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Tropical freshwater ecotones: their formation, functions and use

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Abstract

Tropical water-terrestrial ecotones play important roles in regulating the flow of materials from and to land and water ecosystems. Ecotones exist where active interactions between two or more adjacent ecosystems occur with the appearance of processes that do not exist in either of the adjacent ecosystems.They occur naturally depending on the hydrological and geomorphological structure of the location. External and internal processes can influence the origin and persistence of ecotones. Ecotones regulate the landscape mosaic, affect energy flow between adjacent systems and intervene in landscape connectivity.

The literature on geological and climatic origins of wetlands and open waters, internal influences on their creation and destruction and, finally, their use by society is reviewed.

Introduction

Water and other aquatic resource problems are increasing in developing countries in the tropics, in general, and Africa in particular. These problems arise because demand is not balanced adequately by supply. Population growth in African countries and increasing urbanisation strain the availability, and quantity of water. Tropical Africa is in a state of serious economic and environmental crises in which water related resources play a major role. These crises derive not only from African structures but also from international economic structures and the general environmental degradation. This is evidenced by deforestation, soil erosion, alarming desertification, over-exploitation of fisheries and other resources and atmospheric pollution.

There is need to formulate conservation and management strategies for African freshwater resources through a full understanding of the tropical ecological processes. In this context, it is important to consider wetland ecotones or interfaces between land and inland waters and the major roles they play in the water resources management, such as: capture-release regulatory roles; filtering and cleansing roles to the incoming water flowing from the watershed (point or non-point) sources; zones of protection and habitats for fauna, including fish, and they can also be used for other socio-economic benefits.

Wetland ecotones have been adequately defined by Holland (1988) as 'zones of transition between adjacent ecological systems, having sets of characteristics uniquely defined by space and time scales and by the strength of interactions between the adjacent ecological systems'.

Factors influencing creation and stability of ecotones

In general, the ecotone concept is related strongly to geomorphic processes creating border zones between freshwater bodies and dry land. These geomorphic border zones can be classified on the basis of their spatial arrangement, their rate of emergence/formation and their persistence (Naiman & Decamps, 1990). The fundamental external factors behind these events are related, in most cases, to plate tectonics and subsequent processes of orogeny and formation of depositional basis.

Within these processes (technically known as megaform, macroform, mesoform and microform), it is possible to apply the classification adopted from landscape ecology which is related to the spatio-

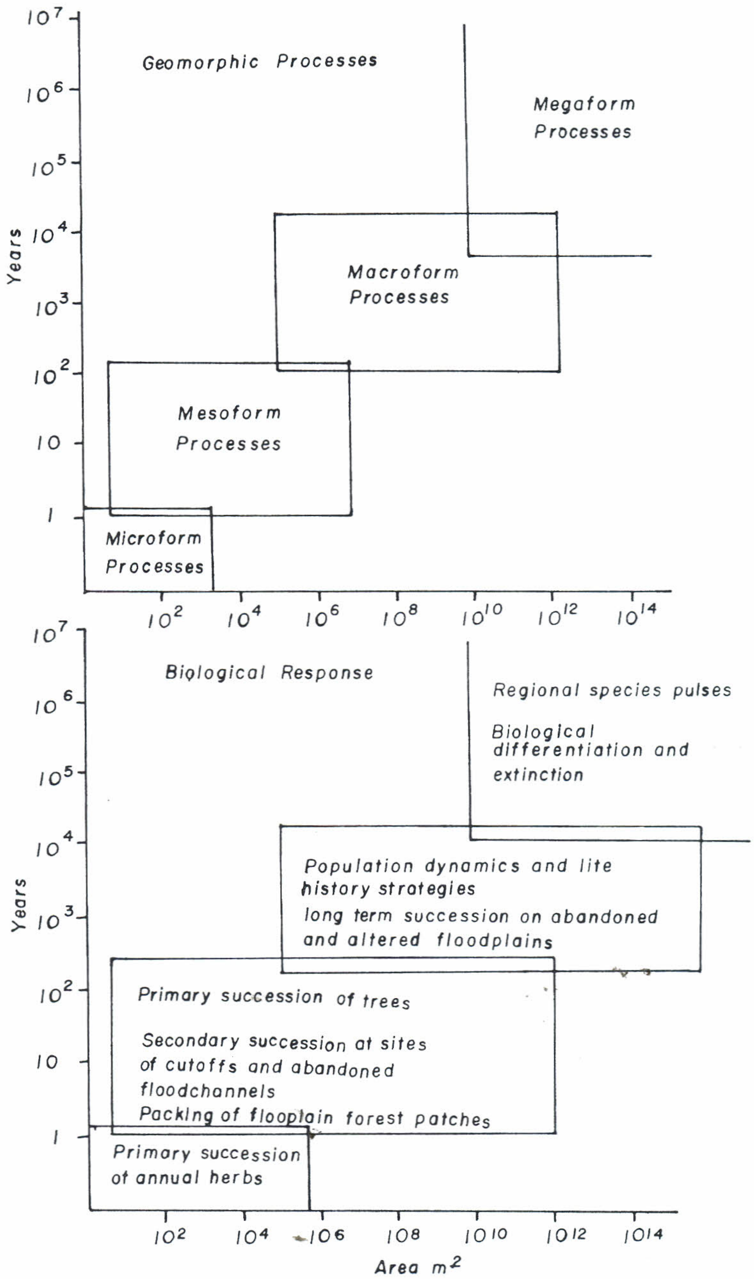

Figure 1. Fluvial geomorphic processes and their biotic correlates arranged on a spatiotemporal scale (from Lewin, 1978).

temporal dynamics of land patches created by sedimentary processes in environments with net depositions (Fig. 1, Walker et al., 1986). Megaform processes of terrestrial relief/plate tectonics, eustatic uplift and climate change affect biotic evolution by creating water/land interfaces or ecotones and patches that persist long enough (>10000 yrs) to promote biological differentiation.

These megaform border zones along dynamic forelands of mountain ridges are characterised by reliefs of net erosion and deposition in direct contact with each other. Macroform processes, the large river basin changes, primarily affect areas of net deposition in the basin. These changes result from changes in processes of, for example, the hydrologic regime, catchment properties, floodplain geometry and channel character-

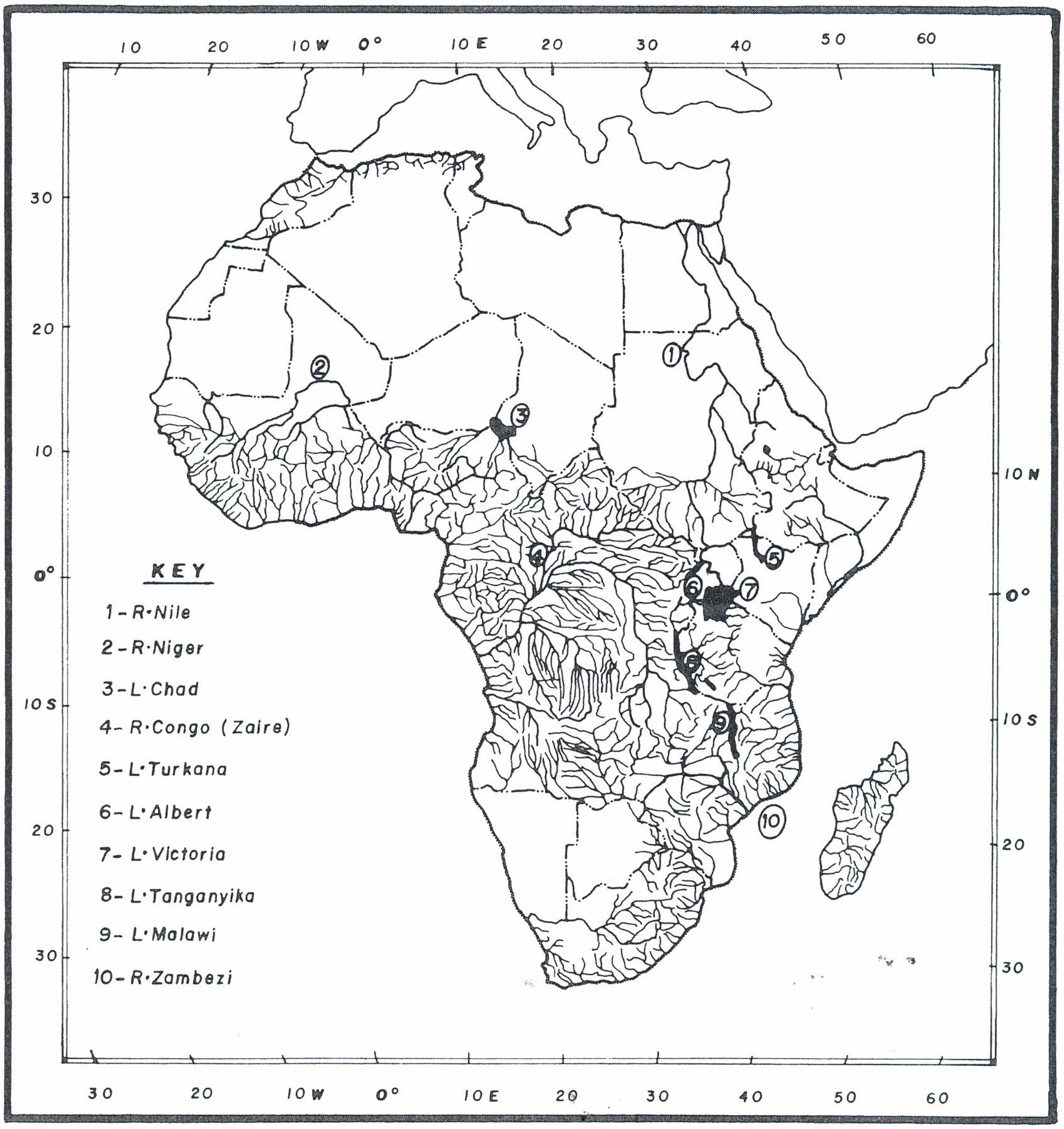

Figure 2. Some of the major inland waters of Africa (from Beadle (1974)).

istics (Lewin, 1978). Mesoform processes have their major biological impact on colonising strategies on the primary succession and zonation of woody angiosperms on the newly created depositional patches (Gill, 1972), and on the secondary succession of depositional sites associated with meandering rivers, cut-offs and former river beds (Walker et al., 1986). Microform processes, the smallest-scale fluvially induced processes, take place generally during the annual environmental regime of the fluvial system. In particular, these factors that are not directly caused by human activity but are due to climate and geology, for example, have, in the past, been responsible for Africa's hydrology and geomorphology. Uplifting and subsidence have moulded the surface of the African continent to a pattern of large depressions separated by ridges (basins and swells) and it is this pattern which has determined the outlines of Africa's hydrology (Beadle, 1974) (Fig. 2).

The catchment areas or surfaces (of the African inland waters) have been mainly shaped by spasmodic earth movements (tectonics) in a vertical direction: uplifting, faulting, subsidence and volcanic outpourings, as well as by the continuous forces of erosion.

In much of the surfaces of Africa and especially in the Lake basin, there is evidence of cyclic land uplift and erosion (Kendall, 1969). Most of the basins, which are the main catchment areas, now drain into the seas through gaps in their runs, via the Congo or (Zaire), Niger, Nile, Zambezi and Orange rivers. Most of the basins, therefore, are open. A few are closed, like Lake Chad basin. In the past (Pleistocene period), this lake was larger than any of the world's existing lakes (Beadle, 1974).

In the central and east of the continent, the ancient pattern of drainage has been disrupted by dramatic earth movements, mainly in the Miocene period (about 20 million years ago) and this has had profound hydrological, biological and human consequences. A very large tract running from North East (from Eritrea) to South East (Zambezi), about 700–800 km, wide and rising to about 1000 space metres has resulted from the vigorous vertical upwarping of the African surface. This has occured since the Miocene. The centre of the great ridge formed sagged thus forming many lakes with adjacent swamp basins (wetland ecotones) like the Lake Victoria basin. The two edges have been raised further and the consequent stretching of the crust has caused it to crack and a central strip to sink along the crest of the two ridges thus forming the Great Rift Valleys of Eastern Africa (Fig. 3). Other lakes with or without adjacent swamps were formed as a result of volcanic activities. There are several hundred of these lakes in East Africa, particularly along the the Western Rift. The importance of earth movements and of climatic changes in initial formation of lakes and swamps and that which later caused fluctuations in standing waters is known to have occurred during the Pleistocene (one or two million years ago). Evidence for previous much higher water levels of many of these newly formed lakes and of the existence of lakes in regions where there are now none, has been provided by raised beaches and sediments, some of which contain fossils of fish and other aquatic organisms. Naturally, it is only the climatic events of the past 20 000 years or so (in the very late Pleistocene) that can be related easily to the present conditions of the East African lakes and their florae and faunas. Not only that, but the amount of standing waves in a lake basin, a river basin, or a swamp valley depends not only on rainfall, rate of surface inflow and outflow but also on the rate of evaporation. The latter is dependent on the temperature and humidity of the atmosphere as well as on wind stress.

Evaporation and potential transpiration losses from water and vegetated surfaces are every where high in Africa. Evaporation from open water is of the order of 1500–2500 mm per annum (Grove, 1996).

A recent rise in levels of the East African Great Lakes (Fig. 4) took place quite suddenly late in 1961 (Flohn, 1987). Until that time, fluctuations in level this century have taken place on a modest scale with a pseudo periodicity of about 11 years evident in Lake Victoria record. Heavy rains towards the end of 1961 had a dramatic effect, the levels of Lakes Victoria and Tanganyika both rising at the end of 1961 by one metre and by another metre the following year. During this same period, a much smaller (in surface area size and shallowness) Lake Naivasha rose by about 2 m (Vincent et al., 1979). All three lakes eventually peaked in 1964. By this time Lake Victoria stood less than 0.5 m below the maximum it reached in the 1870s. The heavy rains of the regions, responsible these fluctuations in lake level were responsible for destruction or submergence of adjacent wetland ecotones and creation of others and were part of a climatic perturbation that extended from East Africa far out over the Indian Ocean.

In Africa, river discharge records show that high rainfall totals in 1961 extended far to the west of the Western Rift. The main discharge of the Chari into Lake Chad was the highest in November for the period 1961–1964 at least (Flohn, 1987). The discharge of the Zaire at Kinsasha in November 1961 was the highest value recorded between 1910 and 1983. The 1961 event, therefore, extended as far west as longitude 10°E. The new prospect of climatic change threatens to cause large changes in regional biomes/adjacent systems (or patches or ecological communities). These effects could be in the form of qualitative changes within the adjacent systems, as well as spatial changes in the boundaries of these ecological communities (Holland et al., 1991). The 'boundaries' or 'transition zones' or 'ecotones' between patches have been suggested as potentially sensitive areas to climatic change and therefore useful for monitoring change (i.e. they serve as indicators). Regional gradients of vegetation communities are used as utilities to detect ecotone location and movement where these are, being driven by climatic change. Maximal habitat or communities 'variability' and 'activity' is centred around/and within the ecotone zone/boundary (Bugenyi, 1991).

The principles developed for analysis of abrupt changes in spatial habitat patterns (the ecotones) can also be used for the analysis and detection of poten-

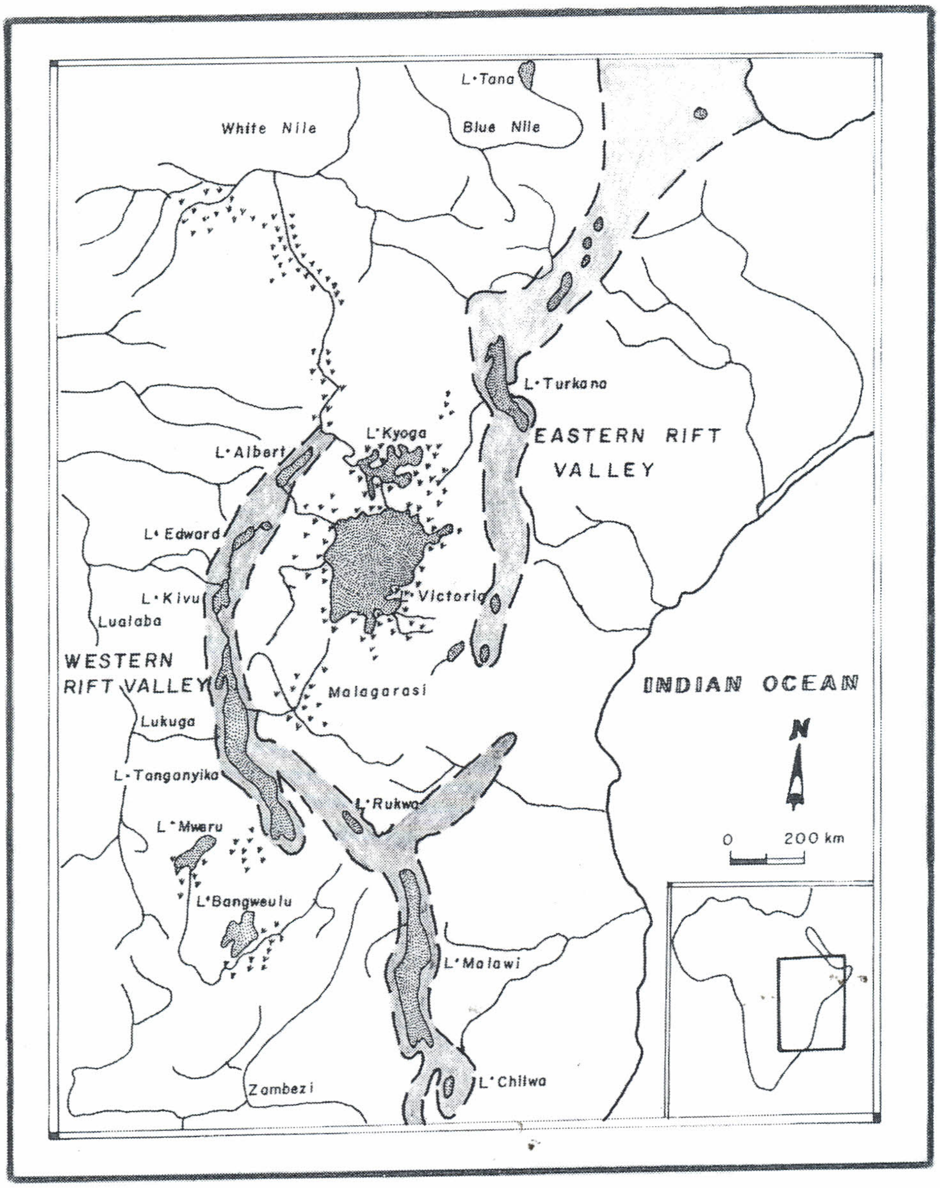

Figure 3. East African Great Lakes and other freshwater systems in the region.

tially abrupt physiognomic changes through time over large regions (Holland et al., 1991).

There are two types of change: boundary shifts of regions and physiognomic shifts within regions. These are potentially independent and may require different monitoring strategies to detect the impending changes in the used ecotones as 'indicators of changes'.

Internal factors responsible for creation and destruction of wetland ecotones

There are other factors that play major roles in the creation and control of wetland ecotones. Like the previously discussed natural factors or perturbations, human activity has a revealing history of impact on East African lake basins (Cohen et al. 1996). The cumulative impact of human activity is focused sharply upon these lakes, a fact with many ramifications for patterns of resource consumption. Demands for pot-

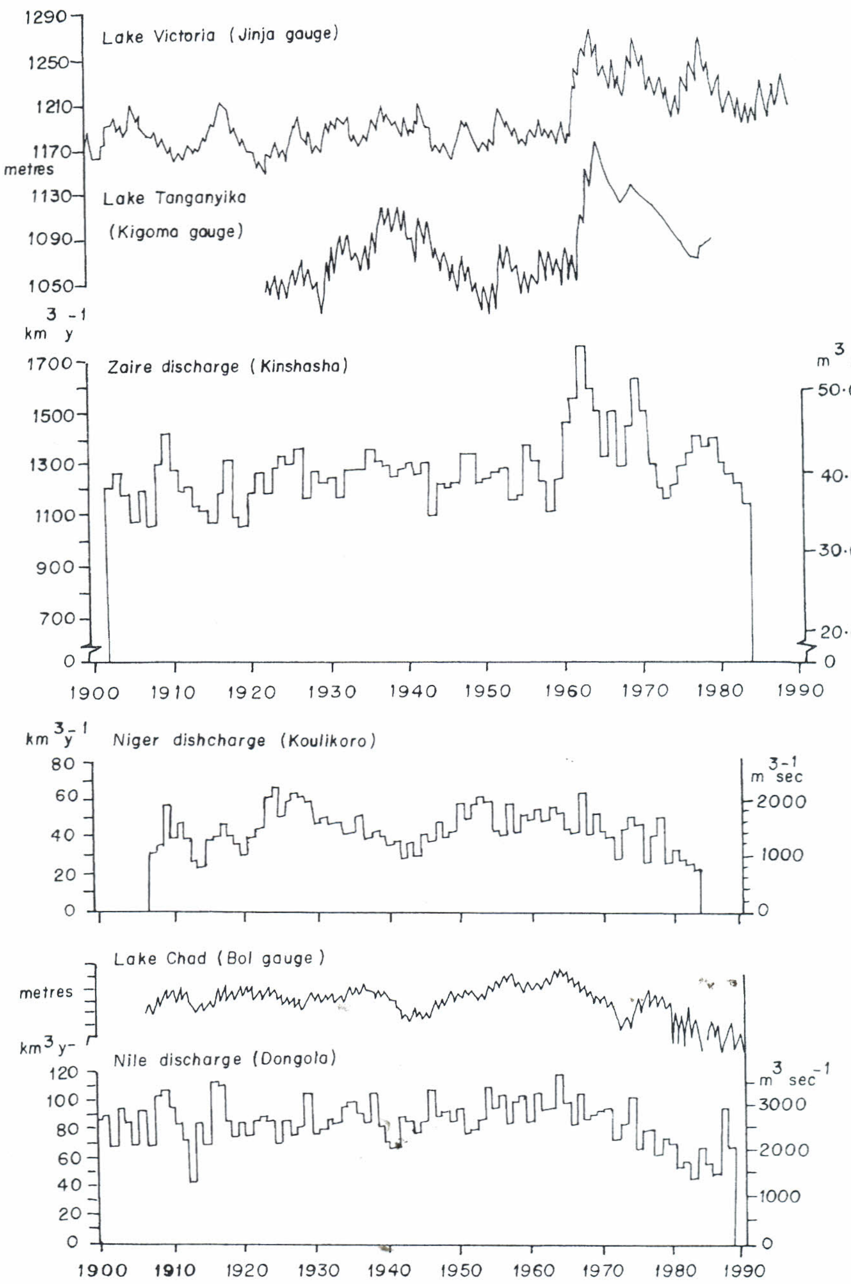

Figure 4. The fluctuations in rise in levels of lakes and discharges of rivers in East, Central and West Africa (from Grove, 1996).

able water and fresh fish are increasing and waste discharges are mostly into the lakes. There is a dramatic rate of population growth in the Great Lake Basins which can only accelerate rates of change of the lake basins (Table 1). The African Great Lakes are undergoing rapid environmental change, the origins of which lie in regional human activities.

As for the African equatorial rainforest, which is the lake's terrestrial counterpart, it has been now understood that the image of impenetrability and unchangeability was the unlikely idea fostered by our ignorance. The truth is that even the largest and most complex ecosystems, Great Lakes among them, have been severely altered by human interference. The

Table 1. Population Statistics for the African Great Lakes basins. From Cohen et al. (1996)

Lake basin	Basin population (mid-1980s)	1980s mean growth rate (%)	% basin population urban (1990)
Victoria	27.7	3.6	7
Tanganyika	6.2	3.4	12
Malawi/Nyasa	5.5	3.4	7
Kyoga	5	3.6	<2
Kivu	3	3.5	13
Edward	2?	3.5	<2
Turkana	2?	3.0?	<2
Albert	1?	3.4	<2

changed environment is still changing, at a rate faster than the scientific literature can track.

There has been rapid conversion of most of the watersheds from forest and savannah woodland to agricultural and range land. This conversion has occurred most rapidly during the past 50 years.

The history of this change provides an important context for understanding other problems in the lake basins. The rural population pressure has also meant that intensive cultivation, soil erosion and loss of soil fertility have resulted. The use of fuel wood (and particularly charcoal) as a primary energy source is a further contributory factor to both accelarating rates of deforestation and enhancing nutrient loading into lakes, notably by way of of particulates carried by wind. There are, therefore, human related factors in the creation/destruction of wetland ecotones directly or indirectly.

The ecological system, patch dynamics and the boundaries between them have been dominant concepts in ecosystem studies of landscape ecology (Hill, 1987). These studies have been related to effects of human induced or natural perturbations. The need to study natural river and lacustrine environments with regard to biotic behaviour has been obvious since it was recognised that some of the world's richest species assemblages are found in tropical lowlands and, in particular, in tropical wetland ecotones (Bugenyi, 1991). In most African countries, freshwater ecosystems (of which wetland ecotones form part) are threatened as a result of policies that emphasise exploitation (development) rather than management (and conservation) (Bugenyi & Balirwa, 1998). This policy emphasis could be a result of limited understanding of dynamic freshwater ecosystem integrity in the midst of increasing human pressure. Historically, lakes and associated ecosystems have been poorly understood. Governments have not taken consideration of aquatic systems as 'whole ecosystems' or 'lake and river basins' consisting of the catchment and the activities within it, the adjacent wetland-ecotone system and all its ecological functions.

Catchment activities, particularly devegetation (biomass harvests) and burning, easily lead to changes in structural components in adjacent wetland ecotones and hence surface waters. The enormous swamps of the Eastern and Central Africa form buffers that regulate water quality in the receiving waters. They are mostly dominated by papyrus, and represent a habitat of great ecological importance. In Lake Victoria, for example, just as in North American Great Lakes, eutrophication has become manifest as fish fauna change (Hecky, 1993). Apart from the percieved 'top-down' effects of exploitation and fish species stockings on species richness and water quality, catchment impacts on aquatic ecosystems caused by environmental degradation (of watersheds and airsheds) are related directly to human socio-economic objectives, and explain many changes in water quality and species assemblages in Lake Victoria.

Wetlands in general and wetland-ecotones in particular are providers of many resources, products and services and there are reciprocal impacts between them and humans. Wetland management has been unco-ordinated with only a few commercial objectives being emphasized. Wetland-ecotones are least studied in the African context, yet habitat associated with them can, for example, provide insight into the origin and structure of fish populations in lakes (Balirwa, 1998). Papyrus swamps in wetlands may influence habitat availability and quality for fish in two ways: (i) by providing structural heterogeneity in which fish can escape predators, and (ii) the swamp closed canopy minimises incident light and the mixing of water below, resulting in oxygen depletion in the water of the swamp and hence the exclusion of predators (Chapman & Liem, 1995; Chapman et al., 1994).

Some studies of such swamps have shown that substantial loss of nutrients to the interface zone from either of the adjacent patches or ecosystems is a result of rain leaching (Gaudet, 1977). Such functional exchanges add to the habitat structural complexity and diversity (Fig. 5) which may be manifested in the trophic diversity responsible for the high productivity associated with wetland-ecotones (Bugenyi, 1991).

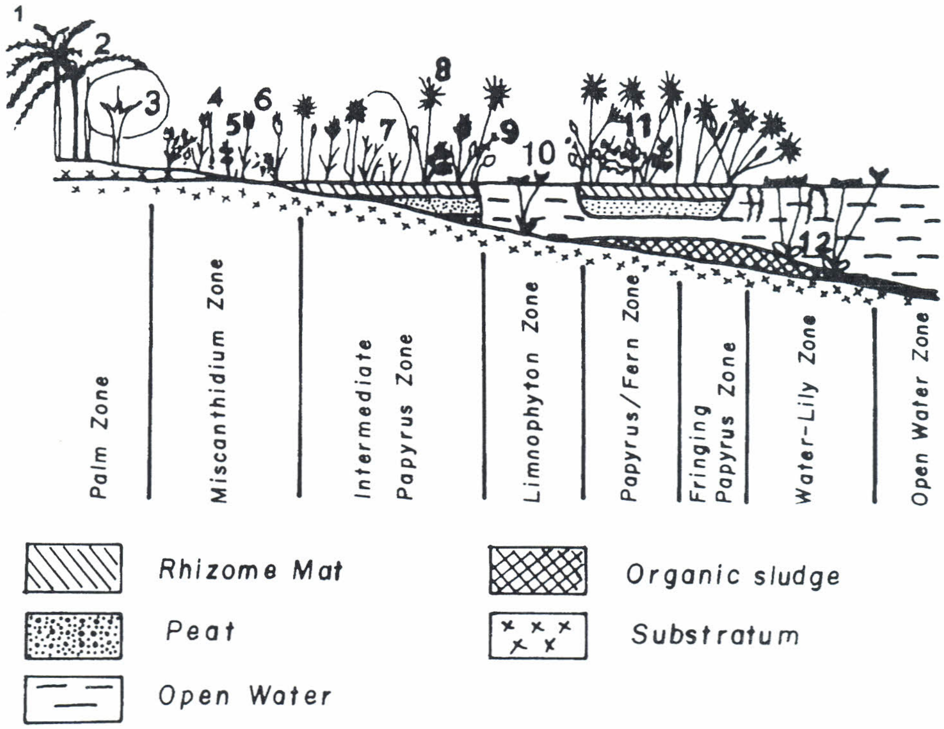

Figure 5. Vegetation typical of a Lake Victoria swamp. The species represented are: (1) *Phoenix reclinata* (2) *Raphia monbuttorum* (3) *Mitragyna stipulosa*. (4) *Sphagnum* spp. (5) *Dissotis brazzei* and *Leersia hexandra*. (6) *Miscanthidium Violaceum*. (7) *Ficus verruculosa*. (8) *Cyperus papyrus*. (9) *Limnophyton obtusifolium*. (10) *Nymphaea caerulea* and *Trapa natans*. (11) *Dryopteris striata*. (12) *Ceratophyllum demersum*, *Utricularia* spp. and *Potamogeton* spp. (From Thompson 1976).

Wetlands and shallow waters have, for generations, been the basis of sustainable socio-economic returns (Fig. 6). These returns have been in the form of: source of food-fish, drinking water, building materials, medicines, protection from floods and as areas of seasonal grazing.

Associated with wetland-ecotone zones is water hyacinth (*Eichhornia crassipes*), an exotic weed that has invaded many tropical water bodies. Quite often this weed has been responsible for many water related problems. These include threats to Hydro-Electric Power (HEP), water supply, fishing activities and commercial transport to mention but a few. There are many methods of controlling the water hyacinth menace. The most effective is a combination of all at particular times and areas i.e the 'integrated control method'. The safest appears to be the 'biological control method'(Twongo & Balirwa, 1996). Some species of wetland vegetation with which the water hyacinth associates, have been known to act as 'control methods'. The hippo grass (*Vossia cuspidata*) has been known to out-grow water hyacinth and dominate it, thus checking on its spread (Twongo & Balirwa, 1996).

The Socio-economic and biological interests and implications

The freshwater ecosystems of Eastern Africa provide the lifeline, in terms of natural resources (Fig. 6) for the Region's estimated population of c.86 million (Rwanda c.6 million, Burundi c.6 million, Uganda c.20 million, Kenya c.26 million and Tanzania c.29 million) and also to scientists, naturalists, tourists and environmentalists worldwide to study and conserve.

People benefit from wetland services and functions. For example, since wetland-ecotones may be sinks for nitrogen and may store phosphorus and other contaminants, they improve water quality to the adjacent body of water. The importance of wetlands in general and wetland-ecotones in particular has been changing with time. Back in the swampy environments of the carboniferous period (some 350 million years ago) wetlands produced and preserved fossil fuels (coal and oil) upon which we depend today (Barbier

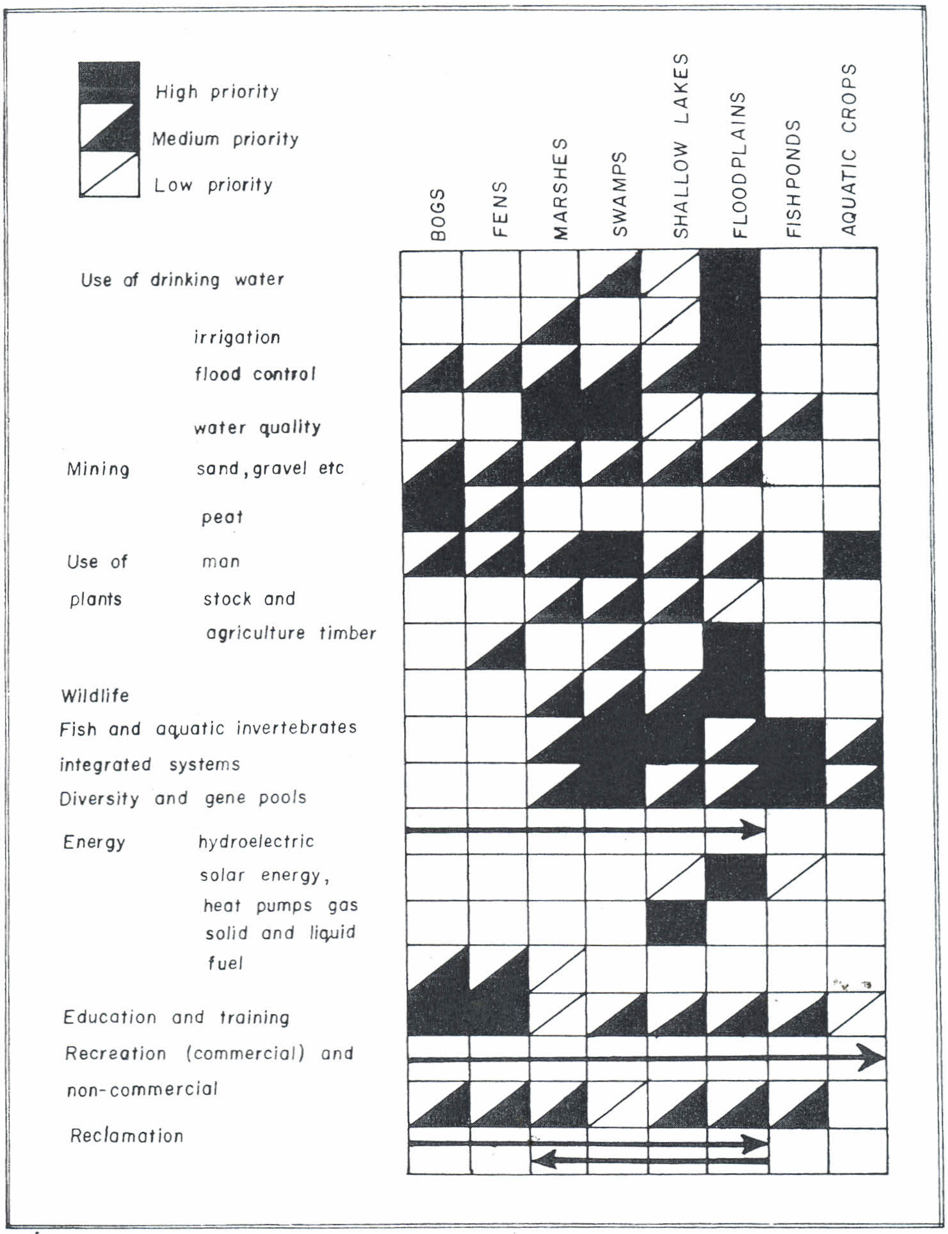

Figure 6. Major global and particularly African wetland uses (from Loffler 1990).

et al., 1996). More recently, wetlands along some of the major rivers of the World, including the Tigris, Euphrates, Niger, Nile, Indus and Mekong have nurtured the great civilisations of history. These ecosystems have provided fish, drinking water, herbal medicine, clay and plant material for building, pasture-land and transport and were part of the cultural history of early people, being a central element of mythology, art and religion.

In recent years, there has been increasing awareness of the fact that natural wetlands provide 'free of charge' many valuable functions (e.g. flood alleviation, ground water recharge, retention and regulation of pollutants and water plant nutrients); refugia for fish and other fauna; and other attributes (biodiversity, aesthetic beauty for tourists, cultural heritage and archeology). The world's wetlands (including the ecotones) are now recognised as some of the most important and productive ecosystems on Earth (Mitsch & Gosselink, 1993), and it is recognised that wetland conservation and management are shared responsibility for all concerned.

To protect wetlands requires combined action from both national and international cooperation in enforcing their 'wise use'. The 'wise use of wetlands' as defined by the Ramsar Convention Bureau (1997), is 'their sustainable use/utilisation for the benefit of mankind in a way compatible with the maintenance of the natural properties of the ecosystem'. To ensure this wise use, a 'value to any wetland/ecotone' should be 'fixed' and appreciated by us all, especially those who use or whose life depends on the wetland ecosystem. It should be realised that although some of wetland uses are sustainable, others lead to their rapid deterioration.

In the Ugandan 'Ecotone Project' (at the Fisheries Research Institute), researchers tried to evaluate, in monetary terms, how much Uganda loses with the progressive destruction of wetlands. The study looked first at, which uses are of importance, and thereafter examined, what data was available to calculate the values of those uses (Luthiga, 1995). The analysis was purely economic and, therefore, excludes the intangible value wetlands may have for society. The methods used in the study asses the value of wetlands through cost-benefit analysis; consisting of adding up the various benefits coming from sustainable uses as compared with possible profits from converted wetlands. It took into consideration that the benefits of wetland protection are mainly social benefits, whereas the profits of non-sustainable use of a wetland area can only accrue to a private individual or developer.

Three major areas were considered for study: the non-sustainable agricultural use of the wetland area, the filtering capacity of the wetland-ecotone, and the existence value and importance of the swamps as breeding (and hiding-from-predators)places for fishes. The study, finally, did provide some hints concerning the rationale behind the progressive wetland degradation, so that immediate remedial measures can be provided.

Conclusions and the way forward

In order to know what action, and what steps to take in order to properly manage, conserve and sustain the wise use of wetlands and wetland-ecotones' systems and their natural resources, they must first be understood. More investigations, for example, on: what kind of resources are available and how can their utilisation be sustained; what are the socio-economic values of these systems; their biodiversity and implications of this as far as indicating, say, climatic and other changes are concerned, and functional dynamics. Tropical Africa suffers from lack of trained manpower (the present number is too small and many of these find greener pastures elsewhere) and the resources to undertake the expensive research. Adequate capacity should be built for addressing these problems. The public should be sensitised to participate fully in co-management ventures of the systems for the resources from these are theirs.

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