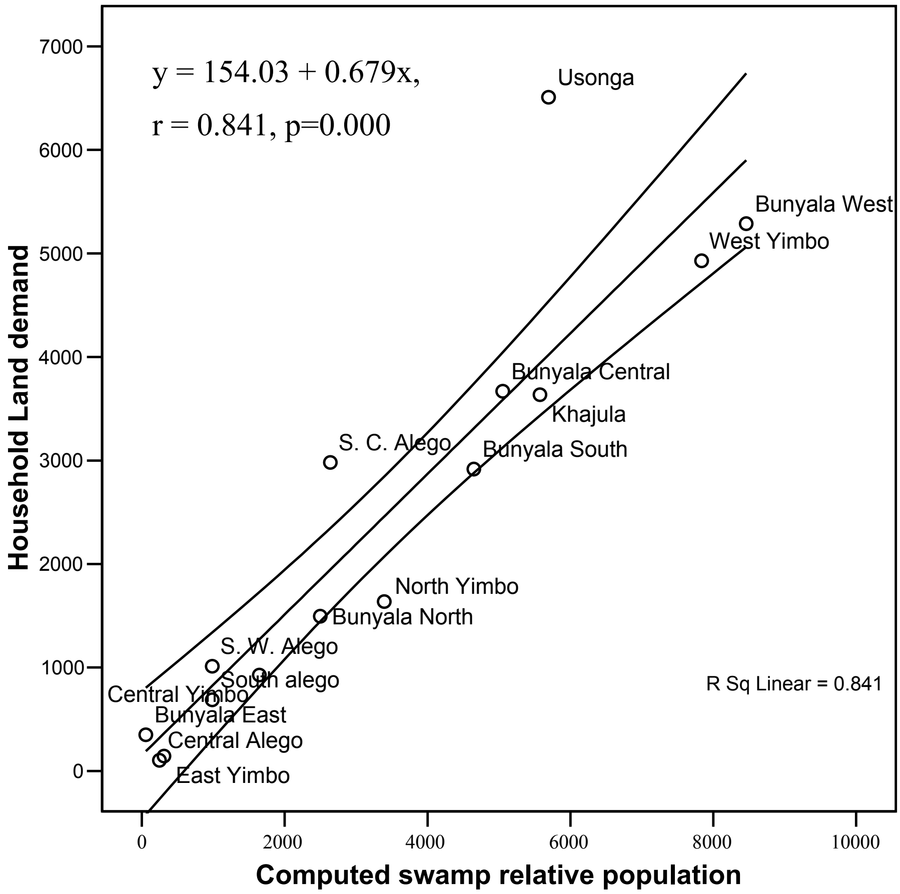

Figure 8.1: Relationship between household demand and computed swamp relative population

However, there are several underlying socio-economic and physical factors in this relationship, which all have high variability in space and time. Socio-economic factors include marketing of goods, domestic food demand, labor supply, migration from the area, and land location. Physical factors include change of flooding patterns, terrain and soil fertility variability. This is likely to be compounded further by the household shareholding (r^2 =0.555) as the household density increases, i.e., as the households density increases, wetland share decreases (r= - 0.745, *y = 1.216-0.006x, where x= density)* with subsequent increased intensification. Again, intensification increases with population increase (*y = -36.04 +0.015x, where x is Location population*).

These interactions between demographic, land accessibility and socio-economic factors were also clearly exhibited in the satellite derived land-cover changes

(Figure 8.2). The swamp area on the northern side is large and the terrain is more easily accessible, hence the relatively higher conversion rate compared to the southern side (Figure 8.2). In the areas with high conversion rates, population and household densities were also high (Table 8.1).

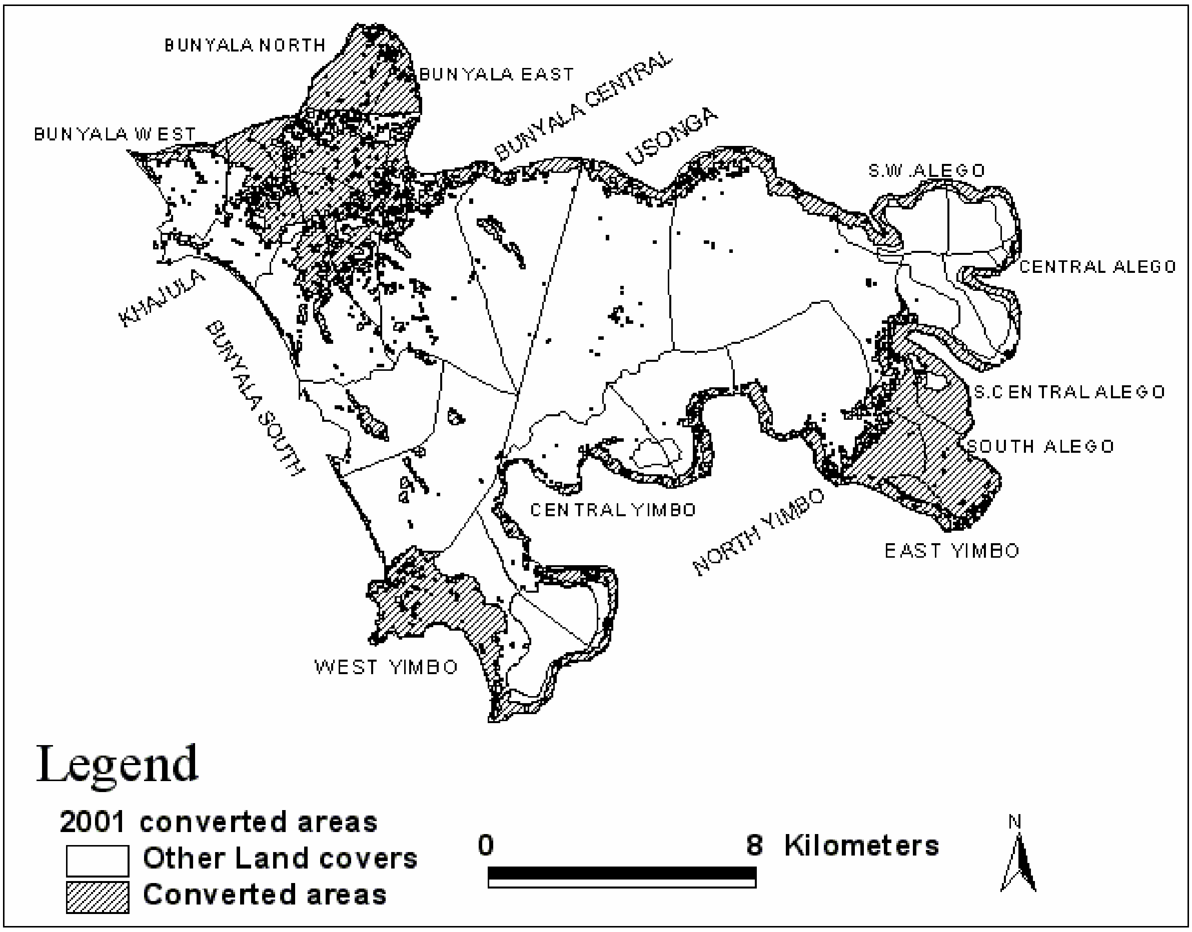

Figure 8.2: Converted areas per administrative Location in 2001

The administrative locations with major changes were in the north-western region, i.e., Bunyala North, East, West and South, and Khajula, (Figure 8.2). Significant conversions were also observed around Lake Kanyaboli, South Central and South Alego, and East and West Yimbo in the south-western region near Lake Sare. These hotspots of conversions to agricultural land represent potential areas of spread of future conversion to the natural parts of the swamp.

Accordingly, those Locations exhibited high conversion indices that is, the northern and north western side as well as the south eastern side (Figure 8.3). These areas have large spatial coverage that are also easily accessible. The satellite-derived land cover indicate large conversions on the northern side, south-east of Lake Kanyaboli and in the south-western region near Lake Victoria. Again, these areas also lie within the administrative Locations with high indices of land-use conversion. These are Bunyala South and Central, Usonga and partly West Yimbo (Figure 8.2, Figure 8.3).

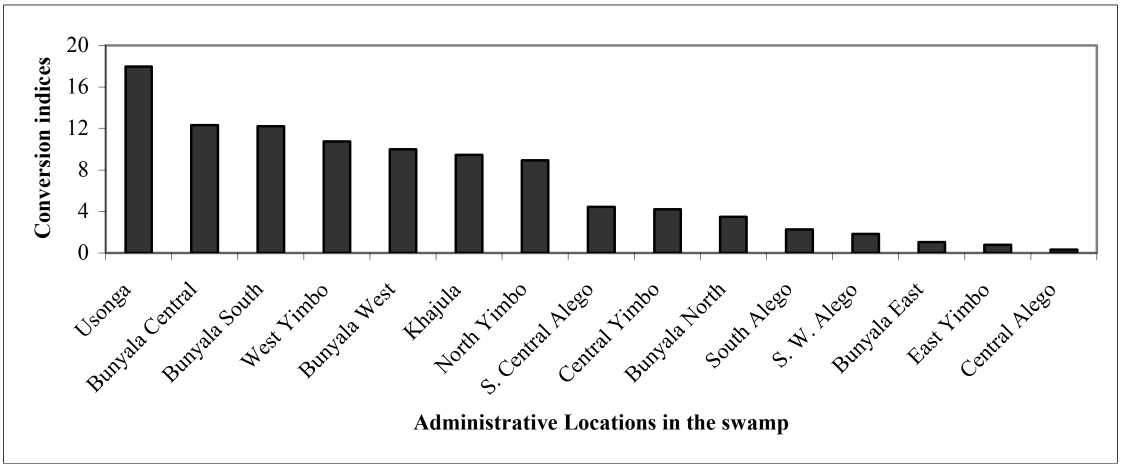

Figure 8.3: Land-use conversion indices per Location

Effect of leasing large-scale farm in the swamp

With a large part of the swampland accessible for cultivation on the south-eastern side near Lake Kanyaboli having been leased out to a large-scale company for farming, the pressure of the displaced small-scale farmers is not likely to be distributed equally over the whole swamp. The nearby administrative Locations are likely to absorb conversion pressure, resulting in more conversions or intensified use. These Locations are likely to be Central and South Central Alego and North Yimbo. However, a great deal of the utilization pressure is likely to be felt in the North Yimbo area with its high swamp coverage. Note, however, that since one of the main drivers of swamp conversion is the supply of subsistence food, employment in the large-scale farm will only serve to substitute income while increasing the demand for food at the local level. However, the new income is likely to have a dual effect. First, it is likely to be devoted to other cash economy needs like school fees and domestic needs such as clothing and building. In addition, it is also likely to increase the purchasing power of the local and migrant workers, thus raising the food demand. However, this possible scenario is presently poorly understood and calls for further research on its likely effect on the swamp resources utilization and its impact on the swamp land cover.

8.3 Co-Validation

To test the significance and the validity of the statistically computed spatial land-use values generated from the household data, the results were compared to the spatial values derived from the 2001 Landsat image. Land-cover classes of the wetland were generated from the satellite image independent of the computation of the wetland land demand based on the household census. The spatial data from the 2001 image indicates a total area converted area to agricultural activities at 5,939.84 ha against a total computed coverage of 11,696 ha for the whole ecosystem. This difference can be attributed to either the household sampling but more likely to the date of the 2001 satellite image and the dates of the seasonal conversions in the swamp. This difference can be compensated by the land-cover classification of the 2001 image, since conversions in the swamp are both seasonal and temporal.

Out of the seven land-cover classes generated from the Landsat images, based on field information and vegetation composition, two classes fall within those that are at risk of conversion or are seasonally converted in the course of the year. These are the bushes-*sesbania* and the sedges-*dives* communities (Figure 7.2, Table 7.5), which cover 2,359.96 ha and 3,435.64 ha, respectively. This gives a total area of 11,735.44 ha from the 2001 satellite image. The two land-cover classes form an interface between the papyrus community and the dry eco-type and are often used for farming. Their coverage on the northern side, south of the large conversions along River Nzoia and north of Lake Kanyaboli was extensive (Figure 7.2). In addition, these areas have relatively high conversion indices (Figure 8.2, Figure 8.3).

Given that the statistically computed household figures fall within the range of 11,696 ha or 90% of the satellite-derived data, this validates the statistical calculation. Thus, the suitability of household and socio-economic data to predict land-use changes is significantly high compared with data derived from remote sensing.

However, there was poor co-validation at the individual Location level. The statistically computed household figures were within the range of 50% of the satellite data with high spatial coverage variability between the Locations. This poor performance can be attributed to either the scale of validation or the household data. One possibility is that the household values used to compute conversions at the ecosystem scale might not be adequate at the lower Location scale, since this result in high spatial variation between the Locations. To reduce these spatial errors at this lower scale, more household conversion data maybe required. This outcome indicates that this approach is not able to clearly pinpoint specific conversion areas in the swamp. However, the success in the co-validation at the scale of the whole swamp ecosystem allows prediction of large-scale conversions and the direction of change in the future.

8.4 Discussion

The most important underlying factor in land-use change has been related to demographic factors (Lambin *et al.,* 2001), which are also relevant to the Yala swamp. Although there are very few studies on wetland land-use change especially in Africa, parallel experience can be drawn from deforestation (Mertens *et al.,* 2000) and rangelands (Serneels and Lambin, 2001). This can be enhanced further through an interdisciplinary studies approach, which was adopted for the Yala swamp. This approach allows good understanding of the relationship between land-cover change and socio-economic factors (Rindfuss *et al.,* 2004). Land-use changes in the Yala swamp are determined by a variety of factors that are largely demographic in nature. One of the most important proximate causes of land-use change in the swamp is cultivation, which emerged clearly in the household data analysis. Other minor causes, though not prominent in land-cover change in the Yala swamp, included brick making, macrophyte harvesting and grazing. A combination of high population density, small landholding size and declining soil fertility make swamp farming a valuable alternative for the local communities. The main reason for the cultivation activities was to create a domestic food supply and raise the subsistence income.

Agriculture especially for food supply has been cited as one of the main dynamic causes of land-cover change (Lambin *et al.,* 2001). A synthesis of studies on land-use changes shows that the major drivers in Latin America are pasture and infrastructure, while in Asia the major driver is commercial logging (Geist and Lambin, 2002). In contrast, subsistence agriculture is the prime factor in Africa. These regional drivers are directly related to the sources of livelihood and preferred use of land. Similarly, studies in Lake Victoria basin wetlands indicate that subsistence farming is an important wetland utilization activity (Mugo and Shikuku, 2000, Gichuki *et al.,* 2001; Abila, 2002). However, other recorded major drivers like settlement have only a minimal impact in the Yala swamp due to the local setting, as the recurrence of annual floods discourages expansion of settlements into the swamp.

The relationship between important demographic determinants of land-use change in the Yala swamp such as population and agriculture were quite clear from the statistical analysis. Identified prominent demographic factors were population and household densities as well as household number. Swamp accessibility was also directly related to the demographic variables which clearly emerged through the combination of remote sensing and household data. Areas with high population and household densities as well as large swamp coverage had overall large conversions. Large swamp coverage, fertile soil, good social infrastructure and easy terrain, among others, attracts more people hence more conversions. These observations support the argument that the role of population depends on specific settings (Schelhas, 1996; Jones, 1998; Pender 1998). Therefore, although most of the land-cover changes were concentrated along the edges of the swamp, in particular large conversions were located along south of Lake Kanyaboli, around Lake Namboyo and along the River Nzoia. These sections had experienced extensive conversion through the initiative of the local community due to several factors. For example, the northern side of the swamp along the River Nzoia had higher population and household densities plus easy accessibility relative to the other parts of the swamp. Hence, high conversion pressure was exerted on the wetland in this area. However, the ability to convert and utilize the land is based on several factors, among them domestic labor supply. It is likely that high-density areas are likely to deliver a higher labor force than low-density areas.

Other underlying socio-economic factors that were indirectly related to land conversion but were important included social infrastructure like roads and urban centers. The northern side, compared to the southern side, had relatively good road connections to larger urban centers like Busia, which provided better marketing opportunities for farm and wetland products. In addition, the main ethnic compositions on the northern side of the swamp are Luhyas, who have agrarian livelihood strategies while the Luo on the southern side are agro-pastoralists. In spite of the high incidences of flooding in the northern part of the swamp, farming activities were high during the dry season as the water receded exposing fertile soils. These socio-economic variables support the argument that the role of population in influencing land-cover change depends on several factors, among them land availability and infrastructures (Jones 1998; Merten *et al.,* 2001). Similarly, the expansions of smallholder agriculture and land-cover change in the Narok District have been linked to some extent to the proximity of social infrastructures like health centers and urban centers (Serneels and Lambin, 2001). Other factors, mainly biophysical have also been linked to land-use changes, which were also relevant in the Yala swamp. For example, studies in Kenya by Githaiga *et al.* (2003) and Reid *et al.* (2004) show that in ASALs, agricultural activities take place or expand near wetlands because of the water availability. Mugisha (2002) linked the land-cover changes in Uganda to population density coupled with land scarcity and declining soil fertility, which also applies to the Yala swamp as well.

However, the variability in time of land-use change processes affects the ability to use regression models for wide range extrapolations. Some variables also evolve over time, creating heterogeneity that is related to the changes in agricultural land use. For example, the expansion of mechanized agriculture with the introduction of high technology in Narok after 1985 changed the variability of land-use change (Serneels and Lambin, 2001). Similarly, in the early 1970s, the government of Kenya opened up the area to the south of Lake Kanyaboli in the Yala swamp for seed production and small-scale farming (GoK, 1994; Aloo, 2003). This facilitated access to a large farming area for more people than would have been possible without the initial conversion by the government. Recently, this portion of the land was leased out to a private company for large-scale mechanized rice farming. This introduced a different variable (mechanized, high technology farming) to the land-use change drivers in the Yala swamp leading to changes from the low technology practices of the indigenous community, thus increasing conversion pressure on the wetland. Kok (2004) made similar observations in Cost Rica, where diversification of agriculture through import and export of produce significantly altered land-use change drivers. Such transformation could also be caused by policy, economic or climate changes. For example, acceleration of deforestation in Cameroon in the early 1990s has been related to changes in macro-economics, which were linked to IMF structural adjustment programmes (Merten *et al.,* 2000).

The high population density coupled with high agricultural land demand and poor economic prospects in the Yala swamp inevitably lead to the expansion of subsistence agriculture. This compares well with studies in Honduras by Kok (2004). Such a move is inevitable, since the area outside the swamp is too dry to support rainfed farming throughout the year. Again, the population, especially the local and migrant workers, is expected to increase on the south-eastern part of the swamp near the large-scale rice farm. This will obviously increase the local food demand in turn leading to a higher demand for farming land in the swamp. This hypothesis requires more temporal data on the changing wetland utilization and livelihood dynamics. In the case of the Yala swamp, the argument advanced by von Thuenen (1966) in terms of market influence on land-cover change exhibits a weak relationship, due to high poverty levels and poor infrastructure, the need for subsistence food currently overrides market-driven demand and encourages swamp conversions. Serneels and Lambin, (2001) made similar observations with other variables in the expansion of smallholder agriculture in the Narok District , showing that, for example, proximity to water is more important.

In the absence of ecosystem management plans and minimal local community conservation initiatives, individual household land demands are bound to increase with time leading to more conversions. In addition, the conclusion from the statistical computation is that, as population densities increase, swampland shareholding will decrease and in turn conversion pressure will increase to cater for the increased population demand. It is also important to acknowledge that the local settings such as local infrastructures are indirectly related to the conversions.

8.4.1 Conclusions

The causes of land-use change in the Yala swamp are diverse, but the demand to meet local livelihood needs, in terms of food supply and income, is a major driving force. However, the use of statistical models allows identification of the sources of conversion pressure, although it is not possible to clearly pinpoint the locations of these effects. Through the use of remote sensing data and demographic variables in combination with the socio-economic data it was possible to point out the direction of change (more conversion) and origin of change (all accessible areas) as an increment to current converted areas. Nevertheless, due to the effect of the temporal transformation of the variables, it is not possible to determine the time “when” and possible scale of change. For example, while population and household variables can be clearly projected, other factors like the development of social infrastructures are more spontaneous and hard to project.

Policy change and infrastructure development are often remote in space and time, but have significant effect on land-use change drivers. For example, improvement of roads in the area would lead to more products reaching the market. This would in turn increase the demand for more land to cater for the improved market access, which is currently a major hindrance to utilization and income levels in the area. The current poor infrastructure has only a minor effect on land-cover change. Alternatively, a combined conservation and management plan for the swamp would lead to reduced wetland conversion and possible wetland restoration, altering the effect of the current drivers.

Variability in land-use change drivers affects land-cover change as well as the scale of co-validation. The question of variability in scale and its effect on the strength of land-cover change drivers is very relevant in land-use studies (Pfaff, 1996; Kok *et al.,* 2001; Serneels and Lambin, 2001). While co-validation works well at the broad scale of the ecosystem, at the finer Location scale it is complicated by the spatial variability of conversions. This limited the ability to pinpoint high conversions “Locations” in this study.

9 SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

The socio-economic and ecological function benefits that are attributed to wetland ecosystems are vital for human sustenance, yet conversion of wetlands to settlements and to agricultural and industrial use is a common practice. The situation in the Yala swamp is not an exception. The swamp is undergoing numerous changes, which include conversion to cultivation plots and clearing of vegetation, which has resulted, for example, in siltation of the water systems. These changes are related to several factors. The major driving force is the demand for farming land to cater for subsistence food supplies due to the high population density, followed by the need to raise incomes. In addition, lack of alternative sources of income coupled with a poor economic situation are increasing dependence on the swamp. Apart from the socio-economic values and ecological benefits that the Yala swamp provides to the local communities, it is also an important habitat for many species of flora and fauna. The macrophytes in particular play an important role as water filters, minimizing siltation of the water systems. Overall, the swamp has tremendous potential for generating income to the local people through eco-tourism, farming, fishing and the sale of macrophyte products. Unfortunately, pervasive poverty and the absence of a resource-use strategy are leading to ecosystem degradation.

9.2 Summary of findings

9.2.1 Utilization of wetland resources

A high socio-economic variability was recorded in the Yala swamp. Settlements around the swamp date back to the beginning of the 20th century, increasing over the years. The sampled households were mainly monogamous (52%) but with a significant proportion of polygamy (26%) households. The living standards were moderate to low with more than 50% of the houses having thatched roofs, 70% earth walls and the rest having a mixture of cement, earth and stones walls. The literacy level was also low, with most people having attained primary level education but with a high average number of years spent in school (about 19 years). This low literacy level was partly attributed to the high out-migration, especially of the educated persons, in search of employment leaving a high net illiteracy level in the area.

Land was regarded as an important asset, which was mainly acquired through inheritance along kinship group, both inside and outside the swamp. The average land holding size outside the swamp is about 1-4 ha while landholdings inside the swamp average 2.4 ±0.163ha. Although the swamp is communally owned land, land is initially acquired through self-allocation and later passed on through inheritance. Again, in the absence of a clear management authority, sale of the land held in the swamp took place also among the locals communities. The swamp does not serve the landless but acts as an additional land for the local communities.

The Yala swamp provides enormous support to the local communities and several products are obtained from the swamp. There is specifically heavy reliance on the macrophytes, with utilization limited mainly to six species for building and craft items. These include *Cyperus papyrus* L., *Phragmites mauritianus* Kunth, *Cyperus dives* syn. *Immensus* Del, *Cyperus distans* L.f., *Echinochloa haploclada* (Stapf) Stapf, *Typha domingensis* Forst. In addition, *Phoenix reclinata* (Schum. & Thonn. syn; *Phoenix spinosa Phoenix leonensis)* and *S. sesban* L. are also used. While the other species are distributed almost equally over the swamp, *Phoenix reclinata* was only found on the northern side of the swamp towards the western section. However, the local communities rely heavily on the *Cyperus* genera. For example, papyrus was largely used for both building and craft items while *C. dives* and *C. distans* were mainly used for thatching. Variability in macrophytes utilization was based on the respective macrophyte biomass availability, intended final use and the ecological occurrence.

Thatching mainly involved the combination of species in sequential layers, unlike the widely recorded use of papyrus alone as thatching material. Quite often, leafy species such as *C. dives* and *C. distans* were used alone, since they offer better protection against the rain than the semi-cylindrical stems of *C. papyrus*. More than 75% of the macrophytes and other wetland products were geared towards domestic needs with only minimal commercialization. In addition to thatching, macrophytes were also used for domestic fuel and craft items like fish traps, mats, doors, windows, ceiling covers, baskets and decorations. Although use of macrophytes as fodder was minimal, grazing in the swamp was an important activity especially in the dry season. Apart from the macrophytes, other products included fish both from the swamp as well as from the open water. These products were mainly transported from the swamp using a combination of bicycles and backloads. This was attributed to the poor infrastructures and low economic level in the area.

Sale of the wetland products was low and took place in the markets near the swamp as well as at the household level through individual local enterprises. However, the variety of traded products was low, which could have contributed to the low returns. The average income was about USD 19 per household per month. Factors contributing to this scenario included lack of market information, absence of organized groups, poor infrastructure, e.g., roads and telephone. There was a high variability of goods and level of business across the seasons with much lower incomes during the dry season. The northern side of the swamp had rather higher enterprise activities than the southern section. This was attributed to the relatively good infrastructure especially road connections to large marketing outlets such as the Busia town. Intermediaries often bought some of these products in bulky and transported them to market centers offering better prices away from the swamp. This often resulted in the exploitation of the local communities due to the absence of organized groups and the weak flow of market information.

However, the wetland was rated high as an important source of income and farming especially in the dry season. This was followed by macrophytes with fishing trailing behind. Of the household swampland holdings, 95 % was allocated to cultivation, which supplied about 70% of the domestic food requirements. This was attributed to the high population density in the area coupled with unreliable rainfall patterns together with declining soil fertility.

The big challenge to sustainable utilization of the Yala swamp in line with "wise use" is to strike a balance between the traditional macrophyte harvesting, grazing, fishing and expansion of farming. Sustainable use of the wetland is constrained by the need to generate income in a high poverty area, where returns from the wetland products are low. Other constraints include diseases such as malaria, poor infrastructure coupled with frequent floods. These bottlenecks curtail the efforts to improve livelihood levels and use the resources sustainably. Again, the absence of a resource-use strategy and unclear swamp ownership complicate the efforts to manage and use the resources in a sustainable way.

9.2.2 Post-harvest macrophytes growth and ecological dynamics

The results of the analyses of the post-harvest growth of the six species that are commonly used by the local communities indicate a high growth rate in the first four weeks. Thereafter, the growth rate reduced to almost a constant rate for the next ten weeks. Likewise, growth after the 14th week was greatly diminished in all species. The subsequent post-harvest growth rate in the second and third generation was relatively lower in the first four weeks and the following ten weeks. Along these observations, macrophyte plants that were not harvested over the entire study period of 33 weeks showed only minimal gain in height after the 14th week. In contrast, the harvested plants were able to reach the height of the unharvested plants in 14 weeks even when the wet season declined and the dry season set in.

In terms of ecological influence, the less disturbed eco-types in the high flooding areas had overall high growth rates and higher height gains. Some species like *C. dives* and *C. distans* failed to regenerate when they were submerged by water immediately after harvesting. In contrast, when submerged immediately after harvesting *C. papyrus* only showed a slow shooting rate, and growth thereafter was fast. Overall, the rate of post-harvest growth was high in the less disturbed eco-types in contrast to the highly disturbed eco-types, which was superimposed across the seasons (wet-dry).

Soil parameters were more influenced by eco-type than by season. Only three parameters were significantly influenced by eco-type namely CEC, phosphorous and nitrogen. Additionally, CEC and nitrogen were significantly influenced by season. These changes were influenced by shift in organic material and water amount in the swamp. This variability corresponds to the post-harvest growth of the macrophytes with high growth and biomass in the wet season and the less disturbed season. Soil bulk density on the other hand showed high variability, with higher values recorded in the less disturbed eco-types than in the highly disturbed eco-types.

In contrast, water parameters were more influenced by the season than eco-type. The pH value was significantly influenced by season and was slightly alkaline, with values increasing from the wet to the dry season as well as from the less disturbed to the highly disturbed eco-types. Electrical conductivity showed the same variability trend as the pH, but there was no significance influence. Water-soluble carbon was only slightly influenced by season with values dropping in the dry season. Phosphorous was more strongly influenced by eco-type than by season, with low values in the dry season and in the less disturbed eco-types. Similarly, nitrogen had low values in the dry season, although it was only significantly influenced by season. The ecological values recorded in both water and soil indicated that the nutrient values were above the ecological limiting levels for productivity. The levels were also within other studies in the tropical region.

The results of the macrophyte nutrient content analysis indicated wide variability. Nutrient content was more influenced by season but the eco-types only showed a weak influence. Nitrogen values showed a wider variation across the species compared to phosphorous. However, the variability of both nitrogen and phosphorous was not significant among the different species. Species in the low-flooded zone like *C. dives* and *C. exaltatus* showed high nitrogen values in their plant biomass compared to the high-flooded zone species like *C. papyrus*. Both nitrogen and phosphorous content in the macrophytes were high compared to the soil.

Macrophyte biomass values decreased from the wet to the dry season. However, eco-type showed only a slight influence. The amount of biomass across the eco-types was distorted by the physiognomically taller plants like phragmites, which showed a high plant biomass in the highly disturbed eco-types. This is in contrast to *C. papyrus* in the less disturbed eco-types, which had lower biomass amounts. However, in terms of specific species, *C. papyrus* had the highest average biomass.

9.2.3 Land-cover analysis

Land-cover analysis was done using 1973-MSS and 2001-ETM satellite images, which indicated numerous land-cover changes in the swamp. Seven land-cover classes were derived from the images. The overall classification accuracy of the seven land-cover classes was high at 75% with Kappa statistics at 70%. The most notable changes were recorded along the edge of the swamp but with relatively more changes on the northern side such as along the River Nzoia. These changes included land conversion to farming as well as high siltation along the Lake Victoria shoreline. Other changes recorded on the northern side were the northward shift of the River Nzoia canal near its mouth to Lake Victoria. Significant conversions were also recorded in the area to the north-west of the swamp at Usenge near Lake Victoria. A large-scale conversion was detected on the eastern side of the swamp, which is part of the former LBDA farm under use by small-scale farmers until 2002 when it was leased to a private large-scale company.

In terms of vegetation cover changes, the most prominent changes were the decrease in the *Papyrus-Phragmites-Typha* community due to the increase in the conversions (cropland complex). Also noted was an increase in the *dives-phragmites* community, which often appears as a colonizer in the disturbed areas with low flooding.

More areas had been opened up for farming with a four-fold increase in farming from ca. 1,564 ha to ca. 5,939 ha between 1973 and 2001, which corresponds to a shift from 7 % to 28 % of the swamp coverage.

A total of 68 plant species represented in 27 families was collected from the Yala swamp. The species were classified into five major vegetation communities based on the spatial distribution, physical factors like flooding and ecological disturbance. These were the (1) *Cyperus papyrus-Phragmites mauritianus-Typha* community, (2) *Cyperus dives- .C. papyrus Phragmites* community, (3) *Phoenix reclinata-Brachiaria brizantha-Eucalyptus* community, (4) *Dives-Sesbania sesban* community and the (5) cropland complex (conversion). These vegetation classes were thereafter overload with the land cover derived from satellite images with the assistance of ground points.

The results of the NDVI calculations indicate a reduction in the positive values and a slight increase in the negative values between 1973 and 2001. Overall, the total NDVI values for 2001 were lower than the 1973 values. Both areas inside the swamp that had not been converted and the converted areas showed a major decrease in NDVI. This rise with siltation was again attributed to increased absorption of NIR by the silted water. These changes reflect a reduction in the vegetation cover between 1973 and 2001 image. In conclusion, most of these land-cover changes reflect population pressure on the wetland mostly on the areas that are easily accessible, especially on the northern side of the swamp. These areas are characterized by high densities of both households and population densities.

9.2.4 Land-use change drivers

High variability was recorded in land-use change drivers in the Yala swamp with high conversion pressure especially in the northern part of the swamp. The highest average conversion factors at Location level were found on the northern side at 2.6 ha compared to the south with 1.8 ha. This was attributed to the fact that the northern side has more accessible areas compared to the southern side. Similarly, according to the 2001 satellite images, this area had also high land-cover changes. The determinants of land-use change in the Yala swamp were identified as wetland accessibility, household numbers, household and population densities. The households were important for determining overall land demand and conversion rates, since in the Yala swamp, wetland land-use decisions for farming are made at the household level. Several of these factors indicated likely high future conversion pressure on the wetland under the current utilization and management scenario. This is further emphasized by the computed high household land demand of 36, 286.65 ha against the lower land availability of 22,650.07 ha versus the lower actual current utilization is of 11,696 ha.

Socio-economic factors provided important explanatory factors for the above-identified land-use change drivers. These include, for example, the allocation of farming to 95% of swampland holdings, which supply 70% of the domestic food from the swamp. In addition, the presence of small landholdings outside the swamp and the lack of alternative sources of income act as important reasons for wetland conversion. Others factors that encourage conversion include low economic and literacy levels, unreliable rainfall and high dependence on the natural resources of the Yala swamp.

There was high co-validation at the ecosystem level, but it was low at the Location level. Comparison of the statistically computed conversion figures (11,696 ha) based on the percentage of land under use in the swamp indicated a good co-validation (more than 90%) with the values derived from the satellite images (11, 735.44 ha) at the ecosystem level. The statistically computed figures were based on the percentage land under use in the swamp while the satellite-derived figures took into account the spatial-temporal variability in the conversion of vegetation communities. While 5,939 ha was permanently converted, other vegetation communities are converted periodically, i.e., sedges-*dives* (3,435.69 ha) and bushes-*sesbania* (2,359.89 ha). This adds up to a total area of 11, 735.44 ha. However, co-validation at the Location level yielded low values of around 50% of the statistically computed compared to the satellite-derived values that were also characterized by high spatial variability.

9.3 Conclusions

The presence of the Yala swamp ecosystem in a high population density area that is also characterized by pervasive poverty and declining soil fertility presents a good and viable alternative for the support of the local livelihood especially for the small landholdings outside the swamp, where farmland and water are scarce and soils are poor. There is high dependence on the swamp especially for farming mainly to meet domestic needs and raise subsistence incomes, for example, by selling small quantities of the food crops grown in the swamp, especially in the dry season. Along the food sales, other wetland products like mats were also sold to provide cash. The availability of fish from the wetland ecosystem served to boost the household food supply and also as a source of income. Using fish traps made from macrophytes, households were able to obtain fish for domestic use, although fish was frequently bought at the landing beaches or from other fishermen.

The macrophytes in the Yala swamp provided a significant source of building material as well as a source of income. The numerous species of macrophytes provide a good base for a sustainable craft industry, although this potential has not been fully exploited. This was due to numerous constraints, which included poor infrastructure, e.g., roads. Other factors included lack of market information and absence of organized groups that could be used for training. The unclear situation with respect to the marketing of wetland products provides a fertile ground for intermediaries to exploit the situation, and make relatively high profits.

Harvesting of macrophytes in the swamp was carried out in a random manner, although this could be organized in a systematic way, e.g., through block harvesting. However, this would require a clear management plan with identified zones for grazing, farming, fishing and macrophyte harvesting. Such an arrangement would ensure that valuable macrophytes for craft items are not burnt or grazed, which is currently a common practice, and at the same time protect important habitats in the ecosystem for biodiversity conservation.

Macrophyte growth was strongly influenced by both season and eco-type, but the most important aspect was the availability of nutrients. Both the wet season and the less disturbed eco-type showed comparatively high post-harvest growth. The critical growing period of the macrophytes was in two phases: the first four weeks and the following ten weeks. After the 14th week, growth was highly diminished. This pattern of growth was maintained throughout the year even during the dry period and in the highly disturbed eco-types. The only variation was reduced height and biomass gain, which was attributed to the reduced nutrient circulation. Sections of the swamp that are flooded throughout the year are able to retain luxuriant vegetation growth even in the dry season. In conclusion, based on the ability of the macrophytes to reach a harvestable level within approximately 14 weeks, it is possible to manage block harvesting. This is an important observation in the light of the current high demand for farming land in the swamp and the subsequent reduction of the macrophytes coverage.

The changes noted in land cover between 1973 and 2001 indicate there are specific hot spot zones of land-cover changes. These zones also show high water siltation, especially on the northern side at the mouth of the River Yala due to reduced macrophyte cover. The River Yala, which flows through the swamp, has no such siltation plume at its mouth. The four-fold increase in the farming area from 1973 to 2001 and the reduction in the vegetation communities coverage point to sustained conversion pressure. The northward shift of the River Nzoia was as a result of these activities, which are also leading to ecosystem degradation. These changes are further supported by the changes observed in the NDVI values, with less positive values observed in 2001 image. The successive applicability of remote sensing skills and GIS methods in change detection indicate their usefulness in monitoring inaccessible ecosystem like swamps.

The identified land-use change drivers were mainly localized anthropogenic proximate activities such as farming as well as the policy driven changes on the eastern side of the swamp. The household demand for farming land acts as an important proxy of the high population density. Remote sensing data showed extensive conversion in the high population density areas and in the more easily accessible northern section. Due to the high dependence by the local communities on the swamp resources, management trends should focus on more sustainable use with community as the central focus, as farming is an important activity that cannot be dissociated from Yala wetland management. However, the rising monopolistic use of farming should be discouraged. To achieve meaningful progress, efforts should also be directed at addressing constraints in sustainable resource utilization like poor infrastructure, ineffective marketing systems and lack of ecosystem management plans. In particular, marketing of wetland products should be addressed so as to raise the level of direct benefits to the local community. In addition to increased benefits, formulation of participatory management approaches would increase community commitment to sustainable activities in the swamp.

9.4 Recommendations

Results indicate that the communities living around the Yala swamp ecosystem are highly dependent on the swamp for their livelihood. Swamp uses included farming, livestock keeping, water supply, fishing, material for building and craft items, food and domestic energy for both subsistence and income provision. To achieve sustainable swamp use in the poor economic environment with its high population density, there is need for a clear management plan. Therefore, a strategy focusing on both subsistence needs like domestic food and income from the ecosystem balanced with conservation initiatives should be developed. This calls for a participatory management approach involving the local communities and other stakeholders.

9.4.1 Ecosystem utilization and "wise use" management

To achieve a balance between utilization and management, the following issues should be considered:

- To maintain ecosystem services and functions especially of the water system, i.e., rivers and lake shores, there is need to conserve a belt of macrophytes with some controlled harvesting. This would be an extra area in addition to the government regulation of non-cultivation of riverrine areas.
- At the same time there is need to create awareness on the Yala swamp ecosystem services by both government departments and civil society.
- An ecosystem management plan should be formulated with the participation of all local stakeholders with a view to both maximizing benefits to the local communities and maintaining ecological services while halting ecosystem degradation.
- Considering the large size of the swamp ecosystem, a strategic plan should be accompanied by specific zone management plans or plan of activities based on community interests while considering the geographical layout. Such ecosystem zones should be managed by community groups like fishermen or farmers so as to control encroachment, uncontrolled exploitation and facilitate sustainable use.
- The conservation and management of the biological resources in the Yala swamp should recognize the indigenous knowledge and technology and borrow from them so as to strengthen management of the ecosystem and the capabilities of the local people.
- Establishment of resource centers on both sides of the swamp, where the local people and researchers can obtain information on the local activities and resources, is necessary. Research findings could also be documented at such centers with the assistance of the local people.

- Provision of sanitation services by the local authority, which are currently inadequate, especially at the landing beaches, is necessary so as to minimize diseases such as cholera.
- Fish exploitation could be increased at the household level, both for subsistence and income, through construction of finger ponds together with the community groups along the swamp edge.
- Farming areas, especially where chemicals and fertilizer are used, should have a belt of macrophyte as a nutrient filter to prevent nutrient enrichment of the water system. This should be the case, for example, along the large-scale Dominion farm and other areas around the swamp where irrigation takes place and since water pollution due to pesticides is possible.

9.4.2 Biodiversity conservation

There is need to:

- Ensure biodiversity conservation especially protection of species habitats. This could be achieved through youth groups, and along their regular activities data on birds can be collected. Such groups should be linked to conservation organizations in the country so as to give their activities some relevance. For example, Nature Kenya (NGO) works with youth groups in areas with important bird habitats or endangered species, which certainly applies to the Yala swamp. As part of this research, a local group (Kombo youth fishing group) was trained as a site support group for the Yala swamp near Lake Kanyaboli, which is an important bird habitat. The group was linked to Nature Kenya through the Kisumu-based Lake Victoria sunset birders (LVSB), an older site support group in the Yala swamp.
- Other groups could be initiated since the ecosystem is big for the two groups to have meaningful impact.
- Identify and protect habitats for endangered species like the Sitatunga antelope (*Tragelaphus spekeii*), among other species.
- Considering the importance of the six macrophytes species investigated in this study there is a need to conserve them to facilitate continued availability to the local community.

- Link up the existing information/databases on the Yala swamp flora and fauna and update them through a comprehensive swamp inventory. This can conveniently be done within Lake Victoria Environment Management Programme.
- Establish a structure for monitoring the swamp resources like vegetation and water bodies, which could be done through satellite images and regular ground data collection. This could be done by organizations currently working in the LVB such as ICRAF and government bodies.

9.4.3 Future research

Most of the research in the Lake Victoria Basin has concentrated on the open waters of Lake Victoria and the satellite lakes like Kanyaboli, Sare and Namboyo and the Rivers Yala and Nzoia.

- With the increasing demand for macrophytes, it is important to monitor nutrient off-take from the ecosystem through local macrophyte harvesting.
- Information on the biomass off-take, per species, for building and crafts is important for guiding sustainable development of the ecosystem. This could be gathered in future research in Yala swamp.
- Phosphorous washed down from the catchments has been identified in the basin and finds it way into the lake especially in areas where macrophytes have been cleared. The phosphorous entering the water system should be monitored to gauge the usefulness of the macrophyte system as a filter and assess the need for ecosystem restoration.
- Communities are always evolving to meet the emerging life challenges, and traditional practices are frequently discarded. Understanding of the indigenous ways of wetland utilization in the Yala swamp would provide important lessons for conservation and management in line with sustainable utilization.
- Although the Yala swamp is documented as an important biodiversity area, especially for fish, birds and the rare swamp antelope Sitatunga, there is still a lack of information on specific habitat locations. This information would be important for the control of encroachment as well as the conservation of the habitat and species.

- Identification of the emerging land-use change drivers in the swamp is also important as a management tool. This could be achieved through the evaluation of household data combined with multi-temporal images and appropriate modelling to investigate trajectories of land-use change.
- Farming being an important activity in the swamp, there is a need to quantify the contribution of the swamp to the local food basket. This should be done with a view to maximising utilization in a sustainable manner by identifying strengths, drawbacks and constraints. ICRAF is in particular suited to do this in conjunction with the ministry of agriculture.
- Yala swamp is an important ecosystem in LVB thus there is a need to determine it significance in ecosystem services such as carbon sequestration, filter functions and fish breeding.
- Considering the importance of the wetland in carbon budget, it is important to consider carbon sequestration in the Yala swamp

10 REFERENCES

Abebe Y. D. and Geheb K. (eds) 2003. Wetlands of Ethiopia. Proceedings of a Seminar on the Resources and Status of Ethiopia's Wetlands.

Abila R. 2002. Utilisation and Economic Valuation of the Yala Swamp, Kenya. In: Gawler, M. (ed) Strategies For Wise Use of Wetlands: Best Practices in Participatory Management. Proceedings of a Workshop Held at the 2nd International Conference on Wetlands and Development. (November 1998, Dakar, Senegal). Wetlands International IUCN, WWF Publications No. 56, Wageningen, The Netherlands, pp. 89-96.

Adelaida K. S. 2000. The Wetlands of Sub-Saharan Africa, their Value and Management. Botany Department, University of Dar es Salaam, Tanzania.

Allison E. H. and Badjeck M. C. 2004. Livelihoods, Local Knowledge and the Integration of Economic Development and Conservation Concerns in the Lower Tana River Basin. Hydrobiologia 527: 19-23.

Aloo P. A. 2003. Biological Diversity of the Yala Swamp Lakes, with Special Emphasis on Fish Species Composition, in Relation to Changes in the Lake Victoria Basin (Kenya): Threats and Conservation Measures. Biodiversity and Conservation 12: 905–920.

Alwashe M. A. and Bokhari A. Y. 1993. Monitoring Vegetation Changes in Al Madinah, Saudi Arabia, Using Thematic Mapper data. International Journal of Remote Sensing 2: 191-197.

Anderson J. M. and Ingram J. S. L. 1993. Tropical Soil Biology and Fertility: A Handbook of Methods. CAB International, Wallingford, U.K.

Andriesse J. P. 1988. Nature and Management of Tropical Peat Soils. FAO Soils Bulletin 59.

Apfelbaum S. I. 1985. Cattail (Typha spp) Management. Natural Areas Journal 5: 9-17.

Barbier E. B. 1989. The Economic Value of Ecosystems 1- Tropical Wetlands. LEEC Gatekeeper Series 89-02, London Environmental Economics Centre, London.

Barbier E. B. 1993. Sustainable Use of Wetlands Valuing Tropical Wetlands Benefits: Economic Methodologies and Applications. The Geographical Journal 159 (1): 22-32.

Barko J. W., Gunnison D. and Carpenter S. R. 1991. Sediment Interactions with Submersed Macrophyte Growth and Community Dynamics. Aquatic Botany 41: 41-65.

Barnes K., Ellery W. and Kindness A. 2002. A Preliminary Analysis of Water Chemistry of the Mkuze Wetland System, Kwazulu-Natal: A Mass Balance Approach. Water S A 28 (1): 1-12.

Beadle L. C. 1974. The Inland Water of Tropical Africa, Longman, New York.

Benson B. J. and Mackenzie M. D. 1995. Effects of Sensor Spatial Resolution on Landscape Structure Parameters. Landscape Ecology 10: 13 - 120.

Binswanger H. P. and McIntire J. 1987. Behaviour and Material Determinants of Production Relations in Land Abundant Tropical Agriculture. Economic Development and Cultural Change 36: 73 - 99.

Boserup E. 1965. The Conditions of Agricultural Growth. The Economics of Agrarian Change Under Population Pressure. London: Earthscan Publications Ltd.

Bremner J. M. and Mulvaney C. S. 1982. Total Nitrogen. In: Page A. A. L. (ed) Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties. 2nd edition. Agron. Ser No. 9 Amer. Soc. Agron., Madison, Wisconsin, pp. 593-624.

Briassoulis H. 2000. Analysis of Land-use Change: Theoretical and Modeling Approaches. Regional Research Institute. West Virginia University.

Bridgham S. D. Pastor, J. Jannsens J. A., Chapin C. and Malterer T. J. 1996. Multiple Limiting Gradient in Peatlands: A Call for a New Paradigm. Wetlands 16: 45 – 65.

Broomer S. W., Seneca E. D. and Woodhouse W. W., Jr. 1986. The Effects of Source, Rate and Placement of Nitrogen and Phosphorous Fertilizers on Growth of *Spartina Alterniflora* Transplants in North Carolina. Estuaries 6: 212 - 226.

Brouwer R., Langford I. H., Bateman J., and Turner R. K. 1999. A Meta-Analysis of Wetland Contingent Valuation Studies, Global Environmental Change Working Paper 47-57. Centre for Social and Economic Research on the Global Environment (CSERGE), University of East Anglia, Norwich, and University College, London.

Brown L. R. 1994. Full House: Reassessing the Earth's Population Carrying Capacity. W. W. Norton, New York.

Bugenyi F. W. B. 2001. Tropical Freshwater Ecotones: Their Formation, Functions and Use. Hydrobiologia 458: 33–43.

Burnmeister M. 2001. *Cyperus papyrus*: From the Nile to Modern Times. Ethnobotanical Leaflets. SIUC College of Science. http://www.siu.edu/~ebl/

Cain S. A. and De Oliveira Castro G. M. 1959. Manual of Vegetation Analysis, Hafner., New York.

Calamari D., Akech M. O. and Ochumba P. B. O. 1995. Pollution of Winam Gulf, Lake Victoria, Kenya: A Case Study for Preliminary Assessment. Lakes and Reservoirs: Research and Management 1: 89 – 106.

Carte G. S. 1955. The Papyrus Swamps of Uganda, W. Heffer and Sons Limited, Cambridge.

Chambers R. M. and Fourqurean J. W. 1991. Alternative Criteria for Assessing Nutrient Limitation of a Wetland Macrophyte (Peltandra virginica (L.) Kunth). Aquat. Bot. 40: 305–320.

Chambers R. M., Meyerson L. A. and Saltonstall K. 1999. Expansion of *Phragmites Australis* into Tidal Wetlands of North America. Aqua Bot. 64: 261 - 273.

Chavangi N. A., Rutger J. E. and Valerie J. 1985. Culture as the Basis for Implementing Self-Sustaining Development Programmes. Kenya Woodfuel Development Programme, Beijer Institute, Nairobi, Kenya. Presented at the ILO Workshop on Women and the "Other Energy Crisis," Nairobi, Kenya, April 1986.

Convention on Biological Diversity 1992. National Interests and Global Imperatives. International Conference on the Convention on Biological Diversity 26-29 January 1992. Acts Nairobi, Kenya.

Crafter S. A., Njuguna S. G. and Howard G. W. (eds) 1992. Wetlands of Kenya. Proceedings of the Kenya Wetlands Working Group Seminar on Wetlands of Kenya, National Museums of Kenya, Nairobi, Kenya 3-5 July 1991.

Davies, J. and Claridge, G. (eds) 1993. Wetland Benefits: The Potential for Wetlands and Integrated River Basin Management. Experiences in Asia and the Pacific. United Nations Environment Programme, Nairobi.

Davis S. M. 1991. Growth, Decomposition and Nutrient Retention of *Cladium jamaicense* Crantz and *Typha Domingensi* Pers. In the Florida Everglades. Aqua Bot. 40: 203 - 224.

Davis J.A. and Froend R. 1999. Loss and Degradation of Wetlands in Southwestern Australia: Underlying Causes, Consequences and Solutions. Wetlands Ecology and Management 7: 13-23.

Denny P. 1985. The Ecology and Management of African Wetland Vegetation, Dr. W. Junk, Dordrecht. Netherlands.

Dietz T., Ostrom E. and Stern P. C. 2003. The Struggle to Govern the Commons. Science 302: 1907 – 1912.

Driessen P. M. and Rochimah L. 1976. The Physical Properties of Lowland Peats from Kalimantan and their Significance for Land Suitability Appraisal. Research on Peat and Podzolic Soils in Indonesia and their Potential for Agriculture. Soil Research Institute, Bogor, Indonesia.

Driessen P. M. and Suhardjo H. 1977. Reclamation and Use of Indonesian Lowland Peats and their Effect on Soil Conditions. 3rd Asian Soil Conference, Kuala Lumpur.

Drijver C. A. and Van Wetten J. C. J. 2000. Sahel Wetlands 2020. Water and Environment: Key to Africa's Development. Centre of Environmental Science (CML), University of Leiden, The Netherlands.

Ducros-Gambart D. and Gastellu-Etchegorry J. P. 1984. Automatic Analysis of Bitemporal Landsat Data: An Application to the Study of the Evolution of Vegetation-Covered Areas in a Tropical Region. Proceeding IGARSS Symposium. Guyenne T. D. and Hunt J. J. (eds) (Paris: European Space Agency), pp. 187 - 192.

Duke J. A. 1983. *Cyperus papyrus* L. Handbook of Energy Crops. Unpublished.

Emerton L. 1999. Economic Tools for Valuing Wetlands, Nature and Economy Programme. IUCN, Eastern Africa Regional Office Nairobi, Kenya.

Ethernington J. R. 1983. Wetland Ecology. The Institute of Biology's Studies in Biology No. 54 Edward Arnold Publishers, Limited, London.

FAO 1998. Wetland Characterization and Classification for Sustainable Agricultural Development. Sub-Regional Office for East and Southern Africa (SAFR), Harare.

Farber S. and Constanza R. 1987. The Economic Value of Wetlands Systems. Journal of Environmental Management 24: 41-51.

FitzPatrick E. A. 1988. An Introduction to Soil Science. 2nd edition. Longman, New York.

Fourqurean J. W., Zieman J. C. and Powell G. V. N. 1992. Phosphorous Limitation of Primary Production in Florida Bay: Evidence from C:N:P Ratios of the Dominant Seagrass *Thalassia testudinum*. Limnol. Oceanogr. 37 (1): 162–171.

Fuller R. M., Groom G. B., Mugisha S., Ipulet P., Pomeroy D. and Katende A. 1998. The Integration of Field Survey and Remote Sensing for Biodiversity Assessment: A Case Study in the Tropical Forests and Wetlands of Sango Bay, Uganda. Biological Conservation 86: 379–391.

Gaudet J. J. 1976. Nutrient Relationship in the Detritus of a Tropical Swamp, Arch Hydrobiology 78: 213 - 239.

Gaudet J. J. 1977 (a) Natural Draw Down on Lake Naivasha Kenya and the Formation of Papyrus Swamps. Aquatic Botany 3: 1- 47.

Gaudet J. J. 1977 (b) Uptake, Accumulation and Loss of Nutrients by Papyrus in Tropical Swamps. Ecology 58: 415 - 422.

Gaudet J. J. 1978. Effect of Tropical Swamp on Water Quality. Limnol. 20: 2202 - 2206.

Gaudet J. J., 1979. Seasonal Changes in Nutrient in a Tropical Swamp, North Swamp Lake Naivasha Kenya. J. of Ecology 67: 953 - 981.

Gaudet J. J. and Melack J. M. 1981. Major Ions Chemistry in the Tropical African Lake Basin. J. of Freshwater Biology 11: 309 – 333.

Gaudet J. J. and Muthuri F. M. 1981. Nutrient Relationship in Shallow Water in an African Lake, Lake Naivasha. Oecologia 49 (1): 109 – 118.

Geist H. M. and Lambin E. F. 2002. Proximate Causes and Underlying Driving Forces of Tropical Deforestation. BioScience 52 (2): 143 - 150.

Gichuki J., Guebas F. D., Mugo J. C., Rabuor O., Triest L. and Dehairs F. 2001. Species Inventory and the Local Uses of the Plants and Fishes of the Lower Sondu Miriu Wetland of Lake Victoria, Kenya. Hydrobiologia 458: 99 – 106.

Gilliam F. S., May J. D., Fisher M. A. and Evans D. K. 1999. Short-term Changes in Soil Nutrients During Wetland Creation. Wetlands Ecology and Management 6: 203–208.

Githaiga J. M., Reid R., Muchiru A. and van Dijk S. 2003. Survey of Water Quality Changes with Land-use Type, in the Loitokitok Area, Kajiado District, Kenya. Land-use Change Impacts and Dynamics (LUCID) Project Working Paper 35; Nairobi, Kenya: International Livestock Research Institute.

Gosselink J. G. and Maltby E. B. 1990. Wetland Losses and Gains. In: Williams M. (ed)Wetlands: A Threatened Landscape. Blackwells, England, pp. 296-322.

Government of Kenya. 1994. National Environment Action Plan (NEAP). Government Press, Nairobi

Green G. M. and Sussman R. W. 1990. Deforestation History of the Eastern Rain Forest of Madagascar from Satellite Images. Science 2: 212 - 215.

Greve C. (ed) 1996. Digital Photogrammetry. An Addendum to the Manual of Photogrammetry. America Society for Photogrammetry and Remote Sensing.

Groffman P. M. 1994. Denitrification in Freshwater Wetlands. Current Tropics Wetland Biogeochem. 1: 15-35.

Halls A. J. (eds) 1997. Wetlands, Biodiversity and the Ramsar Convention: The Role of the Convention on Wetlands in the Conservation and Wise Use of Biodiversity. Ramsar Convention Bureau, Gland, Switzerland.

Hardin G. 1968. The Tragedy of the Commons. Science 162: 1243 – 1248.

Harvey K. R. and Hill G. J. E. 2001. Vegetation Mapping of a Tropical Freshwater Swamp in the Northern Territory, Australia: A Comparison of Aerial Photography, Landsat T. M. and SPOT satellite imagery. International Journal of Remote Sensing 22: 2911-2925.

Hesse P. R. 1971. A Textbook of Soil Chemical Analysis. John Murry, London, United Kingdom.

Hoekstra D. and Corbett J. 1995. Sustainable Agricultural Growth for Highlands of East and Central Africa: Prospects to 2020. International Food Policy Research Institute, Washington, DC.

Hollis G. E. 1990. Environmental Impact of Development on Wetlands in Arid and Semi-arid Lands. Hydrological Sciences Journal 35 (4): 411-428.

Hollis G. E. 1993. Goals and Objectives of Wetland Restoration and Rehabilitation. In: Moser M., Prentice R. C. and van Vessem J. (eds)Waterflow and Wetland Conservation in the 1990s: A Global Perspective. Proceedings of the IWRB Symposium, St. Petersburg, Florida, November 1992, IWRB Special Publication 26: 187–194.

Hughes R. H. and Hughes J. S. 1992. A Directory of African Wetlands. IUCN, Gland, Switzerland and Cambridge, UK.

Huigen M. G. A. 2004. First Principles of the Mameluke Multi-actor Modelling Framework for Land-use Change, Illustrated with a Philippine Case Study. Environmental Management 72: 5-21.

ICRAF 1995. Laboratory Methods for Soil and Plant Analysis: Version 1.1. Nairobi.

ICRAF 2000. Improved Land Management in the Lake Victoria Basin: Linking Land and Lake, Research and Extension, Catchment and Lake Basin. First Technical Report, Start-up Phase, July 1999 to June 2000. ICRAF and Ministry of Agriculture and Rural Development.

Jha C. S. and Unni N. V. 1994. Digital Change Detection of Forest Conversion of a Dry Tropical Indian Forest Region. International Journal of Remote Sensing 13: 2543-2552.

JICA 1980. National Water Master Plan, Stage 1 Study Report. Republic of Kenya, Ministry of Water Development.

JICA 1991. National Water Master Plan. Republic of Kenya, Ministry of Water Development.

Johnson T. C., Kelts K. and Odada E. 2000. The Holocene History of Lake Victoria. AMBIO: A Journal of the Human Environment 29 (1): 2 - 11.

Jones U. S. 1987. Fertlizer and Soil Fertility, 2nd edition. Prentice –Hall of India Private Limited, New Delhi.

Jones J. R. 1998. Colonization in Central America. In: Mansherd W., Morgan B. (eds) Agriculture Expansion and Pioneer Settlement in the Humid Tropics, United Nations University, Tokyo, pp. 241-265.

Kairu J. K. 2001. Wetland Use and Impact on Lake Victoria, Kenya Region. Lakes and Reservoirs. Research and Management 6: 117 - 125.

Kansiime F., Nalubega M., van Bruggen J. J. and Denny P. 2003. The Effect of Wastewater Discharge on Biomass Production and Nutrient Content of *Cyperus papyrus* and *Miscanthidium violaceum* in the Nakivubo wetland, Kampala, Uganda. Water Science Technology 48 (5): 233 - 40.

Kareri R.W. 1992. The Sociological and Economic Values of Kenya's Wetlands. In: Crafter S. A., Njuguna S. G and Howard G. W (eds) Wetlands of Kenya, Proceedings of the Kenya Wetlands Working Group Seminar on Wetlands of Kenya, National Museums of Kenya, Nairobi, Kenya 3-5 July 1991.

Katondo J. M. 2001. Traditional Uses of *Cyperus papyrus* (L) and Associated Problems at Simiyu Fringing Wetland of Lake Victoria, Mwanza Region, Tanzania. Proceedings of Lake Victoria Environment Management Programme (LVEMP), First Regional Scientific Conference 3rd-7th December 2001, Kisumu, Kenya.

Kaufman L. and Ochumba P. B. O. 1993. Evolutionary and Conservation Biology of Cichlid Fishes as Revealed by Faunal Remnants in Northern Lake Victoria. Conservation Biology 7 (3): 719-730.

Keeland B. D. and Conner W. H. 1999. Natural Regeneration and Growth of *Taxodium distichum* (L.) Rich. In Lake Chicot, Louisiana after 44 years of Flooding. Wetlands 19: 1-12.

Kipkemboi J., Kansiime F. and Denny P. 2002. The Response of *Cyperus papyrus* (L.) and *Miscanthidium violaceum* (K. Schum.) Robyns to Eutrophication in Natural Wetlands of Lake Victoria, Uganda. African Journal of Aquatic Science 27 (1): 11-20.

Kisusu R. W., Onyango P. O, Haule T. and Salehe M. 2001. Factors Influencing Involvement of Local Communities in the Fishing Industry in Lake Victoria, Tanzania: From Production to Marketing. Proceedings of Lake Victoria Environment Management Programme (LVEMP), First Regional Scientific Conference 3rd-7th December 2001, Kisumu, Kenya.

Kiwazi I. L., Tindamanyire T., Kaganzi E., Busulwa H. and Mafabi P. 2001. Traditional Wetland Practices in Rural Communities in Uganda. Proceedings of Lake Victoria Environment Management Programme (LVEMP), First Regional Scientific Conference 3rd-7th December 2001, Kisumu, Kenya.

Kloer B. R. 1994. Hybrid Parametric/Non-parametric Image Classification. Paper Presented at the ACSM-ASPRS Annual Convention, April 1994, Reno, Nevada.

Kok K., Farrow A., Veldkamp A. and Verburg P. H. 2001. A Method and Application of Multi-scale Validation in Spatial Land-use Models. Agriculture Ecosystems and Environment, 85 (1-3): 223 - 238.

Kok K. 2004. The Role of Population in Understanding Honduran Land-use Patterns. Environmental Management 72: 73 - 89.

Kyambadde J., Kansiime F., Gumaelius L. and Dalhammar G. 2004. A Comparative Study of *Cyperus papyrus* and *Miscanthidium violaceum*-Based Constructed Wetlands for Wastewater Treatment in a Tropical Climate. Water Res. 38: 475 – 485.

Lambin E. F., Baulies X., Bockstael N., Fischer G., Krug T., Leemans R., Moran E. F., Rindfus R. R., Sato Y., Skole D., Turner II B. L. and Vogel C., 1999. Land-use and Land-cover Change, Implementation Strategy. IGBP Report No. 48, IHDP Report No. 10.

Lambin E. F., Turner II B. L., Geist H. J., Agbola S. B., Angelsen A., Bruce J. W., Coomes O. T., Dirzo R., Fischer G., Folke C., George P. S., Homewood K., Imbernon J., Leemans R., Xi Li., Moran E. F., Mortimore M., Ramakrishnan P. S., Richards J. F., Skanes H., Steffen W., Stone G. D., Svedin U., Veldkamp T. A., Vogel C. and Xu J. 2001. The Causes of Land-use and Land-cover Change: Moving Beyond the Myths Global Environmental Change, Human and Policy Dimensions 11 (4): 261-269.

Landon J. R. (ed) 1984. Booker Tropical Soil Manual. A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman, New York.

Lillesand T. M. and Kiefer R. W. 1994. Remote Sensing and Photo Interpretation, 3rd edition. John Wiley and Sons: New York. 750pp.

Lind E. M. and Morrison E. S. 1974. East African Vegetation. Longman, London, UK.

Linder W. 2003. Digital Photogrammetry, Theory and Applications. Springer, Berlin.

Liverman D., Moran E. F., Rindfuss R. R. and Stern P. C. (eds) 1998. People and Pixels: Linking Remote Sensing and Social Science. National Academy Press, Washington, DC.

Lucas R. E. 1982. Organic Soils (Histosols). Formation, Distribution, Physical and Chemical Properties and Management for Crop Production. Crop Soil Sci. Dept., Michigan State University, Agr. Exp. Stn. Series Res. Rep. 435. 77 pp.

Lung'ayia H., Sitoki L. and Kenyanya M. 2001. The Nutrient Enrichment of Lake Victoria (Kenyan Waters). Hydrobiologia 458: 75–82.

Maclean I. M. D., Tinch R., Hassal M. and Boar R. 2003. Social and Economic Use of Wetland Resources: A Case Study from Lake Bunyonyi, Uganda. Centre for Social and Economic Research on the Global Environment, University of East Anglia (CSERGE), Working Paper ECM 03-09.

Maltby E. 1986. Waterlogged Wealth: Why Waste the World's Wet Places? IIED, London.

Maltby E. 1988. Global Wetlands – History, Current Status and Future. In: Hook D. D., McKee W. H., Smith H. K., Gregory J., Burrel V.G., De Voe M.R., Sojka R. E., Gilbert S., Banks R., Stolzy L. H., Brooks C., Matthews T. D. and Shear T. H. (eds) The Ecology and Management of Wetlands (1). Croom Helm Ltd, Kent.

Mango N. A. R. 1999. Integrated Soil Fertility Management in Siaya District, Kenya. Managing Africa's Soils No. 7. Russell Press, Nottingham.

Mas J. F. 1999. Monitoring Land-cover Changes: A Comparison of Change Detection Techniques. Remote Sensing International. Journal 25 (24): 5745-5758.

Mavuti K. M. 1989. Ecology of the Yala Swamp. Resources 1:16 - 19.

Mavuti K. M. 1992. An Account of Some Important Freshwater Wetlands of Kenya. In: Crafter S.A., Njuguna S. G. and Howard, G. W. (eds) Wetlands of Kenya, Proceedings of the Kenya Wetlands Working Group Seminar on Wetlands of Kenya, National Museums of Kenya, Nairobi, Kenya 3-5 July 1991.

Mavuti K. M. and Litterick M. R. 1992. Composition, Distribution and Ecological Role of Zooplankton Community in Lake Victoria, Kenyan Waters. Verhandlungen Internationale Vereinigung Limnologie 24: 1117–1122.

Mbuvi J. M. and Kironchi G. 1994. Explanation and Profile Description to Reconnaissance Soil Survey of the Ewaso Ng'iro Basin-Laikipia East and Slope West to North of Mount Kenya. Series B: Baseline Data Laikipia_Mt. Kenya LRP paper B-8.

Mbuvi J. P. and Mainga P. M., 1991. Soils of the Proposed Ol' Kiramatian Irrigation Scheme (Magadi-Kajiado District), Nairobi.

McConnel W. 2001. Land-use and Cover Change. In: Smelser N., P. Baltes (ed) International Encyclopedia of the Social and Behaviour Sciences. Elsevier, Oxford, pp. 8251-8255.

Mertens B, W., Sunderlin D., Ndoye O. and Lambin E. F. 2000. Impact of Macroeconomic Change on Deforestation in South Cameroon: Integration of Household Survey and Remotely-Sensed Data. World Development 28 (6): 983-999.

Mfundisi K. B. 2005. Analysis of Carbon Pools and Human Impacts in the Yala Swamp (Western Kenya): A Landscape Approach. Cuvillier Verlag, Göttingen, Germany.

Mitsch W. J. and Gosselink J. G. 1993. Wetlands and Integrated River Basin Management. Experiences in Asia and the Pacific. United Nations Environment Programme, Nairobi.

M'mayi P., Katua S. and Mbarire S. K. (eds) 1997. Buffering Capacity of Lake Victoria Wetlands Project and the Sustainable Utilization and Management of Wetlands and Wetlands Products Pilot Project. Proceedings of the induction workshop of the wetland management component of Lake Victoria Environment Management Programme, National Environment Secretariat, Ministry of Environment and Natural Resources.

Mohamed M. A. 2002. Mitigating the Effects of Intensive Agriculture on Wetlands: The Case of Saiwa Wetlands, Kenya. In: Gawler M. (ed) Strategies for Wise Use of Wetlands: Best Practices in Participatory Management. Proceedings of a Workshop held at the 2nd International Conference on Wetlands and Development (November 1998, Dakar, Senegal). Wetlands International IUCN, WWF Publications No. 56, Wageningen, The Netherlands, pp. 97-100.

Mugisha S. 2002. Root Causes of Land-cover/Use Change in Uganda: An Account of the Past 100 Years. Land-use Change Impacts and Dynamics (LUCID) Project Working Paper 14; Nairobi, Kenya: International Livestock Research Institute.

Mugo F. W. and Shikuku O. 2000. Improved Land Management in the Lake Victoria Basin: Linking Land & Lake, Research and Extension, Catchment and Lake Basin. Natural Resources Use, Constrains and Possible Intervention. The Case for Ombaka Wetlands Focal Area in Nyando District. World Agroforestry Centre-ICRAF, Nairobi.

Mugo F., Place F., Swallow B. and Lwayo, M. 2001. Socio-economic Baseline Study. Nyando River Basin Baseline Data Report. Improved Land Management Project. World Agroforestry Centre-ICRAF, Nairobi.

Muiruri W. 1977. The Aberdare Ecosystem, its Bio-economic Functions, Interactions and Problems of Management, Unpublished Ph.D Thesis, University of Nairobi.

Muthuri F. M 1985. The Primary Productivity of Papyrus (*Cyperus papyrus* (L.) in Relation to Environmental Variables. Unpublished Ph.D Thesis, University of Nairobi.

Muthuri F. M. 1992. Classification and Vegetation of Freshwater Wetlands. In: Crafter S.A., Njuguna S. G. and Howard G. W. (eds) Wetlands of Kenya, Proceedings of the Kenya Wetlands Working Group Seminar on Wetlands of Kenya, National Museums of Kenya, Nairobi, Kenya 3-5 July 1991.

Mwaura F. B. 1981. Nitrogen Fixation in the Papyrus Swamp of Lake Naivasha, Unpublished M.Sc Thesis, University of Nairobi.

Nair D. V., Graetz D. A., Reddy K. R. and Olila O. G. 2001. Soil Development in Phosphate-Mined Created Wetlands of Florida, USA. Wetlands, 21 (2): 232-239.

Nalubega M. and Nakawunde R. 1995. Phosphorous Removal in Macrophytes Based Treatment. Proceedings of 21st WEDC Conference, Sustainability of Water and Sanitation Systems, Kampala, Uganda.

Narumalani S., Rundquist D, C., Maeder J. and Payton S. 1999. Characterizing Patterns and Trends of Wetland Vegetation Using the Normalized Difference Vegetation Index (NDVI). Centre for Advanced Land Management Information Technologies (CALMIT), University of Nebraska, USA.

Njuguna S. G. 1982. Nutrient Productivity Relationship in Tropical Naivasha Basins Lake, Kenya. Unpublished Ph.D Thesis, University of Nairobi.

Njuru P. G. 2001. An Overview of the Present Status of Water Quality of Lake Victoria, Kenya: A Limnological Perspective. Proceedings of Lake Victoria Environment Management Programme (LVEMP), First Regional Scientific Conference 3rd-7th December 2001, Kisumu, Kenya.

Ocholla J. 1997. Buffering Capacity Activity in the Yala Swamp: In: M'mayi, P., S. Katua, and Mbarire, S. K. (eds) Buffering Capacity of Lake Victoria Wetlands Project and the Sustainable Utilization and Management of Wetlands and Wetlands Products Pilot Project. Proceedings of the Induction Workshop of the Wetland Management Component of Lake Victoria Environment Management Programme, National Environment Secretariat, Ministry of Environment and Natural Resources.

Odada E. O., Olago D. O., Kulindwa K., Ntiba M. and Wandiga S. 2004. Mitigation of Environmental Problems in Lake Victoria, East Africa: Casual Chain and Policy Options Analyses. Ambio 33: 1–2.

Odak O. 1987. Materials Culture and Design. In: Kareri R.W. 1992. The Sociological and Economic Values of Kenya's Wetlands. Wetlands of Kenya, Proceedings of the Kenya Wetlands Working Group Seminar on Wetlands of Kenya, National Museums of Kenya, Nairobi, Kenya 3-5 July 1991.

Odland A. and del Moral R. 2002. Thirteen Years of Wetland Vegetation Succession Following a Permanent Drawdown, Myrkdalen Lake, Norway. Plant Ecology 162: 185–198.

Odongo O. R. 1996. Building and Inventory of Kenya's Wetlands: An Ethnobotany Study of Wetlands Plants of Uasin Gishu District of Kenya. Kenya Wetland Working Group 35pp.

Odum E. P. 1971. Fundamentals of Ecology. 3rd edition. W. B. Saunders, Philadelphia, PA, USA.

Ogutu M. A. 1987. Fisheries and fishing. Siaya District Socio-Cultural Profile. Ministry of Planning and National Development and Institute of Agricultural Studies, University of Nairobi, Republic of Kenya, Kenya, pp. 86-105.

Okemwa E. N. 1981. A Preliminary Survey of the Fisheries and Limnology of Lake Kanyaboli and Lake Sare in Western Kenya. Proceedings of the Workshop of the Kenya Marine and Fisheries Research on Aquatic Resources of Kenya, pp. 192–211.

Okondo O. 1989. The Yala Swamp is Useless. Resources 1: 11-14.

Okot-Okumu J. 2004. Primary Production and Decomposition of *Loudetia phragmitoides* the Littoral Wetland of Small Satellite Lakes (Lake Nabugabo, Uganda). African Journal of Ecology 42 (S1):108-113.

Olsen S. R. and Sommer L. E. 1982. Phosphorous. In: Page A. A. L. (ed) Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties. 2nd edition. Agron. Ser No. 9 Amer. Soc. Agron., Madison, Wisconsin, pp. 114-148.

Otieno M. N., Odenyo V. O. A. and Okeyo J. B. 2001. The Capabilities of Multispectral Landsat TM for Mapping Spatial Landscape Characteristics of a Tropical Wetland. The Case of Yala swamp, Kenya. Proceedings of Lake Victoria Environment Management Programme (LVEMP), First Regional Scientific Conference 3rd-7th December 2001, Kisumu, Kenya.

Ozesmi S. L. and Bauer M. E. 2002. Satellite Remote Sensing of Wetlands. Wetland Ecology and Management 10 (5): 381- 402.

Panayotou T., 1994. The Economics of Environmental Degradation: Problems, Causes and Responses. HIID Discussion Paper no. 355, Boston, April 1990.

Parkinson J. A. and Allen S. E. 1975. A Wet Oxidation Procedure Suitable for the Determination of Nitrogen and Mineral Nutrients in Biological Materials. Communications in Soil Science and Plant Analysis 6: 1-11.

Pearce D., Markandya A. and Barbier E. 1989. Blueprint for a Green Economy. Earthscan, London. HB847.3.P4.

Pender J. 1998. Population Growth, Agricultural Intensification, Induced Innovation and Natural Resource Sustainability: An Application of Neoclassical Growth Theory. Agricultural Economics 19: 99-112.

Pfaf A. S. P. 1996. What Drives Deforestation in the Brazilian Amazon Evidence from Satellite and Socio-Economic Data. World Bank Policy Research Working Paper No. 1772, World Bank, Washington, DC.

Pilon P. G., Howarth P. J. and Bullock R. A. 1988. An Enhanced Classification Approach to Change Detection in Semi-Arid Environments. Photogrammetric Engineering and Remote Sensing 12: 1709 -1716.

Pingali P., Bigot T. and Binswanger P. H. 1987. Agricultural Mechanisation and the Evolution of Farming Systems in Sub-Saharan Africa. World Bank and Johns Hopkins University Press, Baltimore, MD, USA. 216pp.

Pratt D. J. and Gwynne M. D. 1978. Rangeland Management and Ecology in East Africa. Hodder and Straughton, London.

Rasul G., Thapa G. B. and Zoebisch M. A. 2004. Determinant of Land-use Changes in the Chittagong Hill Tracts of Bangladesh. Applied Geography 24: 217 – 240.

Reid R. S., Gachimbi L. N., Worden J., Wangui E. E., Mathai S., Mugatha S. M., Campbell D. J., Maitima J. M., Butt B., Gichohi H. and Ogol E. 2004. Linkages Between Changes in Land Use, Biodiversity and Land Degradation in the Loitokitok Area of Kenya. Land-use Change Impacts and Dynamics (LUCID) Project Working Paper 49 Nairobi, Kenya: International Livestock Research Institute.

Rindfuss R. R. and Stern P. C. 1998. Linking Remote Sensing and Social Science: The Need and the Challenges. In: Liverman D., Moran E. F., Rindfuss R. R., Stern P. C. (eds) People and Pixels: Linking Remote Sensing and Social Science, National Academy Press, Washington, DC, pp. 1-27.

Rindfuss R. R., Stephen J., Walsh S. J., Turner II B. L., Fox J. and Mishra V. 2004. Developing a Science of Land Change: Challenges and Methodological Issues. Proceedings of the National Academy of Sciences 101 (39): 13976–13981.

Robarge W. P., Edwards A. and Johnson B. 1983. Water and Waste Water Analysis for Nitrate via Nitration of Salicylic Acid. Commun. Soil Science Plant Analysis 14: 1207-1215.

Rouse J. W., Haas R. H., Schell J. A. and Deering D. W., 1974. Monitoring Vegetation Systems in the Great Plains with ERTS. Proceedings, Third Earth Resources Technology Satellite-1 Symposium, Greenbelt: NASA SP-351: 3010-317.

Rudel T. K. and Roper J. 1996. Regional Patterns and Historical Trends in Tropical Deforestation, 1976-1990: A Qualitative Comparative Analysis. Ambio 27 (4): 160-166.

Ruthenberg H. 1976. Farming Systems in the Tropics, 2nd edition. Oxford University Press. Oxford, England, 385pp.

Sager E. P. S., Whillans T. H. and Fox M. G. 1998. Factors Influencing the Recovery of Submersed Macrophytes in Four Coastal Marshes of Lake Ontario. Wetlands 18 (2): 256-265.

Sangale F., Okungu J. and Opanga P. 2001. Variation of Flow of Water from Rivers Nzoia, Yala and Sio into Lake Victoria. Proceedings of Lake Victoria Environment Management Programme (LVEMP), First Regional Scientific Conference 3rd-7th December 2001, Kisumu, Kenya.

Saura S. 2003. Effects of Remote Sensor Spatial Resolution and Data Aggregation on Selected Fragmentation Indices. Landscape Ecology 19: 197-209.

Schelhas J. 1996. Land-use Choice and Change: Intensification and Diversification in the Lowland Tropics of Costa Rica. Human Organization 55: 298-306.

Schlesinger W. H. 1991. Biogeochemistry: An Analysis of Global Change. Academic Press, New York.

Scott J. T. and Condron L. M. 2004. Short Term Effects of *Radiata pine* and Selected Pasture Species on Soil Organic Phosphorus Mineralization. Plant and Soil 266: 153–163.

Seabloom E. W., Moloney K. A. and van der Valk A. G. 2001. Constraints on the Establishment of Plants along a Fluctuating Water-Depth Gradient. Ecology 82: 2216 - 2232.

Sene K. J. and Plinston D. T. 1994. A Review and Update of the Hydrology of Lake Victoria in East Africa. Hydrological Science Journal 39: 47- 62

Serneels S. and Lambin E. F. 2001. Proximate Causes of Land-use Change in Narok District, Kenya: A Spatial Statistical Model. Agriculture, Ecosystem and Environment 85: 65 - 81.

Seto K. C., Woodcock C. E., Huang X., Lu J. and Kaufmann R. K. 2002. Monitoring Land-use Change in the Pearl River Delta Using Landsat TM. International Journal of Remote Sensing 23: 1985-2004.

Silvan N., Vasander H. and Laine J. 2004. Vegetation is the Main Factor in Nutrient Retention in a Constructed Wetland Buffer. Plant and Soil 258: 179-187

Smart P. F. M. and Grainger J. E. A. 1974, Sampling for Vegetation Survey: Some Aspects of the Behaviour of Unrestricted, Restricted and Stratified Techniques, J. of Biogeography 1: 193 - 206.

Steel R. G. D. and Torrie J. D. 1986. Principles and Procedures of Statistics. 2nd edition, McGraw-Hall, New York.

Stoll-Kleemann S. 2004. The Rationale of Socio-Economic Research for the Successful Protection and Use of Wetlands: The Examples of Participatory Management Approaches. Hydrobiologia 527: 15-17.

Stonich S. C. 1993. "I am destroying the land": the Political Ecology of Poverty and Environmental Destruction in Honduras. Westview Press Inc, Oxford.

Symoens J. J., Bugis M. and Gaudet J. J. 1981. The Ecology and Utilization of African Inland Waters. In: Crafter S.A., Njuguna S. G. and Howard G. W. (eds) Wetlands of Kenya, Proceedings of the Kenya Wetlands Working Group Seminar on Wetlands of Kenya, National Museums of Kenya, Nairobi, Kenya 3-5 July 1991.

Talling J. F. 1957. The Longitudinal Succession of the Water Characteristics in the White Nile. Hydrobiologia 11: 73-89.

Tandiga 1990. Vegetation Sampling. Unpublished Field Manual, Department of Range Management, University of Nairobi, 256pp.

Taylor R. D., Howard G. W. and Begg G. W. 1995. Developing Wetland Inventories in Southern Africa: A Review. Vegetation 118: 57– 79.

Templeton S. R. and Scherr S. J. 1997. Population Pressure and the Micro Economy of Land Management in Hills and Mountains of Developing Countries. EPTD Discussion paper No. 26. Environment and Production Technology Division International Food Policy Research Institute Washington, U.S.A.

Terer T., Ndiritu G. G. and Gichuki N. N. 2004. Socio-Economic Values and Traditional Strategies of Managing Wetland Resources in Lower Tana River, Kenya. Hydrobiologia 527: 3-14.

Thenya T. 1998. Some Ecological Aspects Bio-Economic Value of Tropical Papyrus Wetland, Ewaso Narok swamp, Laikipia Kenya. Unpublished M.Sc Thesis, Department of Geography, University of Nairobi.

Thenya T. 2001. Challenges of Conservation of Dryland Shallow Waters, Ewaso Narok Swamp, Laikipia District Wetlands, Kenya. Hydrobiologia 458: 121 - 130.

Thomas G. W. 1982. Exchangeable Cations. In: Page A. L., (ed) Methods of soil Analysis: Part 2. Chemical and Microbiological properties. ASA Monograph Number 9, pp. 159 -165.

Thompson K. 1976. Swamp Development in the Head Waters of the White Nile, In: Rzoska J. (ed) The Nile Biology of an Ancient River, Dr. W. Junk BV, Publisher. The Hague.

Thormann M. N. and Bayley E. S. 1997. Response of Aboveground Net Primary Plant Production to Nitrogen and Phosphorous Fertilization in Peatlands in Southern Boreal Alberta, Canada. Wetlands Journal 17: 502 - 512.

Turner II B. L., Skole D., Sanderson S., Fischer G., Fresco L. and Leemans R. 1995. Land-use and Land-cover Change, Science/Research Plan. IGBP Report No. 35, HDP Report No. 7.

Turner M. G., O'Neill R. V., Gardner R. H. and Milne B. T. 1989. Effects of Changing Spatial Scale on the Analysis of Landscape Pattern. Landscape Ecology 3: 153-162.

UNEP. 1997. Wetlands and Integrated River Basin Management. Experiences in Asia and the Pacific. United Nations Environment Programme, Nairobi.

United States Environmental Protection Agency (U.S. EPA). 2002. Methods for Evaluating Wetland Condition No. 16 Vegetation- Based Indicators of Wetland Nutrient Enrichment. Office of Water, U. S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-024.

Urban N. H., Davis S. M. and Aumen N. G. 1993. Fluctuations in Sawgrass and Cattail Density in Everglades Water Conservation Area 2A under Varying Nutrient, Hydrologic and Fire Regimes. Aqua Bot 46: 203 - 223.

United State Geological Survey 1973. Landsat MSS Scene, WRS- 1, Path (path 183), Row (row 060), Level Orthorectified. Sioux Falls, South Dakota: USGS.

United State Geological Survey 2001. Landsat ETM Scene, WRS-2 Path (path 170), Row (row 060), Level Orthorectified. Sioux Falls, South Dakota: USGS.

Van der Kwast J. 2002. Land-cover Classification and DEM Generation, Using SPOT and Landsat Images in the Lake Victoria Basin, Western Kenya.

Veldkamp A. and Fresco L. O. 1997. Reconstructing Land-use Drivers and their Spatial Scale Dependence for Costa Rica (1973 and 1984). Agricultural Systems 55: 19- 43.

Veldkamp A. and Lambin E. 2001. Predicting Land-use Change. Agric. Ecosyst. Environ. 85 (1-3): 1 - 6.

Verburg P. H., Overmars K. P. and Witte N. 2004. Accessibility and Land-use Patterns at the Forest Fringe in the Northeastern Part of the Philippines. The Geographical Journal 170 (3): 238–255

Verhoeven J. T. A. and Schmitz M. B. 1991. Control of Plant Growth by Nitrogen and Phosphorus in Mesotrophic Fens. Biogeochemistry 12:135-148.

Viner A. B. 1973. Response of a Phytoplankton Population to Nutrient Enrichment with Ammonia and Phosphate and Associated Ecological Implications: Proceedings of the Royal Society of London 13: 351-380.

Volarovich M. P. and Churaev N. V. 1968. Application of the Methods of Physics and Physical Chemistry to the Study of Peat. In: Robertson R. A. (ed) Transactions of the 2nd International Peat Congress, Leningrad 2:819-831. HMSO, Edinburgh.

Von Thünen J. H. 1966. Isolated State: an English edition of Der isolierte Staat. Translated by Wartenberg C. M. Edited with an introduction by Hall P. Pergamon Press, Oxford.

Wigand C., Stevenson J. C. and Cornwell J. C. 1997. Effects of Different Submersed Macrophytes on Sediment Biogeochemistry. Aquatic Botany 56: 233 - 244.

Wood A. 1997. Wetlands in Highlands: The Search for Sustainable Use of Valley Bottom Swamp in the Highlands of South-West Ethiopia. Department of Geographical and Environmental Science, University of Huddersfield, UK.

Wood A., Hailu A., Abbot P. and Dixon A. 2002. Sustainable Management of Wetlands in Ethiopia: Local Knowledge Versus Government Policy. In: Gawler M. (ed) Strategies for Wise Use of Wetlands: Best Practices in Participatory Management. Proceedings of A Workshop Held at the 2nd International Conference on Wetlands and Development (November 1998, Dakar, Senegal). Wetlands International IUCN, WWF Publications No. 56, Wageningen, The Netherlands, pp. 81-88.

Wood C. H. and Skole D. 1998. Linking Satellite Census and Survey Data to Study Deforestation in the Brazilian Amazon. In: Liverman D., Moran E.F., Rindfuss R.R. and Stern P.C. (eds) People and Pixels, National Academy Press, Washington DC, pp. 70-93.

Work E. A. Jr. and Gilmer D.S. 1976. Utilization of Satellite Data Inventorying Prairie Ponds and Lakes. Photogrammetric Engineering and Remote Sensing 42: 685–694.

Wu J., Jelinski D. E., Luck M. and Tueller P. T. 2002. Multiscale Analysis of Landscape Heterogeneity: Scale Variance and Pattern Metrics. Geographical Information Science 6 (1): 6-19.

11 APPENDICES

Appendix 1: Wetland resource utilization survey

Recording schedule:
Wetland Resource and Product Utilization Survey Yala Swamp, Siaya District

Analysis of Macrophytes Biomass Productivity, Utilization and its Impact on Various Eco-Types of a Tropical Wetland, Yala Swamp, Lake Victoria Basin, Kenya.

Section A: Location Data

1.1.1 Questionnaire Identification District: ………………………….. Division : ………………………… Location: ………………………… Sub location: ……………………. Village:..…………………………. Questionnaire Serial Number: …. .	Enumerator Name: ……………………… Date of Interview: …………………… Start Time: ……………………………… End Time: ……………………………… Side of the swamp a) Usenge/Yala R_________(South) b) Kanyaboli/LBDA_______(North) c) Hobe/Mudika/Musoma___(North)

Name of Household Head: ____

Name of Respondent:____

Relationship of Respondent to Household Head: _______________________

Section B: Household Characteristics

B/1 What is the household type? ______________________________________[ ]

1= Male headed/single wife **2**= Female headed husband absent **3**= Female headed widowed **4**= Male headed /polygamous **5**= Male headed, divorced or single, widower **6**=Female headed, divorced or single **7**=Child headed

B/2 What is the ethnic affiliation of the head of household ?__ _____________[ ]

1= Luhya **2**=Kalenjin **3**=Kikuyu **4**=Luo **5**=Others (Specify): _______________________

B/3 How many people live in this household a) adults males (18>)_______ b) adult females (18>)____________c) teens (12> and <18)_____d) children(<12)________

B/4 What is the original home area of the husband :_____________________________

B/5 How many years of schooling have you had (a) husband______ (b) wife_______

B/6 What is the highest education level of the (a) husband_______ (b) wife_______
1) None (2) Primary (3) Secondary (4) College (5) University

B/7 Which year did your household settle here?_________________________________

1= Before 1950 **2**=1960 **3**=1970 **4**= 1980 **5**= 1990 **6=** 2003 :____________________

B/8 What is the nature of land tenure of the household (a) Trust land___b) Government land c) Bought___d) Rented land___e) family____f) others____

B/8 How was land acquired here first (historically) (a) Self allocation ____b) GK settlement scheme___c) Rented land____d) Not sure how____e) Bought___ f) if so from whom____

B/9 What is the size of the farm(s) in acres (a) Trust land___b) Government land c) Bought__d) Rented land__.e) family__.f) others____

B/10 Does the household live here throughout the year_____(a) YES_____(b) NO___

B/11 If NO, how long do they live here_______________________________________

B/12 What is the reason for migrating____

B/13 How far is the homestead from the edge of the swamp a) Respondent__ (m) b) Enumerator__

B/14 How far is the homestead from the nearest road a) Respondent___(m) b) Enumerator___

Section C: Wetland Utilization Data

C/1 What is your house constructed of? (*Observe rather than ask the building structure types)* (a)Roof [ ] (b) Walls[ ] (c) Floor [ ]

Type of roof

1= thatch - papyrus 2= thatch grass 3= thatch siege grass 4= thatch other 5= iron sheets 6= tiles 7= not applicable

Type of walls

1= mud 2= wood 3= stone/brick/cement 4= iron sheets7= not applicable

Type of Floor

1= earth 2= wood 3= stone/brick/cement 7= not applicable

C/2 What are the major income/ bartering livelihoods of the household (per season)? (List the major ones, at least three)

Types	Long rains		short rains		Dry seasons	
	Domestic use	**Income from sales**	**Domestic use**	**Income from sales**	**Domestic use**	**Income from sales**

C/3 How important is wetland vs other income, livelihood (farm, employment etc) income sources?
1 = On-wetland has a greater contribution than off-wetland
2 = Off wetland activities a greater contribution than on-wetland
3 = Same (both contribute equally to income in the household)

C/4 Does the household own land in the wetland? a)YES____ b)NO_____

C/5 If yes, how many acres? a)1______b)2_____ c)3_____ d)4______ e)5 above_____

C/6 How much of that land is under cultivation? a) 0.5__ b)1__ c)1.5__ d)2__ e)Others_

C/7 By how much (%) does the wetland farm contribute to domestic food?…………
(1) 0-25%___(2) 25-50%___(3) 50-75%____(4) 75-100%_____(5) 100%_____

C/8 How did you acquire land in the wetland

1-allocation by authority____ **2**-self-allocation____ **3**-both_____4) bought_________

C/9 When did you start farming in the wetland ________________________

C/10 Why did you decide to start farming there, list compelling reasons
a)____

b)____

c)____

C/11 What is the sequence of transition of opening land in the wetland (give sequence)

a) burning__________ b) clearing_______c) grazing_________d) digging_________

C/12 Does the preferred location for farming change in the course of the year _If YES why _

C/13 According to your knowledge has the area under cultivation increased/decreased over the years in the wetland ____

C/14 What is the reason for the above-observed change___________________________

C/15 List the products obtained from the wetland

Source of resource → / **Type of resource ↓**	**Source (dist.) in Rain season 2 (m)**	**Source (dist.) in dry season (m)**	*****Quantity sort e.g. back load or number e.g. fish per month**	***Mode of resource transport (if consumed at the wetland (e.g. grazing), write NA)**	****Purpose of use – which products (e.g. fruits, food, feed)**	**Total average (where Ksh per month**
Thatch for roofing						
Thatch for household items e.g. amts						
Reeds for market items e.g. mats						
Soil e.g. for bricks						
Sand						
Poles						
Firewood						
Water for animals						
Water for drinking						
Grasses for animals						
Grazing land						
Fish						
Vegetables						
Others						

*****Quantity:** 1) back load 2) One bicycle load 3) Animal drawn cart 4)One pick up
***Transport to home:** 1) carried by foot, 2) bicycle, 3) animal power, 4) motor vehicle
****Purpose of product:** 1) human consumption 2) animal consumption 3) building materials, 4) household products/items 5) selling/commercial 6) cultural activities

C/16 Commonly used products obtained from Macrophytes and their quantities

Commonly used species of macrophytes used in 2002	**Source dist. (m) in long rains**	**Source dist.(m) in dry season**	**Quantity sort e.g. back load**	**Eventual transformed products '*if not raw'**	**End use of transformed product (1-home, 2-sold, 3-both)**	**Total income from these products per month** **Kshs**

C/17 How much wetland area (meters) is used for a) Reeds Harvesting________ b)Sand Harvesting______ c) Soil harvesting for Bricks____ d) Grazing_____ e)Others_______

C/18 What is your main source of domestic energy________________________________
C/19 Does the wetland provide any form of domestic energy________Yes________No

C/20 If YES list the forms of energy____

C/21 Do you pay for use of wetland products a)Yes_____ b) No____, If YES indicate authority____Kshs_________

C/22 Are the wetland products easily accessible a)Yes___________ b) NO_________

C/23 If NO what is the hindrance to accessibility?______________________________

C/24 What are some of the problems/risks you face in the utilization of wetland resources and the sale of wetland products?

C/25 Which problems do you face living near/in the wetland region?____________________

C/26 To what extent do the floods affect your family during the long rains? __________

1=Not at all 2=Average/not much 3=Severely __________________________________

C/27 How far do the floods cover from the edge of the swamp (metres) a) Respondent___ b) Enumerator___

C/28 How do you cope with the floods during the long rains ______________________

C/29 Do members of the community help one another during the floods;
a) Yes___b)No__

C/30 If Yes, List the ways

1)____

2) ____

3) ____

4) ____

C/31 What form of development/use and managements would you prefer to see carried out in the wetland in the future (List in order of priority ways)

1)____

2)____

3) ____

4) ____

D REMARKS (to be answered privately by the enumerator soon after the interview)

D/1 In your opinion, how would you rank the household's wealth category? (Use questions in SECTION B House hold Data to asses this) **1** = rich **2** = average **3** = poor

D/2 Overall, how did the respondents give answer to the question? [ ]
1= willingly **2** = reluctantly **3** = with persuasion **4** = it was hard to find to get answers

D/3 How often do you think the respondent was telling the truth? [ ]
1 = rarely **2** = sometimes **3** = most of the times **4** = all the times

D/4 Reliability index : how reliable do you think information you have is ? [ ]
1 = very high **2** = high **3** = average **4** = low **5** = very low

Appendix 2: Wetland products market survey

Wetland products market survey Date………………

1. Establishment………………….Town………………….Business starting data

2. Individual………………….Town………………….Business starting data

3. Was capital required in starting the business a)….. b)No………..

4. If Yes source of starting capital if any……………………..

5. Products on sale at the outlet **(tick)**

No.	**Products –list**	**Presence - tick**
	Mats	
	Papyrus ropes	
	Fish (indicate type)	
	Fish (indicate type)	
	Fish (indicate type)	
	Thatch material (type)	

6. Source of the products

No.	**Products**	**Area- Village**	**Location**	**Town**
	Mats			
	Papyrus ropes			
	Fish (indicate type)			
	Fish (indicate type)			
	Fish (indicate type)			
	Thatch material			

7. Mode of transportation

a) Bicycle……. b) Motor vehicle……… c) Back load……… d) Donkey cart……

8. Relative prices and unit sold

No.	Products	Prices Ksh per unit indicate unit	Unit e.g. 1 Kg	Unit sold per month
	Mats			
	Papyrus ropes			
	Fish (indicate type)			
	Fish (indicate type)			
	Fish (indicate type)			
	Thatch material			

9. Targeted customers
   a) Local…………………….. b) Distant traders………………………….

10) Products destinations (indicate towns)

11. Marketing problems of the products e.g. flooded market

12. Customer complaints on the products
   a) Size

   b) Quality

   c) Prices

   d) Supply quantity

13. Overall rating of the products

No.	Status	Low-1	2	3	4-High
	Quality				
	Marketing demand				
	Supply				
	Variety				
	Quantity				
	Size				
	Hygiene e.g. fish				

Appendix 3: Mean values of macrophytes growth data –height measurements (cm)

															HVT		
Species	*wk-1*	*wk -2*	*wk -3*	*Wk -4*	*wk -5*	*wk -6*	*wk -7*	*wk -8*	*wk -9*	*wk -10*	*wk -11*	*wk -12*	*wk -13*	*wk -14*	*wk -15*	*wk -16*	*wk -17*
C. distans	20.00	50.00	84.00	95.00	120.00	122.00	148.00	160.00	180.00	183.00	190.00	192.00	192.00	194.00	43.00	62.00	89.50
T. domingensis	19.33	75.00	110.00	145.33	169.67	174.67	183.67	199.33	203.33	211.00	212.00	213.00	215.50	219.00	22.67	40.33	74.33
P. mauritianus	25.00	100.00	110.00	140.00	167.00	205.00	235.00	240.00	256.00	270.00	276.00	279.00	0.00	0.00	63.00	82.50	95.00
											HVT						
		wk - 18	*wk-19*	*wk- 20*	*wk-21*	*wk -22*	*wk -23*	*wk- 24*	*wk -25*	*wk --26*	*wk -27*	*wk -28*	*wk -29*	*wk -30*	*wk -31*	*wk -32*	*wk -33*
C. distans		101.00	126.00	130.00	131.00	133.00	139.00	157.50	159.50	169.50	174.00	27.00	52.00	83.00	106.00	109.50	119.00
T. domingensis		96.33	119.33	133.83	141.17	161.67	167.33	183.33	252.00	257.00	258.50	30.33	52.83	85.83	135.50	138.83	142.50
P. mauritianus		104.00	104.00	134.00	134.00	163.00	181.00	207.00	212.50	224.50	226.50	51.00	63.00	86.50	0.00	0.00	0.00
														HVT			
Species	*wk-1*	*wk -2*	*wk -3*	*Wk -4*	*wk -5*	*wk -6*	*wk -7*	*wk -8*	*wk -9*	*wk -10*	*wk -11*	*wk -12*	*wk -13*	*wk -14*	*wk -15*	*wk -16*	*wk -17*
C. papyrus	2.00	47.00	86.00	121.50	127.00	133.50	140.00	162.00	166.00	173.00	178.50	185.00	195.00	375.50	11.25	35.25	62.00
C. distans	18.00	50.00	107.00	112.00	120.00	125.00	125.00	128.00	128.00	128.00	128.00	128.00	128.00	346.00	0.00	0.00	0.00
T. domingensis	15.00	50.00	112.00	122.00	155.00	176.00	200.00	208.00	211.00	222.00	238.00	239.00	240.00	450.00	15.00	32.00	59.00
										HVT							
		wk - 18	*wk-19*	*wk- 20*	*wk-21*	*wk -22*	*wk -23*	*wk- 24*	*wk -25*	*wk --26*	*wk -27*	*wk -28*	*wk -29*	*wk -30*	*wk -31*	*wk -32*	*wk -33*
C. papyrus		85.50	108.00	114.75	121.50	130.25	149.25	160.25	162.50	177.00	157.50	14.00	16.00	100.50	158.50	116.50	91.00
C. distans		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T. domingensis		76.50	104.00	123.00	148.00	166.50	179.00	189.50	192.00	210.00	186.50	22.00	34.00	143.00	198.50	203.50	0.00

Appendix 3: continued

													HVT				
Species	*wk-1*	*wk -2*	*wk -3*	*Wk -4*	*wk -5*	*wk -6*	*wk -7*	*wk -8*	*wk -9*	*wk -10*	*wk -11*	*wk -12*	*wk -13*	*wk -14*	*wk -15*	*wk -16*	*wk -17*
C. papyrus	7.00	23.00	63.00	82.50	102.50	113.00	116.50	160.50	167.00	242.00	258.00	262.00	265.00	405.00	38.00	80.00	133.50
C. distans	8.00	33.00	110.50	114.00	127.00	139.50	147.00	147.50	148.50	153.00	157.00	157.50	158.50	0.00	10.50	56.50	51.50
P. mauritianus	20.00	38.50	58.00	76.33	93.33	107.00	111.67	135.33	149.67	170.33	172.00	173.33	184.00	425.00	0.00	15.00	30.00
										HVT							
	wk - 18	*wk-19*	*wk- 20*	*wk-21*	*wk -22*	*wk -23*	*wk- 24*	*wk -25*	*wk --26*	*wk -27*	*wk -28*	*wk -29*	*wk -30*	*wk -31*	*wk -32*	*wk -33*	
C. papyrus	141.50	164.00	184.00	207.50	220.00	247.00	254.00	264.00	267.50	250.50	0.00	0.00	81.00	171.50	225.00	238.00	
C. distans	91.25	96.25	121.00	115.75	122.25	125.50	128.00	130.00	131.50	126.25	13.50	18.00	28.00	0.00	37.50	91.25	
P. mauritianus	60.83	83.33	101.50	107.83	111.67	121.50	138.00	143.00	149.25	132.33	0.00	0.00	71.50	56.33	129.00	126.00	
											HVT						
Species	*wk-1*	*wk -2*	*wk -3*	*wk -4*	*wk -5*	*wk -6*	*wk -7*	*wk -8*	*wk -9*	*wk -10*	*wk -11*	*wk -12*	*wk -13*	*wk -14*	*wk -15*	*wk -16*	*wk -17*
C. dives	29.50	73.00	97.00	101.16	108.83	117.00	118.00	120.00	133.50	144.66	146.50	106.43	77.71	92.29	104.79	122.93	130.50
E. haploclada	22.00	76.00	82.00	99.00	105.00	117.00	119.00	121.00	128.00	130.00	134.00	98.00	107.00	120.00	130.00	133.50	142.00
										HVT							
Species	*wk - 18*	*wk-19*	*wk- 20*	*wk-21*	*wk -22*	*wk -23*	*wk- 24*	*wk -25*	*wk --26*	*wk -27*	*wk -28*	*wk -29*	*wk -30*	*wk -31*	*wk -32*	*wk -33*	
C. dives	138.79	124.86	112.07	102.14	51.42	83.14	93.64	105.28	77.35	83.14		90.93	92.64	94.50	95.57	72.42	
E. haploclada	147.50	151.00	156.00	159.00	22.00	40.50	78.00	118.50	121.00	123.50		180.00	199.00	199.00	199.00	199.00	
													HVT				
species	*wk-1*	*wk -2*	*wk -3*	*Wk -4*	*wk -5*	*wk -6*	*wk -7*	*wk -8*	*wk -9*	*wk -10*	*wk -11*	*wk -12*	*wk -13*	*wk -14*	*wk -15*	*wk -16*	*wk -17*
C .papyrus	47.00	69.00	99.00	110.00	140.00	153.00	175.00	177.00	179.00	180.00	182.00	96.00	flooded	132.67	153.33	170.00	172.00
P. mauritianus	10.00	35.00	109.00	190.00	240.00	277.00	300.00	321.00	324.00	333.00	352.00	16.00	51.00	18.33	24.00	157.00	204.50
T. domingensis	27.00	71.00	111.00	143.00	167.00	201.00	207.00	233.00	233.00	248.00	258.00	flooded	flooded	no shoots	no shoots		0.00
											HVT						
Species	*wk-18*	*wk-19*	*wk-20*	*wk-21*	*wk-22*	*wk-23*	*wk-24*	*wk-25*	*wk-26*	*wk-27*	*wk-28*	*wk-29*					
C .papyrus	174.00	194.00	198.00	199.50	205.00	207.00	194.00	195.00	0.00	0.00	8.00	0.00					
P. mauritianus	232.50	247.50	270.00	272.50	275.00	287.50	313.00	317.00	24.50	27.00	29.50	48.50					
T. domingensis	0.00	70.50	96.00	97.50	102.50	107.50	136.50	139.50	0.00	38.00	43.50	48.50					

Note: *Zero values are mainly result of interference like burning, grazing and cultivation and slashing which are quite common. HV- point of harvest*

Appendix 4: Mean values of macrophytes growth data – computed growth rate (%)

														HVT		
Species	*wk-1*	*wk -2*	*wk -3*	*Wk -4*	*wk -5*	*wk -6*	*wk -7*	*wk -8*	*wk -9*	*wk -10*	*wk -11*	*wk -12*	*wk -13*	*wk -14*	*wk -15*	*wk -16*	*wk -17*
C. distans		150.00	68.00	13.10	26.32	1.67	21.31	8.11	12.50	1.67	3.83	1.05	0.00	1.04		44.19	44.35
T. domingensis		287.93	46.67	32.12	16.74	2.95	5.15	8.53	2.01	3.77	0.47	0.47	1.17	1.39		77.94	84.30
P. mauritianus		300.00	10.00	27.27	19.29	22.75	14.63	2.13	6.67	5.47	2.22	1.09	0.00	0.00		30.95	15.15
											HVT						
Species		*wk - 18*	*wk-19*	*wk- 20*	*wk-21*	*wk -22*	*wk -23*	*wk- 24*	*wk -25*	*wk --26*	*wk -27*	*wk -28*	*wk -29*	*wk -30*	*wk -31*	*wk -32*	*wk -33*
C. distans		12.85	24.75	3.17	0.77	1.53	4.51	13.31	1.27	6.27	2.65		92.59	59.62	27.71	3.30	8.68
T. domingensis		29.60	23.88	12.15	5.48	14.52	3.51	9.56	37.45	1.98	0.58		74.18	62.46	57.86	2.46	2.64
P. mauritianus		9.47	0.00	28.85	0.00	21.64	11.04	14.36	2.66	5.65	0.89		23.53	37.30	-100.0	0.00	0.00
														HVT			
Species	*wk-1*	*wk -2*	*wk -3*	*Wk -4*	*wk -5*	*wk -6*	*wk -7*	*wk -8*	*wk -9*	*wk -10*	*wk -11*	*wk -12*	*wk -13*	*wk -14*	*wk -15*	*wk -16*	*wk -17*
C. papyrus		2250.00	82.98	41.28	4.53	5.12	4.87	15.71	2.47	4.22	3.18	3.64	5.41	92.56	-97.00	213.33	75.89
C. distans		177.78	114.00	4.67	7.14	4.17	0.00	2.40	0.00	0.00	0.00	0.00	0.00	170.31	0.00	0.00	0.00
T. domingensis		233.33	124.00	8.93	27.05	13.55	13.64	4.00	1.44	5.21	7.21	0.42	0.42	87.50	0.00	113.33	84.38
										HVT							
Species		*wk - 18*	*wk-19*	*wk- 20*	*wk-21*	*wk -22*	*wk -23*	*wk- 24*	*wk -25*	*wk --26*	*wk -27*	*wk -28*	*wk -29*	*wk -30*	*wk -31*	*wk -32*	*wk -33*
C. papyrus		37.90	26.32	6.25	5.88	7.20	14.59	7.37	1.40	8.92			14.29	528.13	57.71	-26.50	-21.89
C. distans		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00			0.00	0.00	0.00	0.00	0.00
T. domingensis		29.66	35.95	18.27	20.33	12.50	7.51	5.87	1.32	9.38			54.55	320.59	38.81	2.52	-100.00
														HVT			
Species	*wk-1*	*wk -2*	*wk -3*	*Wk -4*	*wk -5*	*wk -6*	*wk -7*	*wk -8*	*wk -9*	*wk -10*	*wk -11*	*wk -12*	*wk -13*	*wk -14*	*wk -15*	*wk -16*	*wk -17*
C. papyrus		228.57	173.91	30.95	24.24	10.24	3.10	37.77	4.05	44.91	6.61	1.55	1.15	52.83	0.00	110.53	66.88
C. distans		312.50	234.85	3.17	11.40	9.84	5.38	0.34	0.68	3.03	2.61	0.32	0.63	0.00	0.00	438.10	-8.85
P. mauritianus		92.50	50.65	31.61	22.27	14.64	4.36	21.19	10.59	13.81	0.98	0.78	6.15	0.00	0.00	0.00	100.00

Appendix 4: continued

									HVT								
Species		*wk - 18*	*wk-19*	*wk- 20*	*wk-21*	*wk -22*	*wk -23*	*wk- 24*	*wk -25*	*wk --26*	*wk -27*	*wk -28*	*wk -29*	*wk -30*	*wk -31*	*wk -32*	*wk -33*
C. papyrus		5.99	15.90	12.20	12.77	6.02	12.27	2.83	3.94	1.33				0.00	111.73	31.20	5.78
C. distans		77.18	5.48	25.71	-4.34	5.62	2.66	1.99	1.56	1.15			33.33	55.56	-100.00	0.00	143.33
P. mauritianus		102.78	36.99	21.80	6.24	3.55	8.81	13.58	3.62	4.37			0.00	0.00	-21.21	128.99	-2.33
											HVT						
species	*wk-1*	*wk -2*	*wk -3*	*Wk -4*	*wk -5*	*wk -6*	*wk -7*	*wk -8*	*wk -9*	*wk -10*	*wk -11*	*wk -12*	*wk -13*	*wk -14*	*wk -15*	*wk -16*	*wk -17*
C. dives		147.46	32.88	4.30	7.58	7.50	0.85	1.69	11.25	8.36	1.27		-0.27	0.19	0.14	0.17	0.06
E. haploclada		245.45	7.89	20.73	6.06	11.43	1.71	1.68	5.79	1.56	3.08		0.09	0.12	0.08	0.03	0.06
											HVT						
species	*WK -1*	*wk-18*	*wk-19*	*wk-20*	*wk-21*	*wk-22*	*wk-23*	*wk-24*	*wk-25*	*wk-26*	*wk-27*						
C. dives		0.06	-0.10	-0.10	-0.09	-0.50	0.62	0.13	0.12	-0.27	0.07						
E. haploclada		0.04	0.02	0.03	0.02	-0.86	0.84	0.93	0.52	0.02	0.02						
													HVT				
species	*wk-1*	*wk -2*	*wk -3*	*Wk -4*	*wk -5*	*wk -6*	*wk -7*	*wk -8*	*wk -9*	*wk -10*	*wk -11*	*wk -12*	*wk -13*	*wk -14*	*wk -15*	*wk -16*	*wk -17*
C .papyrus		47.00	43.00	11.00	27.00	9.00	14.00	1.00	1.00	1.00	1.00	-47.00	0.00		16.00	11.00	1.00
P. mauritianus		250.00	211.00	74.00	26.00	15.00	8.00	7.00	1.00	3.00	6.00	-95.00	219.00		31.00	554.00	30.00
T. domingensis		163.00	56.00	29.00	17.00	20.00	3.00	13.00	0.00	6.00	4.00	0.00	0.00		0.00	0.00	0.00
											HVT						
species		*wk-18*	*wk-19*	*wk-20*	*wk-21*	*wk-22*	*wk-23*	*wk-24*	*wk-25*	*wk-26*	*wk-27*	*wk-28*	*wk-29*				
C .papyrus		1.00	11.00	2.00	1.00	3.00	1.00	-6.00	1.00	-100.0	0.00	0.00	0.00				
P. mauritianus		14.00	6.00	9.00	1.00	1.00	5.00	9.00	1.00	-92.00	10.00	9.00	64.00				
T. domingensis		0.00	0.00	36.00	2.00	5.00	5.00	27.00	2.00	-100.0	0.00	14.00	11.00				

Note*: Growth rate (%) was computed as the difference between two weeks hence there are no figures for the first week in each experiment*
Zero values are mainly result of interference like burning, grazing and cultivation and slashing which are quite common , HVT – point of harvest

Appendix 5: Average above ground biomass variations with both season and eco-types (dry weight in g per m^2)

Eco-type	**Species**	**Wet season**	**Transitional season**	**Dry season**	**Spp average**	**Eco-type average**
HD	*Cyperus distans*	542.80	477.04	223.60	414.48	
HD	*Phragmites mauritianus*	4136.40	729.68	0.00	1622.03	
HD	*Typha domingensis*	1264.00	780.72	468.00	837.57	958.03
MD	*Cyperus dives*	393.40	659.26	746.00	599.55	
MD	*Cyperus exaltatus*	199.60	425.00	0.00	208.20	
MD	*Echinochloa haploclada*	378.80	674.96	1196.00	749.92	
MD	*Typha domingensis*	772.40	1800.96	900.00	1157.79	678.87
LD	*Cyperus dives*	2468.40	327.76	0.00	932.05	
LD	*Cyperus papyrus*	969.92	910.84	1162.29	1014.35	
LD	*Phragmites mauritianus*	1264.80	384.88	0.00	549.89	
LD	*Typha domingensis*	479.60	477.70	1898.00	951.77	862.02
Season average		1,170.01	695.35	599.44	821.60	832.97

Appendix 6: Macropyhte nutrient content in the Yala swamp

Season	**Species / Eco-types**	**Nutrients assessed in plants biomass**			**Standard errors (s.e)**		
Wet	**Species**	Total N -%	Total P -%	N:P ratio	s.e	s.e	s.e
	C. distans	1.14	0.19	6.16	-0.12	-0.01	-0.51
	C. dives	1.32	0.18	7.74	-0.30	0.00	-2.09
	E. haploclada	0.84	0.18	4.72	0.18	0.00	0.93
	C. papyrus	0.98	0.20	4.90	0.05	-0.02	0.76
	P. mauritianus	0.69	0.16	4.80	0.33	0.02	0.85
	T. domingensis	1.15	0.20	5.57	-0.13	-0.02	0.08
	Mean	1.02	0.18	5.65			
Dry		Total N -%	Total P -%	N:P ratio	s.e	s.e	s.e
	C. distans	0.59	0.14	4.61	0.05	0.00	-0.11
	C. dives	0.56	0.13	4.20	0.07	0.01	0.30
	E. haploclada	0.20	0.10	1.96	0.43	0.04	2.54
	C. papyrus	0.68	0.13	5.12	-0.05	0.01	-0.62
	P. mauritianus	0.75	0.16	4.81	-0.12	-0.02	-0.31
	T. domingensis	1.01	0.20	6.30	-0.38	-0.06	-1.80
	Mean	0.63	0.14	4.50			
Average	**species**	**Total N -%**	**Total P -%**	**N:P ratio**	**s.e**	**s.e**	**s.e**
	C. distans	0.86	0.17	5.39	0.02	0.00	0.94
	C. dives	0.94	0.16	5.97	0.06	-0.01	1.23
	E. haploclada	0.52	0.14	3.34	-0.15	-0.02	-0.08
	C. papyrus	0.83	0.17	5.01	0.00	0.00	0.75
	P. mauritianus	0.72	0.16	4.80	-0.05	-0.01	0.65
	T. domingensis	1.08	0.20	5.93	0.13	0.02	1.21
	Mean	0.83	0.16	5.07			
Wet	**Eco-type**	Total N -%	Total P -%	N:P ratio	s.e	s.e	s.e
	HD	0.86	0.16	5.59	0.16	0.02	0.06
	LD	1.13	0.20	5.62	-0.11	-0.02	0.03
	MD	1.07	0.19	6.09	-0.05	-0.01	-0.44
	Mean	1.02	0.18	5.76			
Dry		Total N -%	Total P -%	N:P ratio	s.e	s.e	s.e
	HD	0.76	0.21	4.39	-0.03	-0.04	0.56
	LD	0.69	0.15	4.22	0.04	0.02	0.73
	MD	0.73	0.13	6.24	0.00	0.04	-1.29
	Mean	0.73	0.17	4.95			
Average	**eco-type**	**Total N -%**	**Total P -%**	**N:P ratio**	**s.e**	**s.e**	**s.e**
	HD	0.81	0.19	4.99	0.14	1.38	-8.23
	LD	0.91	0.18	4.92	-0.07	1.40	-8.08
	MD	0.90	0.16	6.17	-0.05	1.44	-10.57
	Mean	0.88	0.18	5.36			

Appendix 7: Plant species inventory in the Yala swamp

No	**Family**	**Genus**	**Species Name**	**Species Authority**	**Common Name**
1.	Amaranthaceae	*Alternanthera*	*sesilis*	(L.) R. Brown ex. DC.	
2.	Amaranthaceae	*Amaranthus*	*spinosa*	(Linn.),	
3.	Araceae	*Enydra*	*fluctuans*	Lour.	
4.	Araceae	*Pistia*	*stratioites*	L.	Water lettuce, tropical duckweed
5.	Asclepidiaceae	*Gomphocarpus*	*semilunatus*	A. Rich.	
6.	Azollaceae	*Azolla*	*africana*	Desv	Water fern
7.	Compositae	*Ageratu*	*conyzoides*	L.	Billy goat weed
8.	Compositae	*Ageratum*	*conyzoides*	L.	Billy goat weed
9.	Compositae	*Enydra*	*fluctuans*	Lour.	
10.	Compositae	*Melanthera*	*scandens*	(Schum. & Thonn.) Brenan	
11.	Compositae	Pluchea	*ovalis. Baccharis ovalis* Pers.; *Pluchea tomentosa*	(Pers.) DC	
12.	Compositae	Sphaeranthus	gomphrenoides		
13.	Compositae	Tagetes	minuta	L.	
14.	Compositae	Vernonia	purpurea		
15.	Convolvulaceae	Hewiltia	sublobata	L. f. Kuntze	
16.	Cucurbitaceae	Mukia	maderaspatana	(L.) M. Roem.	
17.	Cyperaceae	Cyperus	articulatus	L	
18.	Cyperaceae	*Cyperus*	*brevifolius* syn. *Kyllinga brevifolia*	(Rottb.)Hassk	Green kyllinga
19.	Cyperaceae	*Cyperus*	*distans*	L.f.	
20.	Cyperaceae	*Cyperus*	*dives*	Delile	
21.	Cyperaceae	*Cyperus*	*exaltatus*	Retz.	
22.	Cyperaceae	*Cyperus*	*laevigatus*	L	
23.	Cyperaceae	*Cyperus*	*macranthus*	(Boeck.) C.B. Cl.	
24.	Cyperaceae	*Cyperus*	*rotundus ssp merkeri*	L	
25.	Euphorbiaceae	*Euphorbia*	*geniculata Euphorbia heterophylla* (syn. *Euphorbia geniculata* L.; *Euphorbia prunifolia*	L	Painted spurge; Painted euphorbia; Milkweed; Mexican fire plant
26.	Gramineae	*Brachiaria*	*brizantha*	(A. Rich.) Stapf.	

Appendix 7: continued

27.	Gramineae	*Chloris*	*gayana*	Kunth	
28.	Gramineae	*Cynodon*	*dactylon-*	(L) Pers	
29.	Gramineae	*Digitaria*	*scalarum* syn (*Panicum muticum* Hochst.)	(Schweinf.) Chiov.	African couch / Dunn's finger grass
30.	Gramineae	*Digitaria*	*velutina*	(Forsk.) Beauv.	Velvet crabgrass
31.	Gramineae	*Eragrostis*	*exasperata*		
32.	Gramineae	*Eriochloa*	*meyerana*	(Nees) Pilg.	
33.	Gramineae	*Hyparrhenia*	*rufa*	(Nees) Stapf	Thatching grass
34.	Gramineae	*Leersia*	*hexandra*	Sw. (Rice)	Cut-Grass
35.	Gramineae	*Panicum*	*maximum*	Jacq	
36.	Gramineae	*Paspalum*	*carmmersonii*	Lam	Paspalum scrobiculatum
37.	Gramineae	*Phragmites*	*karka*	(Retz.) Steud.	
38.	Gramineae	*Phragmites*	*mauritianus_*	Kunth	
39.	Gramineae	*Sporobolus*	*pellucidus*		
40.	Gramineae	*Sporobolus*	*spicatus*	(Vahl) Kunth	
41.	Iridaceae	*Gloriosa*	*simplex*	L	
42.	Leguminaceae	*Senna*	*hirsute*		sicklepods
43.	Leguminaceae	*Senna*	*obtusifolia*	(L.) Irwin & Barneby	
44.	Leguminaceae	*Sesbania*	*sesban.*	(L.) Merrill - S	
45.	Leguminosae	*Acacia*	*macrothyrsa*	Harms	
46.	Leguminosae	*Clitoria*	*ternate*	L.	
47.	Leguminosae	*Crotalaria*	*pallida* var *obovata*	Aiton (G.Don) Polhill	
48.	Leguminosae	*Mimosa*	*pigra*	L.	
49.	Leguminosae	*Senna*	*occidentalis*	(L.) Link	
50.	Malvaceae	*Abutilon*	*mauritianum* - syn *Abutilon indicum* (L.) Sweet	(Jacq.) Medik	
51.	Malvaceae	*Hibiscus*	*cannabinus*	L.	
52.	Malvaceae	*Hibiscus*	*diversifolius*	Jacq.	“Swamp Hibiscus”
53.	Malvaceae	*Kosteleskya*	*adoensis*	(Hochst. ex A. Rich.) Mast.	
54.	Nymphaeceae	*Nymphaea*	*nouchalii* var. *caerulea* (Sav.) Verdc Syn. *Nymphaea capensis* Thunb.	Burm. f.	Blue Water Lily

Appendix 7: continued

55.	Onagraceae	*Ludwigia*	*stolonifera*	(Guill. & Perr.) Raven	
56.	Palmae	*Phoenix*	*reclinata*	Jacquin	Senegal date, African wild date
57.	Polygonaceae	*Polygonum*	*pulcherum*	Blume	
58.	Polygonaceae	*Polygonum*	*pulchrum*	Blume	
59.	Polygonaceae	*Polygonum*	*salicifolium*	Brouss	
60.	Potamogetaceae	*Potamogeton*	*schweinfurthii*	A.Benn	
61.	Scrophulariaceae	*Cycnium*	*tubulosum* subsp. *tubulosum*	(L.f.)	
62.	Solanaceae	*Solanum*	*anguivi*	Lam	
63.	Thelypteridaceae	*Cyclosorus*	*striatus*	(Schum.) Ching	
64.	Tiliaceae	*Corchorus*	*olitorius*	L.	
65.	Typaceae	*Typha*	*domingensis*	*(Pers.) Steudel*	
66.	Umbelliferae	*Oenanthe*	*palustris*	(Chiov.) Norman	
67.	Verbenaceae	*Lantana*	*camara*	L.	
68.	Vitaceae	*Cayratia*	*ibuensis*	(Hook. f.) Suesseng. & Suesseng.	

ACKNOWLEDGEMENTS

The successful completion of this thesis would not have been possible without the support and logistic contribution from several ends both directly and indirectly. The many months of absence from the University of Nairobi would not have been possible without the kind support from the Department of Geography & Environmental Studies. This enabled me to concentrate on my research work for the entire period. However, this also meant added workload to my colleagues, whose extra devotion to ensure the programmes went on smoothly with the extra schedules is greatly appreciated.

The different forms of support that were received from various organizations during my doctoral research are gratefully appreciated. This included financial support from the German Academic Exchange Programme (DAAD)-Bonn, logistic for fieldwork and laboratory measurements from the World Agroforestry Centre-ICRAF-(Nairobi & Kisumu), data evaluation and writing up from the Center for Development Research (ZEF) Bonn plus the Forschungszentrum Karlsruhe/ Institute for Meteorology and Climate Research (IMK/IFU), Garmisch-Partenkirchen, Germany. My sincere thanks also to my academic supervisors Prof. David Mungai, University of Nairobi, Prof. Paul Vlek, University of Bonn/ZEF and Dr. Louis Verchot, ICRAF, for the great devotion and professional advice. In particular, I do sincerely appreciate the several discussions that we held with Prof. David Mungai that eventually led to my engagement in doctoral studies. The staff of the three institutions and the Kabete Soil Laboratory provided generous support that ensured that my work went on smoothly even during times of short visits. In particular, I would like to express my appreciation to the support received from Dr. Gunther Manske and the secretariat team, Hanna Peters and Rosemarie Zabel, at ZEF. The time and efforts devoted by Ms Margaret Jend_ZEF in reading the final draft is highly appreciated. Also greatly appreciated was the generous support received from ICRAF soil Laboratory, Ms Janet Awimbo from training unit and GIS laboratory. The multinational team at ZEF was a source of great inspiration.

I am also grateful to the several scientists who provided useful advice to my research work. The support from Dr. Brent Swallow-ICRAF on socio-economics is very much appreciated, along with the help from Dr. Robert Zomer-IWMI, whose initial advice assisted in consolidating the research questions and who maintained a keen interest in the study. Dr. Peter Verburg, Wageningen University, provided land-use change literature, and his valuable comments are highly appreciated. In addition, the numerous discussions with Dr. Mathias Braun-ZFL/ZEF on remote sensing applications were very useful in guiding this work. I am also grateful for the excellent guidance and support from Dr. Reiner Wassmann-IMK/IFU, Garmisch-Partenkirchen with whom I held several useful discussions that ensured my research work remained focussed. The several informal discussions and comments on my work by Dr. Francis Mwaura are also acknowledged along with the encouragement from Ms Belinda Rego both of Department of Geography & Environmental Studies, University of Nairobi.

The generous field support provided by technician Mr. Benson Muoki, ICRAF Kisumu, both in the office and in the field, along with research assistants Mzee David Onyango, Mr Maloba, Joseph and Leonard is highly appreciated. My sincere thanks also to those who assisted with the socio-economic survey on short notice. Last but not least, thanks to the friendly people who assisted us in several ways in the field, and for their kind gestures.

For the years that I have spent in search of knowledge, this is neither a proof of this search but of the endless encouragement, unconditional faith from my mentors and piles of reference material from all who saw it fit that we travel this path of knowledge and make a contribution to our generation.