# The wetlands of Lake Victoria, new approaches for understanding their regional and global importance

S. Loiselle[1], L. Bracchini[1], F. Kansiime[2], M. Ikiara[3], C. Perrings[4] & C. Rossi[1]

[1]*University of Siena, Department of Chemical and Biosystem Sciences, Siena, Italy*

[2]*Makerere University, Institute of Environment & Natural Resources, Kampala, Uganda*

[3]*Kenya Institute For Public Policy Research And Analysis, Nairobi, Kenya*

[4]*Environmental Department, York University, Great Britain*

## Abstract

Lake Victoria is the world's largest tropical lake and the second largest lake on the planet. It has a surface area of 68,800 km$^2$ and a catch of 284,000 km$^2$. The Lake Victoria shoreline of 3500 km is managed by three nations (Tanzania 49%, Uganda 45% and Kenya 6%). Wetlands border much of the Lake, in particular in the semiclosed bays that characterise much of the shoreline. These wetlands provide fundamental services for the Lake ecosystem as well as the regional population. The East African countries have one of the fastest growing populations in the world, between 3 and 4% per annum. This has led to an increasing stress on the resource quality and functioning. Proper wetland functioning and ecotone maintenance has a direct role in the quality of life of the regions populations as fish remains the least expensive and most common (70%) source of dietary protein and most drinking water is often drawn directly from the lake with little or no treatment. Additionally, the wetland provides a number of important secondary income services both directly (tourism, transport, vegetation harvesting) and indirect (climate control, ground water replenishing).

During the last 50 years, Lake Victoria has undergone significant changes both in trophic structure as well as in water quality. The causes of the changes can be linked to five major factors, the growth of the local populations, the changing land use in the lake catch, introduction of exotic species, the development of industrial activities and urban centres on the lake borders, and climate change. The results have been a dramatic reduction of the species diversity and a strong reduction of the Lake water quality. The combined reduction of the ecosystem quality and trophic complexity has led to a potentially catastrophic simplification of the energy transfer within the ecosystem that put the functioning of the ecosystem at risk. One important example is the growing eutrophication, caused by a combination of an increased nutrient load, the reduction in the presence the planktivorous fish community, climate change and a reduction in the nutrient retention capacity of the Lake's wetland borders.

To understand the functional and economic role of the Lake Victoria wetland areas, an EU funded multidisciplinary research project, the ECOTOOLS project, was initiated in 2002. The project combines historic data with *in situ* analysis of the key ecosystem functions. Research focuses on key wetland functions, in particular, nutrient retention and wastewater treatment, agriculture and vegetation harvesting, habitat and refuge for the Lake Victoria fisheries and carbon sequestration and release into the lake waters. The results of the in data gathering and modelling will be integrated into a series of instruments for the management and monitoring of the wetlands and their role in maintaining the ecological balance within the Lake Victoria ecosystem.

## 1 Introduction

East Africa has several of the worlds most important freshwater ecosystems, including Lakes Victoria (the second largest lake in the world), Lake Tanganyika (the second deepest lake in the world) and Lake Malawi. Together, these three lakes cover an area of nearly 130,000 square kilometres and are (or were) characterised by one of the richest ichthyofauna in the world [1]. Lake Victoria alone has (or had) over 300 haplochromine ciclid species, over 90% of them endemic [2, 3, 4a, 4b] . The role of wetlands in the maintenance and conservation of these aquatic resources has is important but not completely understood. New analysis and management approaches are needed that link land management, wetland conservation and water resources to favour their integrated and sustainable management.

East Africa has one of the fastest growing populations in the world, between 3 and 4% per annum [1, 5]. Such growth with the accompanying increased requirements on both the aquatic and terrestrial resources, has led to a reduction in the quality of both, in particularly the former which is intimately connected to the well being of the local population. Fish remains the least expensive and most common (70%) source of dietary protein in the region [6]. Drinking water is often drawn directly from lakes and rivers with little or no treatment. Lakes provide a number of important secondary income services both directly (tourism,

Transactions on Ecology and the Environment vol 63, © 2003 WIT Press, www.witpress.com, ISSN 1743-3541



transport, vegetation harvesting) and indirect (climate control, ground water replenishing).

During the last 50 years, many of the East African Great Lakes and Lake Victoria in particular have undergone major changes, both in trophic structure as well as in water quality. Phytoplankton abundance and composition have changed [7], demonstrating an increasing eutrophication [8], which has led to anoxia and a loss of fish habitat [9]. The combined reduction of the water quality and trophic complexity has led to a potentially catastrophic simplification of the energy transfer within the ecosystem. The cascading effect on the trophic chain is yet to be clearly identified and the driving forces that have led to the present state have yet to be completely addressed. These include the increasing nutrient load, further evolution in the aquatic trophic web, climate change and a reduction in the functional capacity of the Lake's wetland borders [1, 10, 11, 12].

In the present condition of the East African Great Lake ecosystems, where the pressure of a growing population of 86 million persons [13] will most likely increase, the role of the extensive wetlands on the lake border has a vital importance in the protection and eventual restoration of the lake ecosystem.

To contribute to this important area, a European Union (EU) sponsored international research project has been initiated with the objective of consolidating and reinforcing the understanding of the role of wetlands in maintaining the resource quality. The project, entitled ECOTOOLS, focuses on the lake wetland ecotones and their functional values with respect to the Lake and the region, in particular in the face of changing land uses in the larger Lake Victoria basin. Seven European and east African research institutions are working together in the four year project focusing on several major Lake Victoria wetland systems. The focus on wetlands is directed in several directions, the nutrient retention capacity of different wetland conditions, the regulation of carbon fluxes by wetland vegetation and decomposition and the impact on ecotone habitat for the Lake fish populations. The ECOTOOLS partners are the Institute of Environment & Natural Resources at Makerere University, Uganda, the International Institute for Infrastructural, Hydraulic and Environmental Engineering, Netherlands, the Department of Chemical and Biosystem Sciences at the University of Siena, Italy (project coordinator), the Department of Botany, Trinity College, Ireland, the Department of the Environment at the University of York (UK), the Kenya Institute for Public Policy Research and Analysis, the Ugandan Ministry of Water Lands and Environment and the Biology Department University RomaTre, Italy.

## 2 Methods

The wetland areas selected for focused study are four wetland ecosystems under varying pressure on the Ugandan and Kenyan borders of Lake Victoria; the Kirinya wetland (near Jinja, Uganda, the Nakivubo wetland (near Kampala, Uganda), Lake Nabugabo (near Masaka, Uganda) and the Yala swamp (in the Nyanza province of Kenya). These wetlands are located in figure 1.

The Yala swamp is Kenya's largest freshwater wetland (17,500 hectares) with a catchment of 160,000 hectares, that includes population centres and agricultural lands. Yala swamp has been under continuous pressure since the 1950s in government plans to convert the wetland to agricultural land. To date, 2300 ha have been converted by re-directing the Yala river directly to Lake Victoria. Lake Nabugabo is a small satellite lake (24 $km^2$, mean depth 4.5 m) surrounded by an extensive wetland (the Lwamunda Swamp) and was formerly a bay on the western shore of Lake Victoria [2, 14, 15]. The Kirinya wetlands are papyrus swamps which receive partially treated wastewater from Jinja city. The Nakivubo wetland received partially treated and untreated wastewater from the Kampala area. The former papyrus and miscanthidium wetland has been largely converted into subsistence farming (yams), damaging the wastewater treatment capacity and increasing possible contamination of Kampala water supply.

All four wetlands are multiuse wetlands which provide important services to the local economy and population. The main ecosystem services; are nutrient retention and wastewater treatment, agriculture and vegetation harvesting, habitat and refuge for the Lake Victoria fisheries and carbon sequestration and release into the lake waters. In the present study, each of these functions will be analysed to determine its value in relation to wetland maintenance.

### 2.1 The study of wetland nutrient retention and wastewater treatment

Wetlands on the Lake provide a fundamental nutrient and pathogen removal when receiving wastewater or runoff from population centres, industry and agricultural areas [16]. The growing threat of eutrophication to Lake Victoria with the coincident increasing anoxia of the Lakes bottom water and the prolonged stratification of the lake are producing conditions that threaten the vital fishing activities. The Lake has reached this state due to its extended flushing times, heavily populated catchment, the reduced retention capability of wetland areas and climate change. While much of the nutrient fluxes are related to atmospheric input from combustion products (agricultural and household, [1]), a significant nutrient load arrives from the Victoria catchment including the partially treated or untreated wastewater from nearby population centres.

Localised nutrient enrichment in Lake Victoria has been linked to an increase in blue green algae blooms and a general increase in phytoplankton productivity [7]. The increase in nutrients concentrations and their resultant impact on the chemical and physical conditions of the Lake are particularly evident in the shallow bays that receive much of the river influent to the Lake. In a study by Lung'ayia et al. [11], the long term trends in the Nyanza Gulf clearly demonstrate an increase in the nutrient concentrations by an order of magnitude in less than ten years. Throughout the Lake, higher chlorophyll concentrations [7] have been reported and with this increased biomass, a reduction in soluble reactive silicon due to diatom growth, reduced transparency, higher turbidity and higher dissolved oxygen concentrations in surface layers with lower concentrations in deep water. These conditions are further compounded by the persistence of the stratification of the Lake for most of the year. This thermal

Transactions on Ecology and the Environment vol 63, © 2003 WIT Press, www.witpress.com, ISSN 1743-3541



stability has caused a significant reduction of the available oxygenated water layer and an increase in overall denitrification rates.

Natural and manmade wetlands have been known for centuries to remove dissolved nutrients from the water column and to incorporate them in vegetation biomass. The presence of extensive wetland areas at the influents of Lake Victoria and along much of the shore of the lake provide a fundamental buffer from high nutrient river waters. However, under increased pressure for arable land and housing, many of these fundamental ecosystems are being damaged or destroyed (eg. Nakivubo, or Yala [16]). As much of these wetlands are dominated by several main vegetation community types, in particular Cyperus papyrus and Miscanthidium [17, 18], the nutrient retention capacity of these ecosystems and their overall extension is important information to understand their role as buffers for the Lake water quality. Recent work by the LVEMP has shown that the floating wetland areas directly reduce nutrient concentrations in the Lake waters, during periods of high water exchange.

The ECOTOOLS project will examine the nutrient retention capabilities of wetland vegetation by using field and mesocosm measurements. Horizontal and longitudinal transects have been cut into the Kirinya wetland and the geographic distribution of nutrients across the wetland will be examined to determine the retention capability of this wetland which receives partially treated wastewater from Jinja city. Mesocosm experiments will be conducted to examine the retention characteristics of other wetland plants, including subsistence agricultural species that are being planted on the wetland edges.

### 2.2 The study of habitat and refuge functions for the Lake Victoria fisheries

The introduction of non-native species into Lake Victoria, in coincidence with important changes in the limnological characteristics of the lake has caused a severe loss of species diversity over then last thirty years. The originally richly diverse fishery of more than 300 species has been reduced to mainly three, the introduced Nile perch (Lates niloticus), the native pelagic minnow (Rastrineobola argentea) and the introduced Nile tilapia (Orechromis niloticus). The first two of these made up more than 90% of the total catch in 1996. Wetlands provide structural complexity [19] and less hospitable conditions (lower oxygen, lower pH) which represent an important reproduction area for many species, as well as a protective area from predation by adult Nile perch. These conditions may act as a biological filter limiting both colonization and survival of the Nile perch. Studies in Nabugabo [14,15] demonstrate that wetlands help maintain fish faunal structure and diversity. Research in the Napoleon Gulf [17] demonstrated that a higher species density and biomass, in particular Nile Tilapia, was present in the wetlands compared to the open water. Marginal wetlands are also fundamental for the maintenance of the shallow water fisheries that are the most important area for the local population. Long term studies [4a, 4b] have demonstrated that the shallow area of the lake contains a higher species diversity and production potential than the offshore areas. It was

estimated in 1972 that wetland and floodplain related fish catches contribute about 40% of the total freshwater catch on the African continent.

To examine the relation between the wetland and the fish community, ECOTOOLS researchers are collaborating with local institutes in examining past ecological and fisheries together with limited ecological analysis. Historical data sets will be compared to the changing conditions of the Lake water and wetland areas. The relationship between the wetland quality and the refuge and breeding value of the wetland is being examined through the use of trophic based models.

### 2.3 Carbon sequestration and release into the lake waters

Wetlands play a fundamental role in the carbon balance of aquatic ecosystems. As primary producers, wetland vegetation removes carbon from the atmosphere and from the water substrate. On the other hand, as vegetation degrades, carbon is returned to the air and to the aquatic ecosystem. The carbon balance will depend on the environmental conditions, the hydrological conditions and the wetland vegetation characteristics.

In aquatic ecosystems, dissolved and particulate organic matter can significantly impact many ecosystem functioning. As degradation products of living organisms, these substances are of basic importance in the aquatic carbon cycle. The wide range of molecular masses and chemical structures give these substances a number of important roles in the ecosystem functioning, as an electron donor in metal complexation, as a removal mechanism for xenobiotics, as an important source in the microbial trophic chain and as an absorption element for short wave radiation. In lake ecosystems with large wetland border areas, such as Lake Victoria, the extension and characteristics of the floating wetlands can contribute significantly to the concentrations of dissolved and particulate organic matter.

The relationship between the wetland produced organic matter, in particular dissolved organic matter and the radiation environment of the Lake will be studied by examining semiclosed bays on the eastern and northern shores of the Lake. Measurements of the dissolved organic matter concentrations, UV and PAR attenuation as well as chlorophyll concentrations and water optical characteristics will be made at varying distances from the wetland border to determine the impact of the littoral wetlands on the Lake radiation environment. Satellite data will be used to extend the transect data to larger areas of the lake and compare wetland extension and vegetation with estimated concentrations of dissolved organic matter.

The exchange of carbon and water between a wetland and the atmosphere has important implications on the local and regional climate, and is an important part of the carbon cycle. Eddy covariance measurements will be made to measure the fluxes of carbon dioxide, water vapour and energy between the wetlands and the atmosphere. One measurement site will be installed in each study wetland, with attention giving to vegetation composition and wetland characteristics. Site data will be combined to extend the measurements of carbon and water fluxes to other

wetlands through satellite based analysis. This data will be used to model the impact of wetland loss on regional and global balances.

### 2.4 Agriculture and vegetation harvesting

Wetlands in Lake Victoria supply several plant products that are used by the local population and shipped to the regional markets. These include poles for construction, materials for thatching, basket, mat and furniture making materials, fuelwood and medicinal herbs. In addition, wetland areas are the sites of small agricultural activities (root crops, sugar cane) that contribute to the local communities diet and income. Wetland borders are often used for grazing area areas during the dry season. The value of these wetland services and products is not clear, but the traditional use of the wetland vegetation has social-cultural and economic importance for the Lake communities that vary from area to area. Papyrus harvesting from Yala swamp has been long practised and has a market in the larger population centres in Kenya. Nakivubo swamp has been significantly modified by subsistence level farming of root crops, to the point where other wetland functions may be compromised [16,20]. Sugar cane is grown in the Kirinya wetland, while in a limited manner. The maintenance of the wetland as a functioning ecosystem and the proper balance between harvesting and conservation are important elements to wetland management in Lake Victoria.

Wetland vegetation harvesting and agricultural activity will be examined in the Yala wetland, using both historical data as well as field surveys. Wetland water quality data will also be measured and compared to past data. This data will be used to examine the value of the wetland vegetation (papyrus) harvesting with respect to the impact on other wetland functions. Tourism and its relation to wetland functioning is being examined in the Nabugabo area, in relation to the growing importance of this activity in the region. Socio-economic models will be constructed examining the impact of catch activities and wetland management on harvesting and tourism values in these two wetland systems.

### 2.5 Ecological modelling

Models of wetland functioning and impact on the Lake resource quality will be elaborated through the collaboration between project partners. A nutrient retention model will examine the relationship between wetland area, nutrient flow and wetland vegetation composition. A wetland growth model will identify the relation between growth in the density and extent of wetlands as a function of nutrient inflows. The humic matter discharge of wetlands will be examined in function of wetland size and vegetation. A phytoplankton growth model will examine the impact of nutrients and a changing light environment on the growth of phytoplankton in the open lake. The impact on the lake trophic web will be examined by using modified trophic models that consider changes in lake water quality. The socio-economic, ecological and chemical models of land-water interactions will be applied to the Yala and Nabugabo catchments, to produce a

simple and generally applicable model of land-water interactions at the level of the lake basin. The integrated model is expected to have the general structure shown in Figure 1.

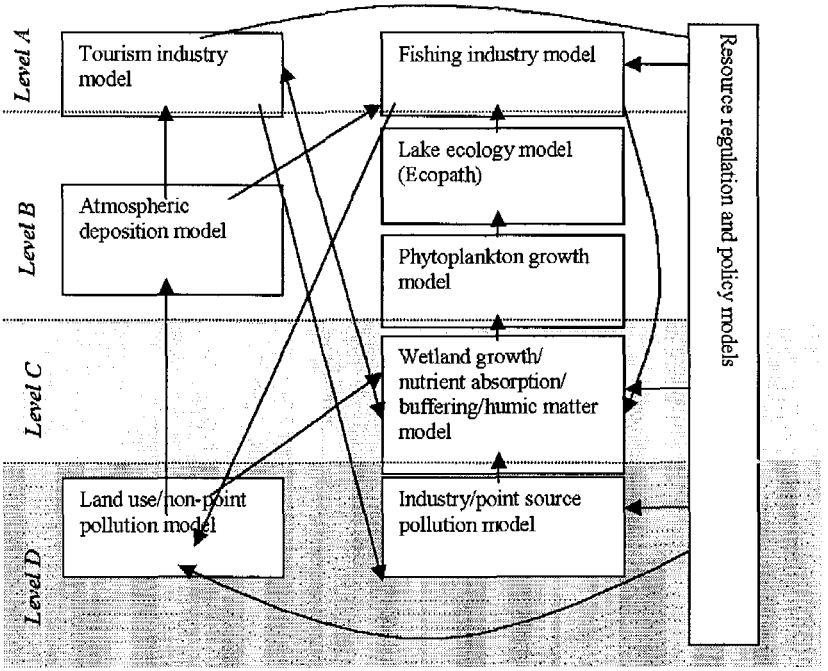


Figure 1: General structure of the integrated model.

The integrated model includes separate but linked components on land use (level D), wetland functioning (level C), lake ecology (level B) and fisheries (level A). At levels A and B, two modelling strategies will be examined. The steady-state trophic model Ecopath/Ecosim approach will be explored and if necessary refined to model the negative effects of eutrophication on populations of commercially exploited fish species. If this steady-state trophic web based approach does not provide sufficient flexibility, a multispecies Gordon-Schaefer model will be explored. The Nabugabo fishery will be modelled in the same way as the general lake fishery. The tourism industry model has will model tourist arrivals as a function of relative prices and a set of environmental variables including water quality and water quality-related health risks and biodiversity.

## 3 Discussion

Wetlands provide fundamental services in maintaining the resource quality for both the terrestrial and aquatic systems. As transitional areas they are also effected by resource use in both ecosystems. In the Lake Victoria basin, the use

made of arable lands, grazing lands, forests and urban areas all affect the rate in which catchment derived materials, in particular nutrients enter the lake. This, in turn, affects the ecology of the lake, and hence its value to the people of Uganda, Kenya and Tanzania as a source of water, as a fishery, as a transport medium, as a moderator of the local climate or as a tourist resource. The goal of the project is to create a set of decision tools to help policy makers evaluate and respond to land-water interactions in the Lake Victoria basin.

The expect outcome is a set of integrated information and ecological models that are direct at helping decision makers evaluate resource management decisions and understand land-water interactions in the Lake Victoria basin.

While the immediate goal is to develop models of land-water interactions at the smaller catch level, the ECOTOOL decision-tools should scale up to evaluate options at the level of the basin level. Since Lake Victoria is a joint resource for three countries, its management should include transboundary land-water effects. The decision-tools generated by ECOTOOLS should contribute to management and conservation of this globally and regionally important ecosystem.

## References


[1] Hecky, R.E. The eutrophication of Lake Victoria.*Verhandlungen der Internationale Vereinigung für Llimnologie* **25**, pp. 39-48, 1993.

[2] Greenwood, P.H. The Ciclid Fishes of Lake Nabugabo, Uganda, Bulletin of the British Museum (Natural History) **12 (9)** pp. 313-357, 1965.

[3] Goldschmidt, T., Witte, F. & Wanink, J. Cascading effects of the introduced Nile perch on detritivorous/phytoplanktivorous species in the sublittoral areas of Lake Victoria. *Conservation Biology* **7**, pp. 686, 1993.

[4a] Witte, F., Goldschmidt, T., Wanink, J., Van Oijen, M., Goudswaard, K., Witte-Maas, E. & Bouton, N. The destruction of an endemic species flock: quantitative data on the decline of the haplochromine chiclids of Lake Victoria. *Environ. Biol. Fish.* **29**, pp. 1-28, 1992.

[4b] Witte, F., Goldsmidt, T., Goudswaard, P.C., Ligtvoet, W., van Oijen, M.J.P. & Wanink, J.H. Species extinction and concomitant ecological changes in Lake Victoria. *Netherlands Journal of Zoology* **42**, pp. 214 - 232, 1992.

[5] Okeyo-Owuor, J.B. A review of biodiversity and socio-economics research in relation to fisheries in Lake Victoria. Socio-economics of the Nile perch Fishery of Lake Victoria Project Report No.5, IUCN-EARO, Nairobi, 1999.

[6] Ogutu-Ohwayo, R. Hecky R.E. Cohen & A.S. Kaufman L. Human Impacts on the African Great LAkes. *Environmental Biology of fishes* **50**, pp. 117-131, 1997.

[7] Mugidde, R. The increase in phytoplankton primary productivity and biomass in Lake Victoria. *Verhandlungen der Internationale Vereinigung für Llimnologie* **25**, pp. 846-849, 1993.

[8] Ochumba, P.B.O. Limnological changes in Lake Victoria since the Nile perch introduction. In T.J. Pitcher and P.B. Hart (Editors), The Impact of Species Change in African Lakes, Chapman & Hall, pp. 33-44, 1995.

[9] Kaufman, L. Catestrophic change in Species Rich Freshwater Ecosystems, The lessons of Lake Victoria. *Bioscience* **42**, pp. 846-858, 1992.

[10] Ogutu-Ohwayo, R. The decline of the native fishes of Lake Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile perch, Lates niloticus, and the Nile tilapia, Oreochromis niloticus. *Environ. Biol. Fish.* ***27***, pp. 81-96, 1990.

[11] Lung'ayia, H., Sitoki, L. & Kenyanya, M. The nutrient enrichment of Lake Victoria (Kenyan waters). *Hydrobiologia 458*, pp. 75-82, 2001.

[12] Lehman, J.T. & Branstrator, D.K. Nutrient dynamics and turnover rates of phosphate and sulfate in Lake Victoria, East Africa. *Limnology and Oceanography 39*, pp. 227-233, 1994.

[13] Bugenyi, F.W.B. Tropical freshwater ecotones: their formation, functions and use. *Hydrobiologia 458*, pp. 33-43, 2001.

[14] Ogutu-Ohwayo, R. The effects of predation by Nile perch, *Lates niloticus*, on the fish of Lake Nabugabo, with suggestions for conservation of endangered endemic chiclids. *Conservation Biology 7*, pp. 701-711, 1993.

[15] Chapman, L. J., Chapman, C. A. &Chandler, M. Wetland ecotones as refugia for endangered fishes. *Biological Conservation 78*, pp. 263-270, 1996.

[16] Kansiime, F. & Nalubega, M. Wastewater treatment by a natural wetland: the Nakivubo swamp, Uganda. PhD thesis, A.A. Balkema Publishers, Rotterdam, Netherlands, 1999.

[17] Balirwa, J.S. Lake Victoria wetlands and the ecology of the Nile Tilapia, *Oreochromis Niloticus* ISBN: 90 5410 411 2 IHE Dissertation 13, 1998.

[18] Denny, P. Wetlands in of Africa: introduction. In Whigham, D.F. Dykyjova, D., Hejny, S. (Ed.), the Ecology and Management of Afrcan Wetland Vegetation. Dr. W. Junk Publishers, Dordrecht, pp. 1-18, 1993.

[19] Carter, G.S. The papyrus swamps of Uganda, W.Heffer and Sons Ltd. Cambridge, UK, 25pp. 1954.

[20] Kansiime, F. Nalubega, M. Bugenyi, F.W.B. & Tukahirwa E.M. The role of Nakivubo swamp in maintaining the water quality of Inner Murchison Bay - Lake Victoria. *J. Trop. Hydrobiol. Fish.* **5 (2)**, pp. 79 – 87, 1994.