academicJournals

Vol. 7(5), pp. 274-291, May 2013
DOI: 10.5897/AJEST12.224
ISSN 1996-0786 ©2013 Academic Journals
http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Ecosystem services and drivers of change in Nyando floodplain wetland, Kenya

P. J. K. Rongoei[1,4]*, J. Kipkemboi[1], J. B. Okeyo-Owuor[2] and A. A. van Dam[3]

[1]Egerton University, Department of Environmental Sciences, P.O. Box 536-20115, Egerton, Kenya.
[2]Chepkoilel University College, Constituent College of Moi University, P.O. Box 1125, Eldoret, Kenya.
[3]UNESCO-IHE Institute for Water Education, Department of Water Science and Engineering, P.O. Box 3015, 2601 Da Delft, Netherlands.

Accepted 12 May, 2013

Papyrus wetlands in East Africa play a vital role in supporting livelihoods of people living around them. Although, subject to natural fluctuations and threats by anthropogenic activities, little is known about historical changes in wetland functions and services, or their present status. We focused on Nyando wetland on the eastern shores of Lake Victoria, Kenya. Three sites in the wetland were identified for assessment of history and current status. Changes during the past fifty years were assessed through participatory exercises with local communities and a review of published work. To establish the current status, we used field surveys and transect walks. Results showed that the wetland is important for hydrological and also ecological functions, which depend on the connectivity of the wetland with river and lake. The major direct drivers of change were hydrological regimes and livelihood activities. The main indirect driver of change was population growth, which leads to more pressure on wetland resources. Provisioning services are important in Nyando wetland but are generated at the expense of regulating services. Hydrology and livelihoods are strongly interlinked as flooding limits access to the wetland. Understanding the historical changes in wetland functions and services is important for rural communities, policy makers and for wetland managers in guiding, planning and wetland management.

Key words: Papyrus wetland, wetland ecosystem services, drivers of change, community perception, Nyando wetland.

INTRODUCTION

The benefits that humans derive from the use of ecosystems are now commonly referred to as ecosystem services (de Groot, 1992; MEA, 2005). A distinction can be made between ecosystem functions, defined as the capacity of natural processes and components to provide goods and services (de Groot, 1992) and ecosystem services, defined as the benefits that people derive from using the ecosystem functions (MEA, 2005; TEEB, 2010). Maltby (2009) defined three categories of ecosystem functions: hydrological, ecological and biogeochemical functions. The Millennium Assessment distinguished provisioning (food and materials provided by the ecosystem), regulating (water purification, flood protection), supporting and cultural (education, spiritual and recreation) ecosystem services. Growing pressure by human exploitation to maximize provisioning services of wetlands has led to the degradation of wetland functions and regulating ecosystem services (MEA, 2005).

Wetlands are important because of their position in the landscape between terrestrial and aquatic environments and their high productivity. The *inter alia* provide food and other materials, store water, improve water quality, sequester carbon and support biodiversity (Mitsch and Gosselink, 2007; Maltby, 2009). Despite their importance, wetlands are threatened by conversion to agriculture, industrialisation and human settlement. They face hydrological modification and pollution from human activities, including climate change. Although, the use of wetlands has contributed to human well-being and economic development, over-exploitation has degraded wetland functions, leading

*Corresponding author. E-mail: priscah.rongoei@gmail.com.

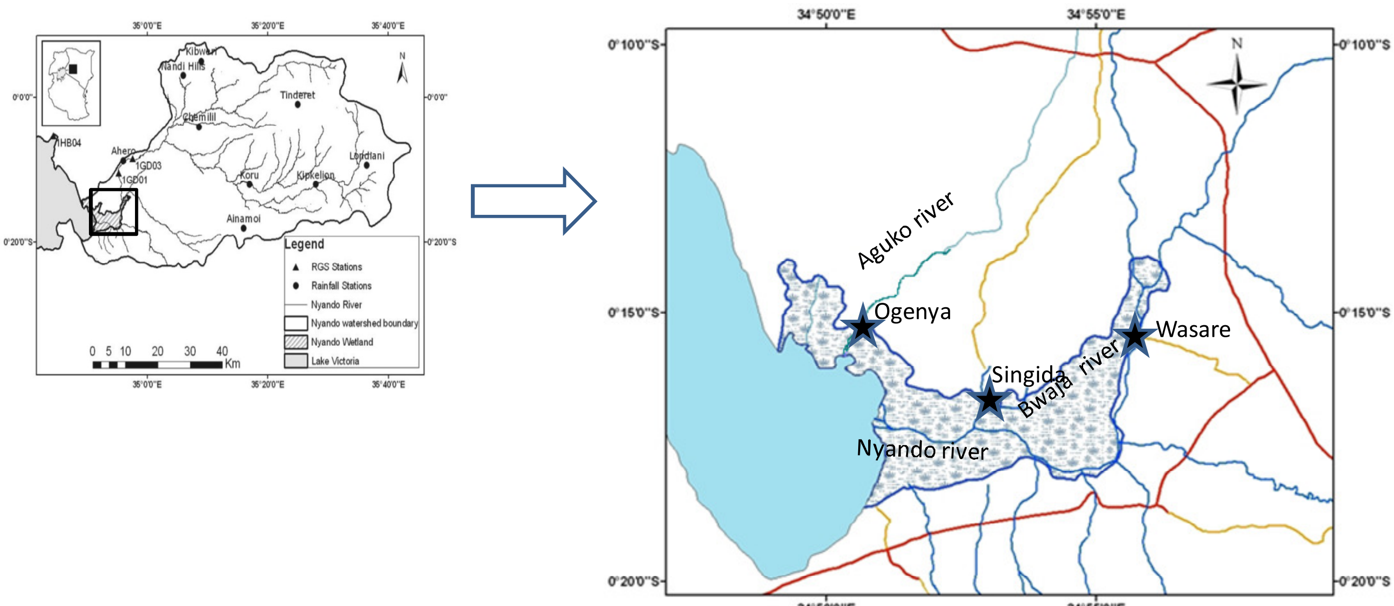


Figure 1. Location of Nyando floodplain wetland in relation to Lake Victoria in East Africa. The transect sites are shown with a black star- Ogenya, Singida and Wasare, while the dotted part is the wetland and the blue colour is the Nyanza Gulf of lake Victoria (Courtesy of P. Khisa).

to increased poverty and loss of biodiversity (Wetlands International, 2009). Improving sustainable exploitation, conservation and "wise use" of wetland ecosystems is needed (MEA, 2005; Finlayson, 2012).

Cyperus papyrus (common name: papyrus) is an emergent macrophyte that occurs in riverine, lacustrine and floodplain wetlands across mid-latitude from the Okavango Delta in southern Africa through central and eastern Africa with isolated occurrences in Egypt, Israel and southern Italy. Papyrus is a tall sedge growing to five meters on average and is known for its rapid growth and dense monoculture stands (Muthuri et al., 1989; Saunders et al., 2007). Papyrus wetlands support livelihoods of millions, providing food, construction materials, clean water and other benefits (Kipkemboi et al., 2006; Swallow et al., 2009). Large areas of papyrus wetlands occur in the Lake Victoria basin in East Africa, and the littoral and floodplain wetlands of the lake are dominated by papyrus. The papyrus vegetation either occurs as rooted in the seasonally flooded areas on the landward side of the wetlands or as floating fringes at the edge of the lake. In the past 50 years, wetland area around Lake Victoria has undergone tremendous change owing to considerably lake level changes due to uncertainty of rainfall events, human encroachment and intensified land use (Owino and Ryan, 2007).

The research project "Ecology of Livelihoods in East African Papyrus Wetlands" (ECOLIVE) integrated studies of hydrology, ecology and livelihoods in the Nyando wetland, aiming at the development of a framework for sustainable wetland management (van Dam et al., 2011). While the study reported here focused on ecosystem functions and services, two related studies focused on the hydrology (Khisa et al., in prep.), livelihoods and governance (Nasongo et al., in prep.) of Nyando wetland. This paper aims at describing and reviewing past and current status of ecosystem functions and services in Nyando wetland in preparation for more in-depth studies. Specific objectives were to: (1) describe the current ecosystem functions and services of Nyando wetland and changes of these during the past 50 years; (2) identify the key drivers of change in the Nyando wetland; and (3) define the main gradients of hydrology and exploitation in the wetland and identify transects for further research.

MATERIALS AND METHODS

Study site location and description

Nyando wetland is located in Nyanza Province, western Kenya, and at the mouth of Nyando River at Nyanza Gulf (on the eastern part of Lake Victoria, East Africa). Administratively, the wetland is part of Nyando, Nyakach and Kisumu East districts which according to the new constitution of Kenya fall in Kisumu County. It stretches from 0°11'- 0°19'S to 34°47'- 34°57' E (Figure 1). Reports of its size vary from 3000 ha in the dry season to 5000 ha in the wet season (Kipkemboi, 2006; Mwakubo and Obare, 2009). In the 2008 dry season, it was estimated at approximately 4212 ha (Khisa et al., in prep.).

The mean annual rainfall for the Nyando wetland is 1184 mm with an estimated mean temperature of 23°C (Muthusi et al., 2005; World Agroforestry Centre, 2006). Rain is divided into March-May ("long rains") and October-December ("short rains") periods. During these wet seasons, flooding of Nyando River creates connectivity between river, wetland and lake. The soil in this area is poorly drained and rich in organic matter (Jaetzold and Schmidt, 1982) which influences crops grown and the distribution of natural vegetation. The human communities living in the floodplain is predominantly the Luo ethnic group who practice subsistence farming, livestock herding and fishing (Kipkemboi et al., 2006).

For this research, three sites were identified based on hydrological characteristics and rural livelihoods activities. Singida (0°16'S and 34°53'E), about 3 km east of Ogenya (Figure 1), is influenced by the Bwaja stream that joins Nyando River before entering the lake. This site becomes inundated during the wet season, with water levels up to 79 cm above the soil surface, but dries up in the dry season. The vegetation is dominated by *C. papyrus* mainly rooted and *Ipomoea wrightii* with *Vossia cuspidata* along the edges of the Bwaja River. On the landward side, natural vegetation has been replaced with crops.

Ogenya (0°16'S and 34°51'E) at the shore of Lake Victoria is influenced directly by wind related positive water balance (seiche effect) that inundate the littoral zone. The drying and wetting of the papyrus vegetation at the edge of the wetland makes this site different from the others. Papyrus vegetation comprises of the rooted zone towards the terrestrial zone and a floating mat at the lake fringe. Water levels above the soil surface fluctuate on a daily basis between 20 and 65 cm depending on the magnitude in the seiche effect associated with the wind action blowing in the lake surface. There is a distinctive zonation of plants from floating *Eichhornia crassipes*, *Pistia stratiotes* and *Nymphaea sp.* to emergent *Vossia cuspidata* at the edge of the lake and along Aguko channel. *C. papyrus* stands float at the lake edge and are rooted at the landward side in association with patches of *Phragmites* sp. and *Typha* sp., including a strip of *Sesbania* spp. and *Triumffeta* sp. The wetland-terrestrial interface and abandoned farms are characterized by occurrence of *Cyperus latifolius* and *Cynodon dactylon*. The spatial extent of the permanently and seasonally flooded zones varies with dry and wet seasons.

Wasare (0°15'S and 34°55'E), located approximately 15 km east from the edge of Lake Victoria, is influenced by annual flooding of Nyando River. Unlike the other two sites, the gradient rises rapidly on the landward site restricting the river into the floodplain. The water depth above the soil surface ranges between 0 and 45 cm. The floodplain is dominated by trees such as *Acacia seyal, Balanites aegyptiaca, Euphorbia* sp. *Thevetia peruviana* and *Eucalyptus* sp. In the wet season, *Cyperus papyrus* dominates the wetland in association with *Ipomoea aquatica*, *Vossia cuspidata* and *Polygonum* sp. However, plant composition changes in the dry season to species like *Leersia hexandra*, *Amaranthus spinosa* and *Cyphostema babuseti* after clearing and burning of the wetland ecosystem. Since burning does not affect the rhizomes, papyrus will regenerate at the onset of rain enabling it to dominate again.

Data collection

Informal and formal sources of knowledge were used to describe the ecosystem services and their main drivers of change. Semi-structured community interviews were used to solicit local knowledge on the wetland and its changes while open-ended questions were asked to recall knowledge on changes that had occurred in the wetland within the past 50 years. Guided questions were used to obtain information on livelihood activities, hydrological regimes and biodiversity (flora and fauna). The number of persons interviewed was 15, 18 and 25 in Singida, Ogenya and Wasare, respectively. Both men and women between 30 and 80 years old were interviewed.

Information obtained during the interviews was supplemented and verified with results from research published in government reports and the scientific literature (CBS, 1999; Gichuki et al., 2001; Kipkemboi et al., 2006; Owino and Ryan, 2007; KNSB, 2009; unpublished reports of the Ministry of Agriculture for the years 2007-2011). Data on historical rainfall, river discharge and lake water level changes were obtained from Kenya Meteorological Department (KMD) through the Water Resource Management Authority (WRMA). Demographic information was obtained from CBS (1999) and KNBS (2009) census data reports of The Republic of Kenya. Based on the interviews and literature review, a list of functions and services and their changes in the last 50 years was established. To classify ecosystem functions, the approach used by Maltby (2009), which includes hydrological, biogeochemical and ecological functions was used. Ecosystem services were identified according to MEA (2005). Because of the overlap of regulating and supporting ecosystem services (MEA, 2005) with Maltby's ecosystem functions, only provisioning and cultural services were identified. The assessment of ecosystem functions and services was qualitative based on own observations and literature review. No attempt was made to quantify indicators or scores for ecosystem services as this was beyond the scope of the present study. This paper therefore focuses on historical to present knowledge on wetland resource use and provisioning ecosystem services.

Community members were asked to list livelihood activities in the wetland that were important to their well-being and rank them in terms of impact on their daily lives using a pair-wise ranking matrix (Jackson and Ingles, 1998; Asia Forest Network, 2002). After ranking, community members scored the three most important livelihood activities in their area during the last 30 years (1980-2010) the year in which these activities intensified in the wetland.

To define the hydrological and exploitation gradients, transect walks were done across each study site in the dry (March 2010) and wet seasons (May 2010) with the help of community members (Lightfoot et al., 1992). At each site, soil types, vegetation and crops, and livelihood activities were observed, photographed and recorded. The results were summarized in resource transect diagrams.

RESULTS

According to the community members, Nyando wetland historically was restricted to the narrow strip along the shores of Lake Victoria and along the river channels. However, with the heavy rains experienced in 1962-1963, the wetland expanded landward resulting in loss of croplands, settlements and even lives. To date, some members of the local community still believe that their land is submerged in water and part of the wetland, which they occasionally clear and grow their crops during severe drought. People's livelihood activities at the time included fishing mainly in the wet season and livestock herding and seasonal wetland cultivation in the dry season.

Ecosystem functions and services of Nyando wetland

Table 1 provides an overview of the current ecosystem functions and services of Nyando wetland. Of the hydrological functions, sediment retention with respect to the river load is important although there has not been quantification of this function in Nyando wetland. Due to its position in the lower floodplain extending to the river mouth, flood water retention and groundwater recharge

Table 1. Description and status of functions and services of Nyando floodplain wetland and the sources of information.

Category	Function/Service	Description and status	Source
Hydrological functions	Flood water detention	Wetland hold flood water and release it slowly to groundwater. However, frequent floods occur causing destruction	Muthusi et al., 2005; Ogutu et al., 2007; Awange et al., 2008b
	Ground water recharge and discharge	Some studies have shown that this wetland discharges water during dry season to maintain river flow. However, more studies are required to prove the extent of this function in Nyando.	Karicho, 2010
	Sediment retention	Papyrus can trap sediments and retain them before entering the lake. However, it is not clear if the wetland still has the capacity to retain as more sediments get to Lake Victoria.	ISRIC, 1997; World Agroforestry Centre 2006; Swallow et al., 2009.
Biogeochemical functions	Nutrient retention	Studies have shown that papyrus wetland is able to retain nutrients in plants and soil reducing nitrogen that cause eutrophication of the lake water. This function is still unclear for the Nyando floodplain wetland which is characterized by seasonal connectivity with River Nyando and Lake Victoria.	Mwaura and Widdowson, 1992; Boar et al., 1999; van Dam et al., 2007; Kelderman et al., 2007; Kansiime et al., 2007
	Insitu carbon retention	Evidence from other studies done on carbon retention shows that papyrus wetlands can be good in retaining carbon.	Gichuki et al., 2005; Saunders et al., 2007
	Trace element storage and export	Wetland may not function well in retaining trace elements including heavy metals as studies have shown that some of these elements were found in lake sediment, water column and fish tissues of Lake Victoria.	Muwanga and Barifaijo, 2006; Ongeri et al., 2009; Oyoo-Okoth et al., 2011
	Organic carbon concentration control	Evidence from studies show that papyrus wetlands are a source of organic carbon to the lake	Gichuki et al., 2005; Loiselle et al., 2008
Ecological functions	Habitat for biodiversity	Papyrus wetland is known for protecting various endemic bird species that have been known to be globally threatened or rare. They also are refuge areas to fish species, reptiles, amphibians and macroinvertebrates	Birdlife International, 2004; Maclean et al., 2006; Owino and Ryan, 2007; Gichuki et al., 2001
	Production, biomass and detritus for food web support	Papyrus wetlands are known to be productive systems in terms of biomass but also provide food for other organisms through high decomposition rate. The litter from plants also supports soil formation that enhances soil fertility of the wetland.	Boar et al., 2006; Mnaya et al., 2007; Terer et al., 2012
Provisioning services	Food	People use a variety of food products from the wetland such as papyrus rhizomes and *Typha* species' stems but also fish, wild vegetables and animal meat. The wetland is used to produce food crops, livestock grazing that give products like milk, meat, skin and dung to the rural communities	Geheb and Binns, 1997; Kipkemboi et al., 2006, 2007; Kibwage et al., 2008; Rongoei, pers. obs.

Table 1. Contd.

	Fresh water	Fresh water for both human and livestock use is gotten from wells, rivers and lake	Rongoei, pers. obs.
	Fibre, fuel and other construction materials	Papyrus culms are used to make mats, furniture, wall hangings, ropes, fish traps and roofing. Papyrus rhizome is used as fuel wood and umbel used as a broom	Kipkemboi et al., 2007; Kibwage et al., 2008; Osumba et al., 2010; Rongoei, pers. obs.
	Biochemical materials	Biochemical materials like medicinal plants for preventing illnesses are collected from the wetland. *Thevedia peruviana* is used as a repellent for mosquitoes in the homesteads. Not much is known about their properties	Kipkemboi et al., 2007; Kuga Ambiso, pers. comm.; Opiyo Yimbo, pers. comm.; Samuel Andega, pers. comm.
	Genetic materials	These resources have not been quantified in Nyando wetland though has potential in adding to the genetic diversity which is currently unknown.	
Cultural services	Spiritual and inspirational	Papyrus wetlands are used for spiritual cleansing and cultural rituals such as driving away bad spirits.	Kipkemboi et al., 2006; Kibwage et al., 2008
	Recreational and aesthetics	Swimming and fishing for locals occur. Wetland ecosystem and the surrounding has the potential for exploiting ecotourism industry because of its support to endemic and rare species that depend on papyrus vegetation	Kibwage et al., 2008
	Educational	Studies have been done in the wetland by universities, government departments and NGOs	www.unesco-ihe.org/ecolive

may be less important as there are no human communities downstream of this part of the river. Nutrient and carbon retention is important as shown by generally high vegetation biomass and peat formation in the permanent wetland zone (Jaetzold and Schmidt, 1982). The importance of the hydrological and biogeochemical functions depends strongly on the degree of connectivity of the wetland with the river. Connectivity seems to be limited for the Nyando wetland, which is flooded once or twice annually, and only for a period of approximately two weeks (Muthusi et al., 2005). It is not clear if the short period in which the river interacts with the floodplain allows for significant sediment retention in the Nyando wetland. This phenomenon is aggravated by the recent construction of dikes on both sides of River Nyando to restrict overtopping of the river. At the time of this study, most river sediment loads were deposited at the river mouth.

In terms of ecological functions, Nyando wetland is a habitat for a variety of flora and fauna. Thirty macrophyte plant species have been identified in the Nyando floodplain wetland (Rongoei et al., in review). These macrophytes form a habitat to the rare and endangered antelope Sitatunga (*Tragelaphus spekei*), and to papyrus endemic bird species such as the white-winged warbler (*Bradypterus carpalis)* and the papyrus gonolek (*Laniarus mufumbiri*) (Birdlife International, 2004). Papyrus biomass is high and can be over 8000 g m^{-2} in Ogenya wetland (Osumba et al., 2010).

Provisioning ecosystem services include food, water, fuelwood, building materials and herbs. Food products that are directly extracted from the wetland are wild vegetables, including *Solanum nigrum*; fish (main species include the lungfish *Protopterus aethiopicus,* local name "kamongo"; catfish *Clarias gariepinus,* local name "mumi"; and *Schilbe intermedius,* local name "sire"); wild meat from Sitatunga *(Tragelaphus spekei*), hippopotamus, birds and insects. In addition, there is farming in the seasonally flooded wetland sugarcane growing for commercial purposes mainly sold to sugar processing industries has been expanding into the macrophyte zone over the recent years. Papyrus biomass is harvested for making mats, furniture, wall hangings, ropes, brooms, fish traps,

Table 2. List of plant and animal species lost or reduced: year of change and their uses in Nyando floodplain wetland.

Scientific name	Common name	Local name (Dholuo)	Year lost	Reasons for loss/reduction	Use
Plants					
Aspilia pluriseta		Get	1960s	Change in climatic conditions: long dry spell	Firewood, medicine
Triumfetta cordifolia.	Burweed	Owich	1963	Flooding after "Uhuru" rains	Firewood, medicine, making robes
Sesbania sesban	Common sesban	Omburi	1980s	The demand for use in rowing boats, fencing, charcoal burning, firewood	Firewood, poles, posts for fencing, charcoal and boat rowing pole
Euphorbia tirucalli	Pencil plant	Ojuok	1990s	Replaced with fast growing *Thevedia sp.*	Live fences around homesteads
Aloë sp.	True aloe	Okaka	1997	El Niño rains	Medicinal, live fences
Ficus sycamore.	Sycamore tree	Ng'ou	2000	Tree felling for timber made easy by use of power saw	Furniture, firewood, building, fencing
Nymphaea sp.	Water lily	Oyungu	2002	Draining of water pans that used to occur at the edges of the wetland	Making straw for taking local brew "busaa"
Animals					
Crocodylus niloticus	Nile crocodile	Nyang'	1948	Flooding after "Uhuru" rains	Hunted for skin for making leather bags and belts
Redunca redunca	Bohor reedbuck	Mwanda	1980	Hunting and habitat encroachment	Meat
Python sebae	African rock python	Ng'ielo	1994	Drought which led to burning and clearing of wetland	Believed to bring rain and bumper harvests
Hylochoerus meinertzhageni meinertzhageni	Giant hog	Mbidhi	1997	El Niño	Meat
Ptemistis squamatus	Scaly francolin	Aywer	1997	El Niño	Meat
Ephippiorhynchus senegalensis	Saddle-billed stork	Rabala	1997	Habitat encroachment	Cultural

fencing and thatching. Other emergent macrophytes harvested for use by local people include *Phragmites* sp. (fish traps and fencing), *Vossia cuspidata* (livestock fodder) and *Cyperus* sp. (thatching). Medicinal plants collected from the wetland are used to treat and prevent ailments, including snake bites. These include plants such as *Cyphostema suaveolens, Solanum nigrum* (herb and vegetable), *Senna* sp. and *Sphaeranthus* sp. while *Thevetia peruviana* is used as a repellent for mosquitoes in the homesteads. However, there is little information on the biochemical characteristics of these plants some of which are known to have medicinal properties. In addition, Nyando wetland is important for domestic water supply and irrigation either through direct abstraction from the river and pools or shallow wells dug in the wetland periphery.

Nyando wetland plays an important role in the tradition and culture of the Luo community, who use the wetland for spiritual cleansing and rituals of sending away evil spirits (Samuel Andega-resident, pers. comm.). The wetland is also home to a reptile used for indigenous weather pattern prediction among the Nyakach community. The famous "omieri" python is mythically associated with flooding and bumper harvests in the region (Peter Guga - resident, pers. comm.). The local community uses the wetland for recreational fishing and swimming but tourism potential remains unexploited.

Table 2 presents a list of wetland plant and animal species considered by the local community to be reduced or lost between 1960 and 2010. The majority of changes were attributed to hydrology, notably rainfall patterns (El Niño); and to human encroachment into the wetland like

Table 3. Fish species perceived by community members as lost or reduced in number and the period when change was detected.

Scientific name	Common name	Local name	Year
Mormyrus kannume		Suma	1950s
Bagrus bajad	Bayad/Lisi	Seu	1950s
**Bagrus docmak*	Semutundu/Sew	Seu	1950s
**Barbus artianalis*	Ripon barbel	Fwani	1952
Brycinus sadleri		Osoga	1960s
**Brycinus jacksonii*	Victoria robber	Osoga	1960s
Mastercembelus frenatus		Okunga	1990s

* These species have been seen in the satellite lakes and fringing wetlands of Lake Victoria.

burning of wetland vegetation, farming in the wetland, hunting for wild animals and livestock herding. Increased encroachment is caused by the expansion of the local population but could also be attributed to the increase in people migrating to the floodplain from upland areas.

Overtime, plant species composition in the wetland has changed. Alongside the loss of native species, new plant species were introduced. One of the dominant of these species is *Thevedia peruviana* (local name: chamama), which is not a wetland plant but dominates areas around homesteads. This plant is used for live fences and, according to respondents, serves as an insect repellent. Other plants that respondents reported to have increased with time include *Eucalyptus* sp. (local name "mbao"), *Azadiractai indica* (local name "mwarubaini") and *Schefflera actinophylla* (common name: umbrella tree), which are used for construction (housing, boats), fencing, furniture, firewood and charcoal production. These plants are exotic and are not wetland plants but grown near homesteads and at farm boundaries. However, there are also introduced species like *Eichhornia crassipes*, *Pistia stratoites* and *Azolla* sp. which dominate open water lake, pools and river channels. Some new animal species have also been noticed, including African hare, *Lepus* sp. (local name: "apwoyo"; since 1994) and squirrel *Paraxerus* sp. (local name: "ayidha"; since 2005).

The Luo community traditionally depended on the lake and wetland fisheries for protein, employment and income. However, respondents reported the reduction and disappearance of a number of fish species from the lake, some of which were delicacies for special occasions (Table 3).

Categories of drivers of change

Three main categories of drivers of change that influence ecosystem functions and services in the Nyando wetland were identified: hydrology, demographic changes and associated livelihoods activities in the wetland. The major hydrological event that shaped Nyando wetland was the El Niño event known as the "Uhuru rains" of 1962-1963 (Figure 2a). The Uhuru (Swahili word for independence) rains referred to as the heavy downpours that affected most parts of the Lake Victoria basin at the time when the Republic of Kenya was gaining its independence. This rain led to extensive inundation along the lake and in the river mouth floodplain and consequently the shift and expansion of once narrow papyrus vegetation to extend into a landward direction, forming the current Lake Victoria fringing wetlands. The raging floods resulted in destruction of property, loss of life and the migration of many people to higher areas in Miwani, Lambwe, Koru, Kibigori and Muhoroni. The respondents identified historical rainfall and drought events over the years which they believed to have shaped the wetland ecosystem. They suggested that before 1961, rainfall patterns were easy to predict as they fell between the months of March and May for long rains and in October to December for short rains. However, abnormal floods were experienced in the years 1962-1963, 1970, 1977-1978, 1984 and 1997-1998 while droughts occurred in the years 1961, 1980, 1985, 1993, 1997, 2003, 2004-2005 and 2007 (Figure 2a).

A result of the heavy rainfall was a change in the flow of River Nyando (Figure 2b) but it generally maintained two discharge peaks, in May and December. However, recently the river has shown a more irregular behaviour, e.g. with a discharge peak observed in the field in September 2010. Apart from rainfall and river discharge, Lake Victoria water level fluctuations (Figure 2c) have an important influence on the Nyando wetland, both on a daily and seasonal scale. On a daily basis, a rise in water level in the littoral zone floods the papyrus vegetation along the edges of the lake, resulting in a permanently flooded wetland zone. This pattern is due to tilting in the orientation of the lake volume in the lake level in the afternoons as a result of change in wind direction blowing over the lake. On a seasonal scale, the lake level is influenced by rainfall and river flow regimes in the Lake Victoria basin.

The second driver identified is the demographic patterns which triggers change in the wetland ecosystem services. Generally, the Kenyan population has increased by over

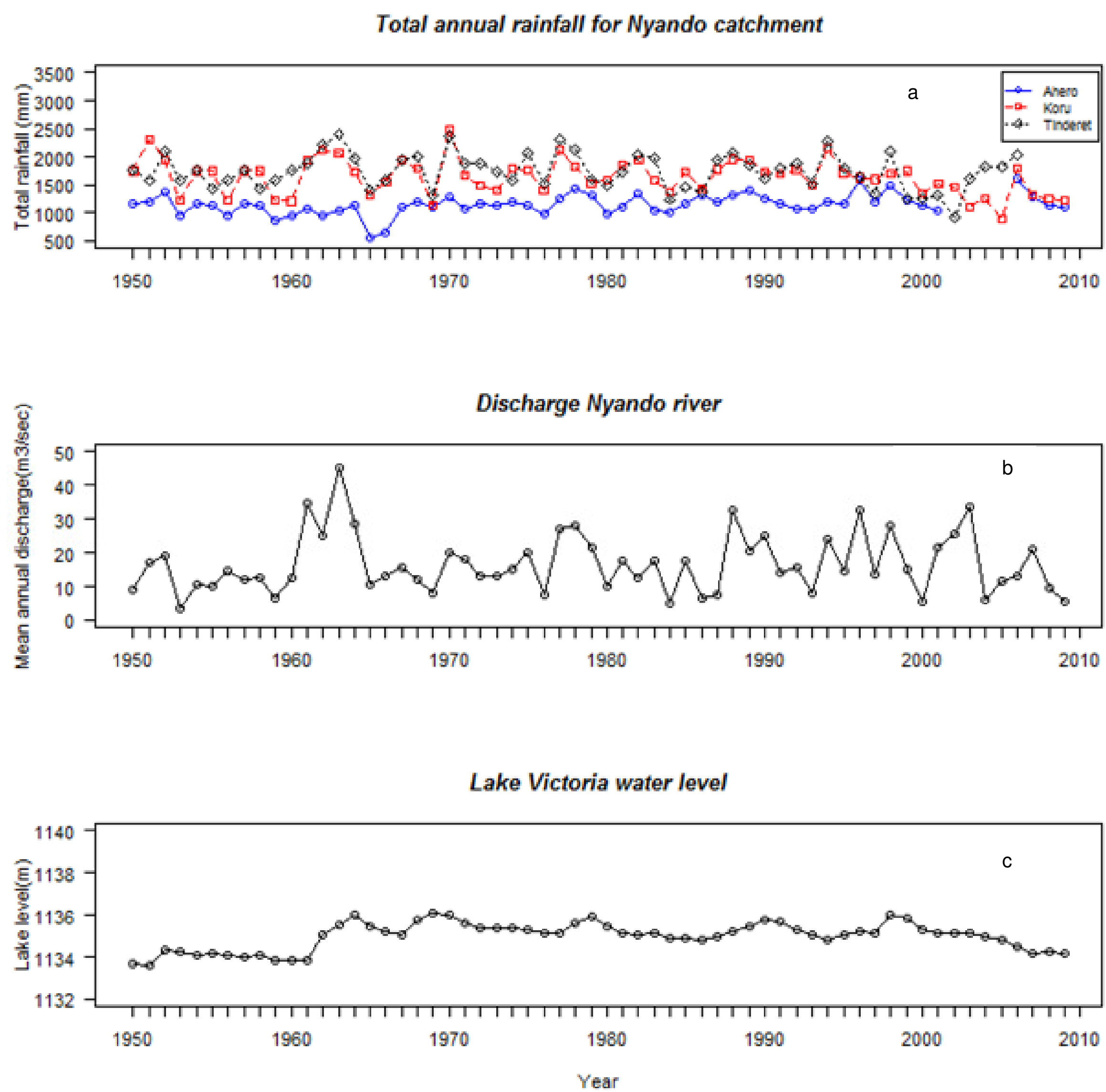


Figure 2. Hydrological regimes in the Nyando River Basin since 1950 – 2009; (a) total annual rainfall for Ahero, Koru and Tinderet stations in Nyando catchment from 1950-2009 measured on a daily basis, (b) River Nyando discharge at Ahero data showing mean of hourly measurements and (c) mean annual lake water level fluctuations at Kisumu. Data points represent annual totals for rainfall and annual mean for river discharge and lake water level.

10 million people by 1969 and reached over 38 million in the year 2009 with a population growth rate of 2.7% per year between 1999 and 2009 (KNBS, 2009). The Kenyan side of Lake Victoria comprises about 40% of the country's population (Odada et al., 2006). Nyando wetland has an average population density of 979 persons per km^2 with a high level of poverty (CBS, 1999). Between 1989 and 2009, human population increased steadily (Table 4). In addition, cattle population also increased steadily in the three transects between 2007 and 2011 (Table 5). The Luo rural communities still value their culture where cattle is turned into cash to pay school fees or dowries and buy food and other household goods. More so, due to increase in population and loss of income opportunities, more people have migrated to the wetland area in search of grazing land (Joel Ouma- resident Wasare, pers. comm.).

The last major category of drivers of change is related to livelihood activities. Table 6 presents the livelihoods activities identified by respondents in the three research sites, ranked in order of importance. Farming in wetland ranked first in Singida and was in the top three of livelihood activities in all sites. Papyrus harvesting and firewood collection were important in Wasare, livestock herding and fishing in Singida, and irrigation and livestock herding in Ogenya. A variety of other livelihoods activities

Table 4. Human population size in the study districts of Nyando floodplain wetland between 1989 and 2009 (before 1999 census, Kisumu East and Nyakach were administratively part of another district; therefore data was not included as it may not be representative).

Location	1989	1999	2009
Kisumu East	-	64,883	473,649
Nyakach	-	196,233	299,930
Nyando	48,914	64,311	350,353

Source: CBS (1999) and KNBS (2009).

Table 5. Cattle population trend in three districts within Nyando floodplain wetland between 2007 and 2011.

Location	Type	2007	2008	2009	2010	2011
Kisumu East	Dairy	8,598	9,728	9,894	10,440	2,123
	Zebu	54,000	57,348	65,000	70,147	49,000
Nyakach	Dairy	2,200	2,300	2,368	2,415	2,467
	Zebu	47,800	49,000	51,400	52,430	137,842
Nyando	Dairy	-	188	285	300	340
	Zebu	-	32,600	35,100	36,600	39,000
Total	Dairy	10,798	12,216	12,547	13,155	4,930
	Zebu	101,800	138,948	151,500	159,177	225,842
	All	112,598	151,164	164,047	172,332	230,772

Source: District Agricultural and Livestock Development Annual Report (unpublished).

Table 6. Pair wise ranking of livelihood activities in the study transects. "Score" is the number of times the activity scored "more important" than the other activities. "Rank" indicates the ranking of an activity within each transect. Overall ranks indicate the mean of the scores in the three transects; and the coefficient of variation (CV) of the means.

Activity	Singida		Wasare		Ogenya		Overall Rank	
	Score	Rank	Score	Rank	Score	Rank	Avg	CV
Wetland farming	7	1	9	3	7	2	2.0	50
Livestock herding	6	2	8	4	5	4	3.3	35
Water for irrigation	4	4	7	5	8	1	3.3	62
Firewood collection	1	7	10	2	6	3	4.0	66
Papyrus harvest	3	5	11	1	3	6	4.0	66
Fishing	5	3	5	7	4	5	5.0	40
Medicinal plants harvest	-	-	5	6	-	-	6.0	-
Fish farming	-	-	4	8	-	-	8.0	-
Sand harvest	-	-	3	9	2	7	8.0	18
Thatching grass harvest	2	6	1	11	1	8	8.3	30
Hunting	0*	8	0*	12	0*	9	9.7	22
Liquor brewing	-	-	3	10	-	-	10.0	-

*The activity was mentioned by communities in all transects but was not important to the livelihoods of the community. These activities were not mentioned as important in Ogenya and Singida transects.

were reported for all sites (Table 6). In the last 30 years, the contribution of these activities to the wetland community livelihoods increased (Figure 3). Farming is a common livelihood activity in all the three transects which gained its importance since 1995 when drought was experienced. As described previously in the hydrology, rainfall patterns

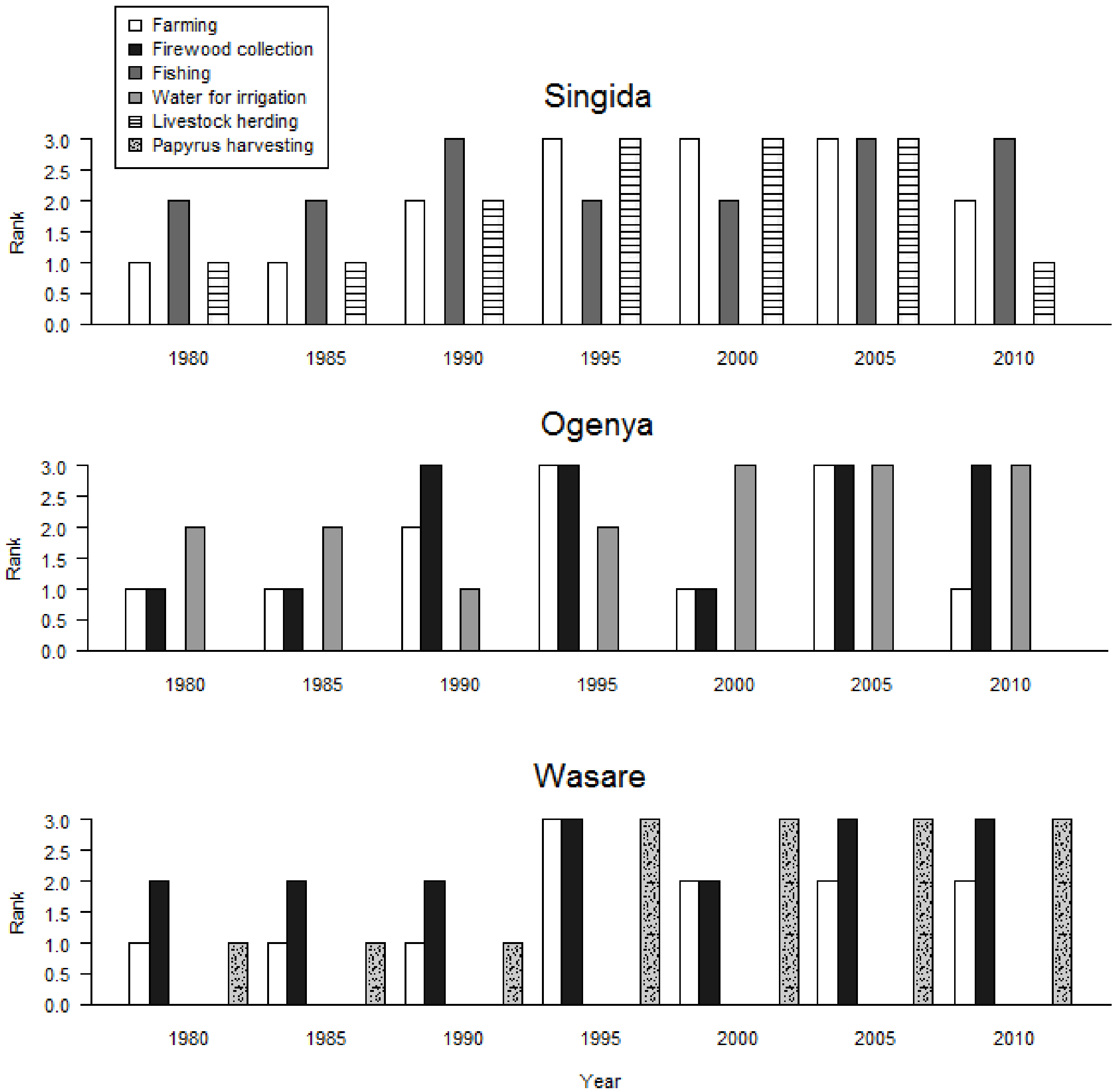


Figure 3. Trend analysis of the three major livelihood activities in Singida, Wasare and Ogenya (data covering the period between 1980 and 2010). White bars indicate farming in wetland which was common in all transects. The scores given are 1- low, 2- moderate and 3- high in importance in contributing to the livelihoods of the rural people. The legend abbreviations of fire_col stand for firewood collection; Irri_water stands for irrigation water while pap_harv stands for papyrus harvesting.

influence the trend of livelihood activities where high water level makes the farms in wetland inaccessible but dry condition opens an opportunity for people to extent their croplands into the wetland where there is enough soil moisture. Firewood collection was common in Ogenya and Wasare and gained its importance from 1990s. This was the time the respondents perceived that more trees had been cleared from the homesteads. Consequently, rural women had to look for firewood in the wetland where there were still intact shrubs and trees. Other activities like livestock herding, fishing and water for irrigation increased too as a result of increase in human population that led to demand for wetland resources. Papyrus harvesting was important too in Wasare as people discovered more uses of papyrus plant such as mat-making, furniture and wall hangings for income purposes.

Of the three transects, Singida had the highest flood inundation water levels in September with an average of 66 cm as compared to Ogenya (20 cm) and Wasare (33 cm) over the six month study period (Figure 4). These changes were influenced by the position of each transect in relation to the water body. The Singida transect is about 1700 m long and starts from the last homestead to Bwaja river running across farms and seasonally flooded areas and finally to the wetland. The land is divided into dry land, seasonally flooded land and a permanently

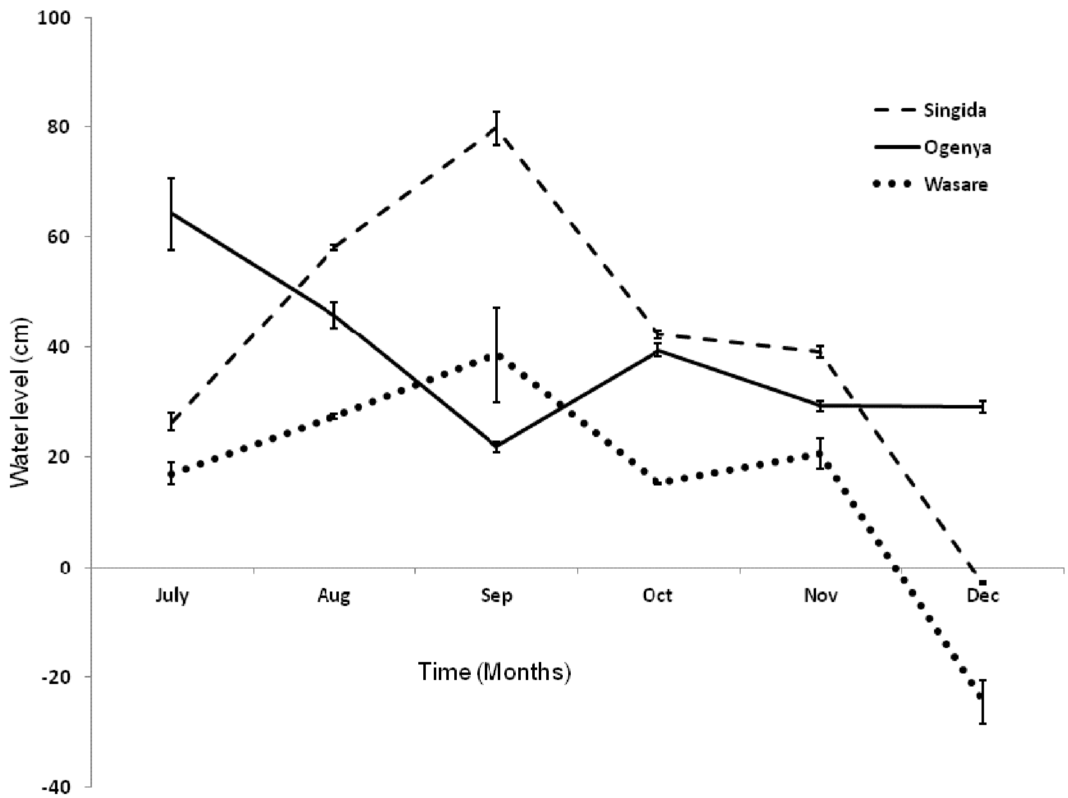
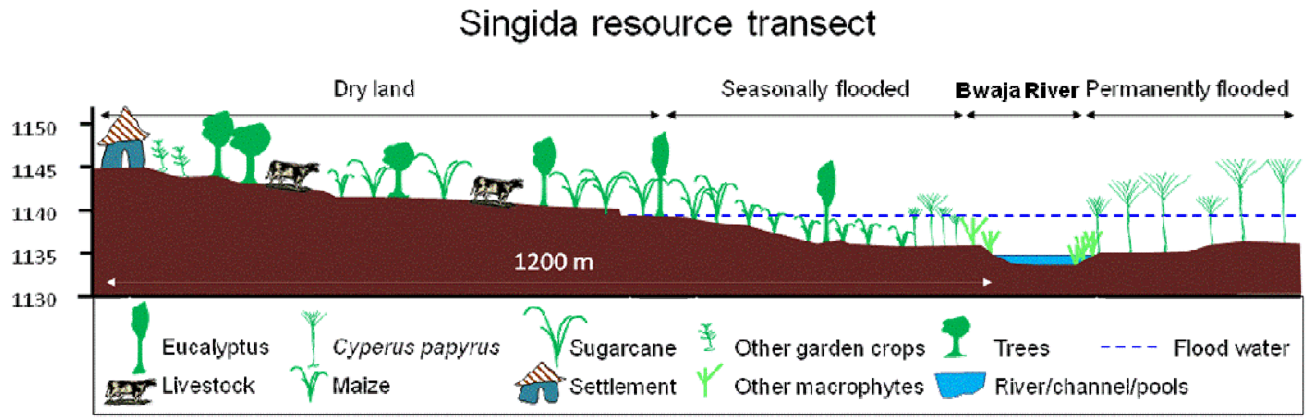


Figure 4. Line graph showing monthly average water depth measurements from July to December 2010 in the three study sites. Measurements were done above the soil surface in centimetres. Data points are the mean of three replicate measurements in the permanently flooded zone at each site. Error bars represent ± S.E.M.

flooded area (Figure 5). In the dry season, the dry land is characterized by a few livelihood activities such as mat making, thatching and trade, while in the wet season, there is farming of crops such as maize, sorghum and vegetables. The average farm size in the wetland is 2 ha, while that of dry land is 5 ha and the average household size was 8 persons. People keep domestic animals such as cattle, goats, sheep and chicken which provide them with meat, skin, milk and cash for the education of their children. In the seasonally flooded area, the dry season is characterized by maize and sugarcane farming, livestock herding, thatch and fodder grass harvesting, and fishing along Bwaja stream. In the wet season, flood waters associated with the onset of rainfall season in the highlands inundates the floodplain destroying maize and vegetable crops while sugarcane can tolerate flooding to some extent. The farms become inaccessible and farm activities are curtailed. However, fishing activity was observed within the wetland farms where fishermen set nets to catch species such as *Xenoclarias* sp. (local name - ndhira), *Synodontis afrofischeri* (local name - okoko rateng'), *Clarias gariepinus* (local name - mumi) and *Protopterus aethiopicus* (local name - kamongo).

The Ogenya transect is influenced by the daily changes in lake water levels and based on this study, extends for about 2 km, starting in the last homestead towards Ogenya beach and ending in Ogenya point on the lake edge. This transect is divided into permanently and seasonally saturated zones and the extent of inundation varies with season (Figure 6).

The dominant livelihood activities are papyrus harvesting, firewood collection, water for irrigation, farming, livestock herding and fishing and depend on the seasonal changes in the wetland. In the dry season, farmers expand their farms towards the wetland to benefit from the moist soil. Farm average size here is less than 1 ha and main crops are maize, sugarcane, cassava, sweet potatoes and vegetables, while in the wet areas of the wetland, rice and arrowroots are planted. In addition, papyrus harvesting occurs at the lake edge in both dry and wet seasons, using boats to access the sites in the flooded conditions. In the wet season, it was observed that farm areas are flooded, destroying crops such as vegetables and maize. During this time, fishing becomes important in the lake, in Aguko channel and in pools within the farms. Fish species commonly harvested in this transect include *Barbus cercops* (local name: adel), *Rastrineobola argentea* (local name: omena), *Oreochromis niloticus* (local name: nyamami), *Clarias gariepinus*, *Protopterus aethiopicus* and juveniles of *Lates niloticus*

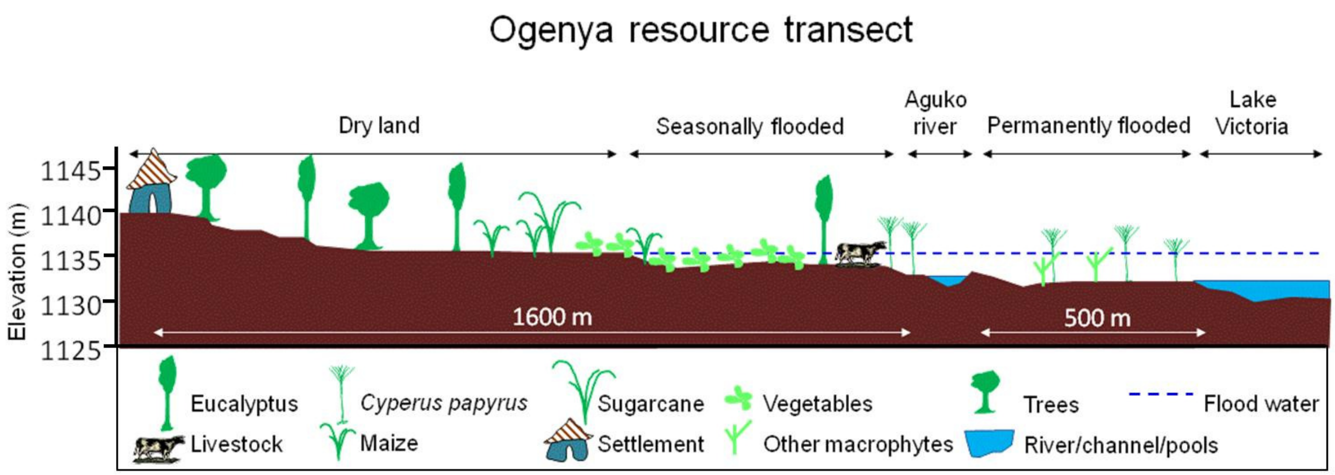


HGMU	Dry land	Seasonally flooded wetland	Permanently flooded wetland
Soil type	Black cotton soil and sandy soil	Black cotton soil	Black cotton soil / clay
Vegetation	Grass, *Markhamia* sp., *Thevedia peruviana*, *Eucaplytus* sp.	*Cyperus latifolia*, shrubs, grass, *Eucalyptus* sp., *Phragmites* sp., *Cyperus papyrus*, *Sesbania* sp.	*Cyperus papyrus*, *Cyperus* sp., *Sesbania* sp. *Ipomoea whightii*, *Azolla* sp., *Pistia stratiotes*, *Phragmites* sp., *Vossia cuspidata*
Crops	Sorghum, maize, beans, cow peas cassava, sweet potatoes	Sugarcane (wet), cowpeas and maize (dry)	-
Avg. farm size (ha)	5	0.1	
Avg. house-hold size (P/HH)	8	-	-
Permanent water source	Borehole	Borehole	Shallow wells, Bwaja river
Domestic animals	Cattle, goats, sheep, chickens, donkeys	Cattle	-
Livelihoods activities	Farming, thatching, mat making, trade	Farming, thatch grass harvesting, thatching, fodder grass harvesting, fishing	Fishing

Figure 5. Resource transect map of Singida from the last homestead to River Bwaja. HGMU-Hydro-geomorphic unit depict different zones from dry land to wetland or open-water. Different characteristics are described for each zone where permanently flooded area may reduce to only the river channel in dry season.

(local name: mbuta).

The Wasare transect (Figure 7) is characterized by a flat floodplain from homesteads near the floodplain and across Nyando river to the edge of the papyrus wetland. Transect stretches approximately 2300 m from the homesteads near the floodplain and across Nyando River to the edge of the papyrus wetland. In the dry season, shrubs and grasses were observed in the floodplain and include the invasive *Xanthium pungens* and *Mimosa pigra* which the local community considers a nuisance to farming and livestock production. While *M. pigra* is utilised as firewood and browsed by goats, *X. pungens* covers the grassland and compromises the grazing land. The farms are divided into small plots of between 400 to 900 m^2 per person and rice is a predominant crop for most part of the year. Activities change in the wet season when the floodplain, papyrus wetland and river are connected and accessibility becomes difficult. In the dry season, livelihoods activities include sand harvesting from the river bed taking advantage of the low discharge in the river; harvesting of papyrus culms and livestock grazing in the wetland; and crop production (mainly vegetables), brick making and local liquor brewing are economic activities that depend on biomass energy from the wetland particularly dead papyrus and phragmites culms and rhizomes. Fishermen burn the wetland to expose aestivating *Protopterus* sp. and to hunt for the only aquatic antelope, commonly known as Sitatunga (*Tragelaphus spekei*) in dense papyrus area. Burning not only clears the senescing plant biomass but also allows regeneration of wetland vegetation for livestock grazing after flood recession. Human activities in the wet season include rice farming and fishing in the floodplain. Fishing becomes important as the floodplain is filled with fish such as *Synodontis afrofischeri* (okoko rateng'), *Synondontis victoriae* (local name: okoko rachar), *Clarias gariepinus* and *Protopterus aethiopicus.* When the flood water recedes, people prepare farms to grow rice, herd livestock on high grounds along the river levees and harvest papyrus.



HGMU	Dry land	Seasonally flooded wetland	Permanently flooded wetland
Soil type	Black cotton soil, clay	Clay	Clay, sand, silt
Vegetation	Grass, scattered trees (*Makhamia* sp., *Eucalyptus* sp., *Thevedia peruviana*	*Cyperus papyrus, Cyperus latifolia, Vossia cuspidata, Pennisetum sp., Sesbania sesban, Phragmites sp., Typha sp.*	*Azolla sp., Nymphea sp., floating Cyperus papyrus, Vossia cuspidata, Eichornia crassipes, Trumpheta sp.*
Crops	Maize, beans, kales, cassava, sorghum, sugarcane, green grams, pumpkin	Maize, beans, kales, sweet potato, cassava, cow peas, tomatoes, sugarcane, banana trees, mango trees	Arrow roots, rice
Avg. farm size (ha)	2.0	1.0	0.12
Avg. house-hold size (P/HH)	10	-	-
Permanent water source	Borehole	Shallow well	Lake, Nyaguko river
Domestic animals	Cattle, goats, poultry	Cattle, sheep, poultry	-
Livelihoods activities	Farming, thatching, mat making	Mat making, papyrus harvesting, farming, fishing, trade	Fishing, papyrus and thatch grass harvesting

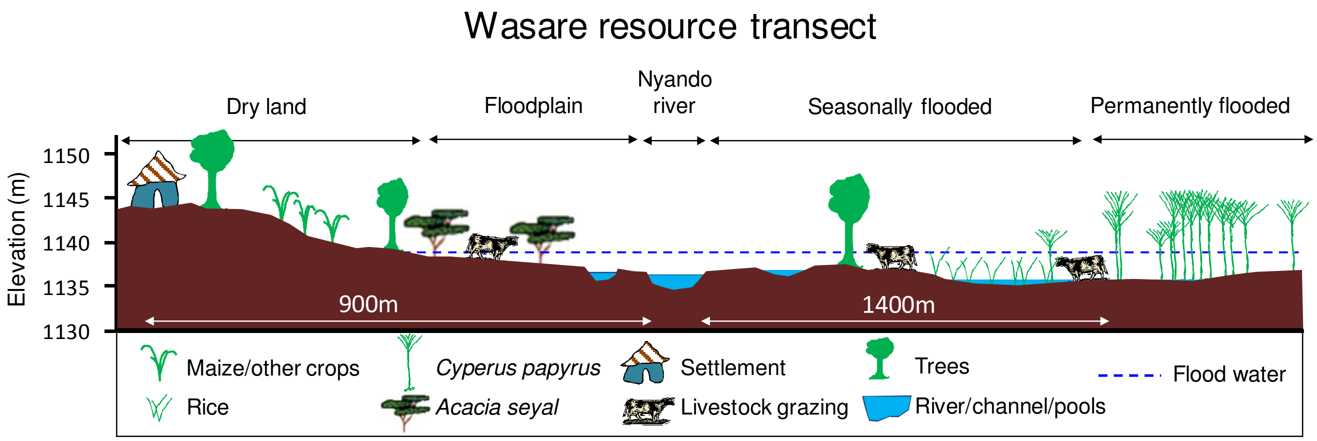
Figure 6. Resource transect of Ogenya from the beginning of the homestead near wetland to Lake Victoria at Ogenya Point. The lake water influences the permanently flooded zone on a daily basis which influences the livelihoods activities.

DISCUSSION

History of change in Nyando wetland

As far as the residents can remember, Nyando wetland existed before 1960 as a narrow stretch of papyrus vegetation along the lake shore and river banks. The floods of 1962-1963 resulted in extension of the wetland area towards croplands and settled areas. According to Khisa et al., in prep.), the wetland area rose from approximately 6000 ha in 1950 to 10,000 ha in 1973 and dropped to 4000 ha in 2008. Nyando wetland has continued to change as a result of natural and human pressures like changes in rainfall patterns and the demand for land for growing crops (BirdLife International, 2004; Owino and Ryan, 2007). According to the residents, changes in the ecosystem became more pronounced in the 1980s when the community intensified farming, livestock herding and papyrus harvesting. In the past, people depended more on fishing as a source of food and income. However, the community lost income from fisheries due to deterioration of water quality and the spread of water hyacinth in the lake (Juma, 1989; GoK, 2000).

Between 1960 and 2010, Nyando wetland has undergone two key changes in hydrological regime. The first change was the Uhuru rains in the period 1961-1964, coinciding with the commissioning of the Owen Falls dam in Uganda, leading to a 2.3 m rise in lake level (Institute of Hydrology, UK, 1984). With the expansion of the lake boundaries the surrounding wetlands, croplands, grazing areas and villages became permanently inundated. Respondents indicated that their ancestral land in the floodplain was lost and several families migrated to higher areas. To date some members of the local community still believe that their farms are submerged in the permanent wetland and the lake. They recall that rainfall in the basin had increased since the 1961 Uhuru rains, and that the frequency of extreme events; droughts and floods



HGMU	Dry land	Floodplain & river channel	Seasonally flooded wetland	Permanently flooded wetland
Soil type	Sandy	Sandy/clay		
Vegetation	*Euphorbia* sp., *Casuarina* sp., sisal, *Eucaplytus* sp.	*Cynodon dactylon*, *Eucaplytus* sp., *Balaites aegyptica*, *Acacia* sp., other weeds	*Cyperus latifolia*, *Datura* sp., *Phragmites* sp., *Cynodon dactylon*, *Mimosa pigra*	*Cyperus papyrus*, *Cyperus* sp., *Ipomoea aquatica*, *Vossia cuspidata*
Crops	Sorghum, maize, groundnuts, green grams, cow peas, cotton, beans	Rice, cow peas, kales	Rice (wet), cowpeas (dry)	-
Avg. farm size (ha)	4	0.2	0.1	-
Avg. house-hold size (P/HH)	13	-	-	-
Permanent water source	Borehole	Borehole, river	Shallow wells, pools, river	-
Domestic animals	Cattle, goats, sheep, poultry, donkeys	Cattle, goats, sheep, donkeys	Cattle, goats, donkeys (dry)	Cattle (dry)
Livelihoods activities	Farming, mat making, trade	Farming, livestock grazing, fishing, sand harvesting, brick making, brewing	Farming, livestock, grazing, firewood collection, bird chasing	Papyrus harvesting, livestock grazing, wild vegetable harvesting

Figure 7. Resource transect of Wasare from homes near Kanyalwal primary school through floodplain and across Nyando River to the wetland with different characteristics and different zones.

have increased and more often they occur in alternation. Residents' recollections of dry and wet years coincide with the published data for the region which shows a shift in the rainfall patterns since 1961/62 (Farmer, 1981). Rainfall was about 8% higher in the 1961-1990 period when compared with the 1930 to 1960 period (Conway, 2002). Annual rainfall totals derived from long-term records of eight stations in the Lake Victoria Basin ranged from 1281 mm in 1949 to 2201 mm in 1961 (Institute of Hydrology, UK, 1984,1985).

The second major change during the last 50 years is the disruption of the regular seasonal flooding pattern of the wetland in the last 10 years, with delays in the onset of rainfall and an increase in duration and frequency of droughts (Ogutu et al., 2007; Awange et al., 2008a). In the early 1960s, hydrology of the wetland was characterized by more or less stable seasonal flooding from Nyando River, which spills into the floodplain over twice per year when the discharge is over 50 $m^3 s^{-1}$ (Muthusi et al., 2005). However, flooding has become both more frequent and erratic, leading to destruction of crops and infrastructure and loss of lives. During this study, we observed a delay in the onset of the long rains with a shift from March to July, and an unusually large flood in December of 2011. Changes in the mean daily flow of rivers discharging into Lake Victoria in the period 1990-2000 has been compared with the period 1950-1960 (Sutcliffe and Parks, 1999) and the results show increase in peak flow by 8, 31 and 38% recorded in Sio, Nzoia and Yala rivers, respectively (Sangale et al., 2005). The change in river flows has been attributed to the decline in vegetation cover in the upper reaches of the rivers by over 50% since 1960s (Melesse et al., 2008).

Apart from river flow, lake level fluctuations cause flooding of the wetland. The areas along the edge of the lake receive daily flooding from waves (local name: "ngeri"), creating a permanent wetland zone in which aquatic plants flourish even when the landward parts of the wetland are dry. Lake Victoria water levels fluctuate seasonally depending on direct precipitation and river flow. Lake water level is controlled mainly by direct precipitation which contributes approximately 85% (Flohn and Burkhardt, 1985; Sutcliffe and Parks, 1999). Between 1896 and 1960, the lake level was stable ranging from 10.2 to 12.0 m at the Jinja gauging station but increased to 13.85-14.46 m in 1961-1964 (Sutcliffe and Parks, 1999; EAC, 2006). Owing to prolonged drought between 1998 and 2005, lake water levels declined by 2.3 m and have not gone back to the 1961-1964 level (EAC, 2006; Swenson and Wahr, 2009). In addition, low lake level was experienced in 2004-2005 which led to loss of wetland area through extensive drawdown and human encroachment (Kiwango and Wolanski, 2008; Obiero et al., 2012). Findings from EAC (2006), Awange et al. (2008b) and Kiwango and Wolanski (2008) show that Lake Victoria water level fluctuation was influenced by over extraction of water at Kiira dam in Uganda. This was an extension project, which was constructed one kilometre downstream from the Owen Falls Dam now called Nalubaale Power Station to supply power to the growing industrial area of Jinja. As a result, the normal water level in the lake decreased as the demand for power increased. However, other factors may have contributed to the dropping of water level which include prolonged drought and demand of water by more than 30 million people living and depending on Lake Victoria.

Population growth influence both hydrology and exploitation indirectly. From a population of 8 million in 1960, Kenya's population is projected to reach 51 million by 2025 (GOK, 2010) which means more land is needed and degradation of the remaining natural forests in the water towers will continue. On the local scale of the wetland, population growth has contributed to a higher need for food production and income generation, and therefore a more intensive exploitation of the wetland. On a wider scale (at the level of the river basin), population growth has led to more intensive land use upstream, leading to deforestation and erosion (affecting both runoff and sediment loss), increases in water abstraction for agriculture and domestic use, and to flood control measures influencing the discharge of Nyando river. Population growth is also related to economic development. When economic growth does not keep pace with population growth, unemployment and poverty are the result. The poverty rate for the Kisumu region in which the Nyando wetland is located (percentage of population earning below US$ 1 per day) was 47.8% (KNBS, 2007). Poverty encourages encroachment and overexploitation of the wetland ecosystem by people with no alternative but to exploit wetland resources (fishing, biomass harvesting and farming) for their survival. The adaptation mechanism of switching between provisioning services (Geheb and Binns, 1997) no longer works as people strive strive to increase their resource exploitation efforts to meet their basic needs. Furthermore, traditional zebu cattle density has steadily increased when compared with dairy cattle which do not need to get to the wetland for herding (Table 5). This has aggravated the problem of degradation in the already stressed ecosystem. Livestock are regarded as savings among the local communities and hence, each individual has the desire to own more cattle as long as there is “free” land (wetland) for grazing.

Status of ecosystem functions and services

Traditionally, the livelihoods of the predominantly Luo community living at the edge of Nyando wetland revolve around provisioning services and depend on three main activities: fishing, farming and livestock herding. The increasing population pressure resulted in increased pressure on the fisheries, overfishing and an increased necessity for farming and other livelihoods activities (Geheb and Binns, 1997). The effect of this increasing pressure has been an increase in the provisioning services. Before 1980, activities of farmers used to be spatially separated in the terrestrial and wetland ecosystems. Depending on the season, livelihoods revolved around fishing in the lake (dry season) and farming or livestock herding in the terrestrial environment (rainy season) (Geheb and Binns, 1997). The changing hydrological regimes led to uncertainty in these provisioning services. Less stable rainfall patterns led to insecurity in dry land agriculture, and stimulated people to make use of the residual moisture in the wetland for crop production.

This study (Table 6) and others (Kipkemboi, 2006; Obiero et al., 2012) show that currently, wetland farming and livestock herding are the most important livelihood activities. Papyrus harvesting is an important provisioning service for earning household income and improving family's wellbeing. The trend of harvesting papyrus increased since the 1990s which coincides with the changes in the hydrological regimes described in the first part of this discussion. The activity becomes the only income earner when both dry and wetland farming have failed as a result of either drought or flooding events. With increasing population pressure, wetland agriculture and papyrus harvesting have become more intensive to the point of becoming commercial in nature. Other vegetation harvesting (*Phragmites* sp., *Vossia cuspidata* and *Cyperus latifolius*) and firewood collection are also important.

Contrary to the maximization of provisioning services, wetland ecosystem functions and cultural services have been declining. Maximization of provisioning services has led to a decline of biodiversity, nutrient and sediment retention and cultural services. While degradation of the ecosystem in terms of species disappearing is perceived by the people, changes in the biogeochemical functions are not immediately visible to them. Individual resource users cannot observe short-term changes in nutrient cycling or soil formation processes. These changes be-

become apparent through changes in water quality or flooding frequency but take place over a relatively long period of time. Yet in the long term, these important factors also affect their livelihoods. An example is Okana wetland in the Nyando floodplain where the community realised that they were poorer after the papyrus wetland had disappeared and consequently embarked on a restoration process (Morrison et al., 2012; Chairman, Okana community wetland group, pers. comm.). There is little data on the impacts of livelihoods activities on the regulating services such as water quality and quantity regulation and on supporting services.

The extent of impact on wetland ecosystem functions depends on the types of livelihood activities and the nature of the disruption. Some activities, such as construction of dikes, digging of channels for irrigation and uprooting of papyrus rhizomes cause structural and irreversible change. Other activities, such as limited burning or vegetation harvesting, is less detrimental for the biogeochemical and hydrological functions because they leave water flow and soil structure intact, and allows the fast-growing papyrus vegetation to recover during the next wet season. There is some evidence that papyrus harvesting may even enhance the nutrient retention function by exporting nutrients from the wetland and increasing the productivity of the plants (van Dam et al., 2007). However, it is likely that most livelihoods activities have a strong impact on the ecological functions of the wetland. Papyrus wetlands serve as a habitat and refuge for fish, birds and wildlife and disturbance, even if non-structural or temporary, can impact negatively on this function. Decrease in wetland area reduces habitat availability for other organisms and also products collected directly from the wetland such as wild vegetables, herbs, fuel and papyrus biomass. These effects have been recorded in other Lake Victoria wetlands like Yala (Thenya, 2006), Sondu Miriu (Gichuki et al., 2001) and Southern Ugandan wetlands (Maclean et al., 2006).

Hydrological and livelihoods gradients

The direct (hydrology and exploitation pressure) and indirect (population growth) drivers of change in Nyando wetland are strongly linked. Exploitation for livelihoods is strongly influenced by hydrological change, both in the long-term history of the wetland and on a seasonal basis. For example, Obiero et al. (2012) suggested that after lake recession in 2005, the contribution of farming to household income increased from 10 to 95%. Farming is done in the seasonal wetland after flood recession, but with more frequent and erratic flooding patterns, the risk of crop loss has been increasing in recent years. In the dry season, the intensity of livelihood activities increases through expansion of farms, burning of vegetation and trampling by cattle in areas with dense papyrus vegetation as access is possible. However, in wet season, livelihoods activities change mainly to fishing and papyrus harvesting. This has been observed in other papyrus wetlands like Naivasha (Harper and Mavuti, 2004) and Yala swamp (Thenya, 2006). Generally, flooding restricts exploitation, while flood recession makes the wetland accessible for livelihoods activities.

The three transects exemplify this strong link between hydrology and livelihoods in Nyando wetland. The three transects chosen for this study represented different combinations of hydrological regimes and livelihoods. Transects were divided into zones related to hydrology (permanent or seasonal inundation) and livelihood activities. The intensity of livelihoods activities depends on hydrology. Understanding the links between hydrology and exploitation pressures in a wetland influenced by wetting and drying is crucial for deriving wise use of wetland resources and wetland management plans. More research would be needed to elucidate the hydrology of the wetland and the impact of human activities upstream, such as water abstraction for irrigation and flood protection schemes, on sediment and nutrient retention. This is important as the growing pressures may interfere with the ecological functions of both the wetland and the lake and reduce services they provide to the local communities.

Conclusions

1. The main direct drivers of change in Nyando wetland were hydrology and livelihoods activities. Irregular rainfall patterns affect the seasonal flooding of the wetland influencing river flows and lake water level fluctuations that are associated with provisioning services. The most important livelihoods activities as perceived by local people were farming, livestock herding and papyrus harvesting. The main indirect driver of change was population growth which led to increased need for exploitation of the wetland.
2. Provisioning services (farming in wetland, herding of livestock and papyrus harvesting) have expanded in Nyando wetland at the expense of the wetland ecosystem (birds, fish, vegetation and soil). However, more research is needed to assess the impact of ecosystem degradation on the regulating and supporting ecosystem services.
3. Hydrology and livelihoods activities are strongly interlinked because flooding prevents people from accessing the wetland. Resource transects identified represent different combinations of hydrological conditions (affected by lake or river flooding or a combination of both) and associated livelihoods activities.

ACKNOWLEGEMENTS

This work was conducted in collaboration with the Victoria Institute for Environment and Development (VIRED International), Kenya. This project was funded by DGIS through UNESCO-IHE under the project "The Ecology of

Livelihoods in East African Papyrus Wetlands" (ECOLIVE). We are thankful to the community members from Singida, Ogenya and Wasare for their contribution. We cannot forget those who took us to the field and helped cross the flooded rivers in their boats. The authors are indebted to Joel Onyango who assisted in the collection of data and bridging the language barrier with the community; and to Serena Nasongo and Patrick Khisa for their collaboration in the field work.

REFERENCES

Asia Forest Network (2002). Participatory Rural Appraisal for Community Forest Management: Tools and Techniques. Asia Forest Network, January 2002. Santa Barbara, California, USA.

Awange JL, Ogallo L, Bae K, Were P, Omondi P, Omute P, Omullo M (2008a) Falling Lake Victoria water levels: is climate a contributing factor? Clim. Change 89: 281-297.

Awange JL, Sharifi MA, Ogonda G, Wickert J, Grafarend EW, Mulo MA (2008b) The falling Lake Victoria water level: GRACE TRIMM and CHAMP satellite analysis of the lake basin. Water Resour. Manage. 22: 775-796.

Bird Life International (2004). Threatened Birds of the World. Bird Life International. Cambridge, U.K.

Boar RR, Harper D, Adams CS (1999) Biomass allocation in *Cyperus papyrus* in a tropical wetland, Lake Naivasha, Kenya. Biotropica 31, 411-421.

Boar RR (2006). Responses of a fringing Cyperus papyrus L. swamp to changes in water level. *Aqua. Bot.* 84, 85-92.

CBS (1999). Population and housing census: counting our people for development Volume I. Central Bureau of Statistics. Ministry of Finance and Planning, Republic of Kenya. January, 2001.

Conway D (2002). Extreme rainfall events and lake level changes in East Africa: recent events and historical precedents. In: The east African Great Lakes: Limnology, Paleolimnology ad Biodiversity Advances in Global Change Research (EO Odada and DO Olago (Eds), Vol. 12, 63-92. Kluwer Dordrecht, The Netherlands.

de Groot RS (1992). Functions of Nature: Evaluation of Nature in Environmental Planning, Management and Decision-making. Wolters Noordhoff BV, Groningen, The Netherlands.

EAC (2006). Special Report on the Declining of water Levels in Lake Victoria. In: K Lubovich (2009). Co-operation and Competition: Managing Transboundary Water Resources in the Lake Victoria Region. East African Community Working Paper No. 5. USAID and FESS.

Farmer G (1981). Regionalisation and study of an alleged change in the rainfall climatology of East Africa. PhD Thesis, University of Sheffield, UK.

Finlayson CM (2012). Forty years of wetland conservation and wise use. Aqu. Cons: Mar. Freshwat. Ecosy. 22:139-143.

Flohn H, Burkhardt T (1985). Nile Runoff of Aswan and Lake Victoria: A case of a discontinuous climate time series Zeitschrift fur Gletscherkunde und Glazialgeologie 21, 125-130.

Geheb K, Binns T (1997). Fishing Farmers or Farming Fishermen? The quest for household income and nutritional security on the Kenyan shores of Lake Victoria. Afri. Aff. 96: 73-93.

Gichuki J, Guebas FD, Mugo J, Rabuor CO, 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. Hydrobiol. 458: 99-106

Gichuki JW, Triest L and Dehairs F (2005). The fate of organic matter in a papyrus (Cyperus papyrus L.) dominated tropical wetland ecosystem in nyanza Gulf (Lake Victoria, Kenya) inferred from ^{13}C and ^{15}N analysis. Isot. Environ. Health Stud. Vol. 41, No. 4. December, 2005, 379-390.

GoK (2000). Kisumu District Development Plan. Government of Kenya. Government Printer, Nairobi, Kenya.

GOK (2010). Population and Housing Census Report 2009. Ministry of State for Planning, National Development and Vision 2030, Government of Kenya Nairobi, Kenya.

Harper DM, Mavuti KM (2004). Lake Naivasha, Kenya: Ecohydrology to guide the management of a tropical protected area. Ecohydrol. and Hydrobiol. 4: 287-305.

Institute of Hydrology (1984). A review of Lake Victoria and the Victoria Nile. Report to Sir Alexander Gibb and Partners. Institute of Hydrology, Wallingford, UK.

Institute of Hydrology (1985). Further review of the hydrology of Lake Victoria. Report to the Overseas Development Administration. Institute of Hydrology, Wellington, UK.

ISRIC (1997). "Impact of soil erosion on maize production in Kenya". International Reference and Information Centre, Wageningen, The Netherlands.

Jackson W, Ingles A (1998) Participatory Techniques for Community Forestry: A field Manual; UK, IUCN Publications Services Unit. Cambridge, UK.

Jaetzold R, Schmidt H (1982). Farm Management Handbook of Kenya: Natural Conditions and Farm Management Information. Ministry of Agriculture Vol. II/A. Kisumu District, West Kenya.

Juma C (1989). Public policy and the Yala Swamp. Resources 1:21-22.

Karicho BM (2010). Regional groundwater flow modelling in the Kano plains, Kenya. MSc. Thesis. UNESCO-IHE. 104 pp.

Kansiime F, Kateyo E, Oryem-Origa H, Mucunguzi P (2007). Nutrient status and retention in pristine and disturbed wetlands in Uganda: management implications. Wetlands Ecology and Management 15: 453-467.

Kelderman P, Kansiime F, Tola MA, and van Dam A (2007). The role of sediments for phosphorus retention in the Kirinya wetland (Uganda). Wetlands Ecol. Manage. 15: 481-488.

KNBS (2009) Kenya Population and Housing Census: Kenya National Bureau of Statistics Vol. 1. Government Printer Nairobi. www.knbs.or.ke. Accessed 11 October 2012.

KNBS (2007). The Kenya Integrated Household Budget Survey 2005/06. Database. Kenya National Bureau of Statistics. , Government Printer, Nairobi.

Khisa PS, Uhlenbrook S, van Dam AA, Wenninger J, van Griensven A, Abira M (in prep.). Eco-hydrological characterization of the Nyando wetland, Lake Victoria, Kenya.

Kibwage JK, Onyango PO, Bakamwesiga H (2008). Local institutions for sustaining wetland resources and community livelihoods in the Lake Victoria basin. Afr. J. Environ. Sci. Technol. 2(5): 97-106.

Kipkemboi J (2006). Fingerponds: Seasonal Integrated Aquaculture in East African Freshwater Wetlands; exploring their potential for wise use strategies. Ph.D Dissertation, UNESCO-IHE Institute for Water Education, Delft, The Netherlands, pp. 73-94.

Kipkemboi J, van Dam AA, Denny P (2006). Biophysical suitability of smallholder integrated aquaculture-agriculture systems (Fingerponds) in East Africa's Lake Victoria freshwater wetlands. Int. J. Ecol. Environ. Sci. 32 (1): 75-83.

Kipkemboi J, van Dam AA, Ikiara MM, Denny P (2007). Integration of smallholder wetland aquaculture-agriculture systems (Fingerponds) into riparian farming systems at the shores of L.Victoria, Kenya: socio-economic and livelihoods. Geogr. J. 173: 257-272.

Kiwango YA, Wolanski E (2008) Papyrus wetlands, nutrients balance, fisheries collapse, food security, and Lake Victoria level decline in 2000-2006. Wetlands Ecol. Manage. (2008) 16:89-96.

Lightfoot C, Gupta MV, Ahmed M (1992). Low external input sustainable aquaculture for Bangladesh -An operational framework. NAGA, the ICLARM Quarterly pp. 9-12.

Loiselle SA, Azza N, Cozar A, Bracchini L, Tognazzi A, Battilo A, Rossi C (2008). Variability in factors causing light attenuation in Lake Victoria. Freshwat. Biol. 53: 535-545.

Maclean IMD, Hassall M, Boar RR, Lake IR (2006). Effects of disturbance and habitat loss on papyrus-dwelling passerines. Biol. Conserv. 131(3): 349-358.

Maltby E (2009). Functional assessment of wetlands: Towards Evaluation of Ecosystem Services. Woodland Publishing Limited (Ed.). CRC Press, New York. pp. 13-15.

MEA (2005). Ecosystems and Human Wellbeing: Wetlands and Water

Synthesis. Millennium Ecosystem Assessment, World Resources Institute, Washington, DC.
Melesse A, McClain M, Abira M, Mutayoba W, Wang XM (2008). Modelling the Impact of land-cover and rainfall regime change scenarios of the flow of Mara River, Kenya ASCE-EWRI. World Environ. Wat. Resour. Congr. "ftp.globalwaters.net/mara.globalwaters.net/EFA/Database/Consultancy/Reports/Melesse et al 2007.pdf Accessed 26th March 2013.
Mitsch WJ, Gosselink JG (2007). Wetlands. 4th Edition. John Wiley & Sons, Inc., New Jersey.
Mnaya B, Asaeda T, Kiwango Y, Ayubu E (2007). Primary production in papyrus (Cyperus papyrus L.) of Rubondo Island, Lake Victoria, Tanzania. Wetlands Ecol. Manage. 15: 269-275.
Morrison EHJ, Odhiambo-K'Oyooh CUK, Harper DM (2012). Managing the natural capital of papyrus within riparian zones of Lake Victoria, Kenya. Hydrobiol. 692: 5-17.
Muthuri FM, Jones MB, Imbamba SK (1989). Primary productivity of papyrus (Cyperus papyrus) in a tropical swamp: Lake Naivasha, Kenya. Biomass 18, 1-14.
Muthusi FM, Gathenya M, Gadain H, Lenga FK (2005). Application of Usgs stream flow model to the Nyando Basin, Western Kenya. Europ. J. Sci. Res. 12: 9-19
Muwanga A, Barifaijo E (2006). Impact of industrial activities on heavy metal loading and their physico-chemical effects on wetlands of Lake Victoria Basin (Uganda). Afri. J. Sci Technol. 7(1): 51-63.
Mwakubo SM, Obare GA (2009). Vulnerability, livelihood assets and institutional dynamics in the management of wetlands in Lake Victoria watershed basin. Wetlands Ecol. Manage. 17(6): 613-626.
Mwaura FB, Widdowson D (1992). Nitrogenase activity in the papyrus swamps of Lake Naivasha, Kenya. Hydrobiologia 232: 23-30.
Nasongo S, Zaal F, Okeyo-Owour JB (in prep) Historical events and land use changes and its impact on biodiversity and livelihoods in the Nyando papyrus wetland, Kenya.
Obiero KO, Raburu PO, Okeyo-Owuor JB, Raburu EA (2012) Community perceptions on the impact of the recession of Lake Victoria Waters on Nyando Wetlands. Sci Res Essays Vol. 7(16), pp. 1647-1661. Academic Journals.
Odada EO, Olago DO, Ochola W (2006) Environment for Development: An Ecosystems Assessment of Lake Victoria Basin, United Nations Environment Program (Eds) (UNEP)/ Pan African START Secretariat (PASS), Nairobi, Kenya.
Ogutu JO, Piepho H-P, Dublin HT, Bhola N, Reid RS (2007) El Niño-Southern Oscillation, rainfall, temperature and normalized difference vegetation index flunctuations in the Mara-Serengeti Ecosystem. Afric. J. Ecol. 46: 132-143.
Ongeri DMK, Lalah JO, Wandiga SO, Schramm KW, Michalke EB (2009) Levels of toxic metals in multisectoral samples from Winam Gulf of Lake Victoria. Bull Environ. Contam. Toxicol. 82: 64-69.
Osumba JJL, Okeyo-Owuor JB, Raburu PO (2010). Effect of harvesting on temporal papyrus (*Cyperus papyrus*) biomass regeneration potential among swamps in Winam Gulf wetlands of lake Victoria Basin, Kenya. *Wetlands* Ecol. Manage. 18: 333-341.
Oyoo-Okoth E, Admiraal W, Osano O, Ngure V, Kraak MHS, Omutange ES (2011). Monitoring exposure to heavy metals among children in Lake Victoria, Kenya: environmental and fish matrix. Ecotoxicol. Environ. Saf. 73: 1797-1803.
Owino AO, Ryan PG (2007). Recent papyrus swamp habitat loss and conservation implications in Western Kenya. Wetlands Ecol. Manage. 15, 1-12.
Rongoei PJK, Kipkemboi J, Kariuki ST, van Dam AA Effects of water level and livelihood activities on plant species composition and diversity in Nyando floodplain wetland, Kenya. In Review.
Sangale F, Okungu J and Opango P (2005). Variation of flow of water from Rivers Nzoia, Yala, and Sio into Lake Victoria. In Mallya GA, Katariga FF, Kang'oha G, Mbwana SB, Katunzi EF, Wambede JT, Azza N, Wakwabi E, Njoka SW, Kusewa M and Busulwa H (eds) Knowledge and Experiences gained from Managing the Lake Victoria Ecosystem. Regional secretariat, Lake Victoria Environmental Management Project (LVEMP): Dar es Salaam: 691-702.
Saunders MJ, Jones MB, Kansiime F (2007) Carbon and water cycles in tropical papyrus wetlands. Wetlands Ecol. Manage. 15: 489-498.
Swallow MB, Sang JK, Nyabenge M, Bundotich DK, Duraiappah AK and Yatich TB (2009). Tradeoffs, synergies and traps among ecosystem services in the Lake Victoria basin of East Africa. Environ. Sci. Policy 12, 504-519.
Swenson S and Wahr J (2009). Monitoring the water balance of Lake Victoria, East Africa, from space. J. Hydrol. 370(2009) 163-176.
Sutcliffe JV and Parks YP (1999). The Hydrology of the Nile. IAHS Special Publication No. 5, 1999: Wallingford, UK.
TEEB (2010). The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB. United Nations Environment Program, Nairobi. Available at: http://www.teebweb.org.
Terer T, Triest L, Muthama MA (2012) Effects of harvesting Cyperus papyrus in undisturbed wetland, Lake Naivasha, Kenya. Hydrobiol. 680(1): 135-148.
Thenya T (2006). Analysis of macrophyte biomass productivity, utilization and its impacts on various eco-types of Yala Swamp, Lake Victoria Basin, Kenya. In: P.L.G. VLEK, M. DENICH, C. MARTIUS and C. RODGERS (Eds). Ecol and Develop Series no. 48, 2006.
Van Dam AA, Dardona A, Kelderman P, Kansiime F (2007). A simulation model for nitrogen retention in a papyrus wetland near Lake Victoria, Uganda (EA). Wetlands Ecol. Manage. 15: 469-480
van Dam A, Kipkemboi J, Zaal F, Okeyo-Owuor J (2011). The ecology of livelihoods in East African papyrus wetlands (ECOLIVE). Rev. Environ. Sci. Biotechnol. 10(4): 291-300. doi: 10.1007/s11157-011-9255-6.
Wetlands International (2009). Planting trees to eat fish: Field experiences in wetlands and poverty reduction. Wetlands International, Wageningen, The Netherlands.
World Agro-forestry Centre (2006). Improved Land Management in the Lake Victoria Basin: Final Report of the TransVic Project. World Agro-forestry Centre, Occasion Paper No. 7. World Agroforestry Centre, Nairobi, Kenya.