The Recent History of the Lake Victoria Ecosystem: Eutrophication and Biodiversity Decline

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Lake Victoria, the second largest freshwater lake in the world by area and the largest in Africa, has been fundamentally altered from its condition of the 1950's by eutrophication, species introductions and climatic variation. The lake is the first of the African great lakes to undergo substantial change from its historical condition, but the processes that contributed to the changes are at work in all the African great lakes. These great lakes are extremely important to the riparian peoples as sources of water for domestic and agricultural uses, as modifiers of local climate and especially rainfall patterns, and as producers of cheap animal protein as fish. The lake basins are ancient and endemic species flocks have evolved within them with the result that the fish faunas are the most diverse known in freshwater. Changes were manifested first in Victoria because its catchment is the most densely populated of the African great lakes, and it is the shallowest. Its water renewal time is on the order of 100 years which means that any pollutants which enter the lake will remain and effect the biological communities for a very long time. Consequently it is imperative to identify undesirable changes in the lakes as early as possible in order to prevent changes which may be extremely long-lived because of slow water renewal times. Lake Victoria was the site of intensive and comprehensive study by the East African Freshwater Fisheries Organization during the 1950's and that information provides the best available baseline for the African lakes against which modern data can be compared. Starting in the late 1980's, systematic study has continued conducted by the Fisheries Research Institute of Uganda and several international partners. The recent studies have confirmed a number of disturbing facts about the present ecosystem when compared to earlier observation in Ugandan waters.

The lake has been enriched by nutrients with phosphorus loading having increased over twofold based on increased sedimentation of phosphorus and increasing concentrations in the water column. This has led to a doubling of pelagic photosynthesis and an approximately 5x increase in algal standing crops. These algal crops have shifted in composition from dominance by diatoms of the genus *Aulacoseira* during algal maxima to dominance by filamentous cyanobacteria of the genera *Cylindrospermopsis* and *Planktolyngbya* with diatoms of the genus *Nitzschia* being subdominants. Algal growth in the pelagic ecosystem may now be limited by light, nitrogen and partially by carbon for much of the year. Highest algal biomasses occur inshore where chlorophyll can routinely exceed 40 ug/l. In these inshore areas phosphorus still sets upper bounds on algal biomass as nitrogen fixation by some species overcomes nitrogen limitation when light is available. Seasonal deoxygenation has spread horizontally and vertically during the nine month stratified seasonal eliminating demersal habitats for fishes over much of the lake for most of the year and contributing to increased frequency of fishkills. The increased extent of anoxia and hypoxia has increased rates of denitrification. The increased loading of phosphorus and increased extent and intensity of denitrification has distorted the nitrogen budget which is now dominated by direct fixation of atmospheric nitrogen by filamentous cyanobacteria e.g. *Cylindrospermopsis* and *Anabaena*. These taxa and increasingly abundant *Microcystis* are potential producers of algal toxins, and they create water treatment problems for domestic and agricultural use. The decreased transparency attendant with the increased planktonic algal biomass has reduced benthic algal photosynthesis which is a crucial food source for inshore endemic haplochromines which were marvellously diverse and adapted to make use of specialized feeding niches.

The introduction of the Nile perch and the Nile Tilapia (and other tilapias) in the late 1950's put new and apparently effective predators and competitors into an ecosystem which had been numerically dominated by hundreds of species of highly adapted, endemic haplochromine cichlids. The biodiversity of this endemic species flock has plummeted although there is evidence of reemergence of some of the endemic species as fishing pressure on the Nile perch, in what is now the most productive freshwater fishery on the globe, has put the Nile perch at risk from overfishing. Concern about the sustainability of the this intense fishing pressure has led to banning of trawling in the three riparian countries, but other fishing techniques remain unrestricted. The loci of the fishing effort for Nile perch has shifted from inshore to offshore in order to maintain catches. The fishery is now landing more fish annually than were estimated to be present in the lake when the last stock assessment was done in 1968-70. A new stock assessment is currently underway. This high yield from the fisheries suggests that the current fish community must be more efficient than the previous haplochromine community in converting pelagic primary production into fish production. The twofold increase in primary productivity has also likely contributed to sustaining the unexpectedly high yield. The high yields of Nile perch have been a mixed blessing as much of the perch catch goes to export from the lake basin. The emergence of international marketing has driven up the price of fish in local markets beyond what most people can afford. Fish which used to be the most inexpensive form of animal protein is now the most expensive. To meet the local demand, less capital intensive fishing techniques, e.g. beach seining using mosquito nets, has increased; but these techniques can destroy near shore spawning and nursery areas and remove large numbers of young fishes along with their mouthbrooding parents.

Recent paleolimnologic studies have shown that nutrient enrichment began in Lake Victoria early in this century following European occupation, and it accelerated rapidly during the 1960's. Nitrogen loading increased before phosphorus probably as a response to increasing land clearance for agriculture. A substantial rise in sedimentation of biogenic silicon resulted from the increased diatom productivity and occurred contemporaneously with the increase in phosphorus sedimentation. Dissolved silicon is now found in low concentrations throughout the year. With nutrient enrichment, the diatom community showed increased productivity as species of *Cyclostephanos* and *Nitzschia* benefitted from eutrophication while the *Aulacoseira* and several green algal species did not increase or began to decline in abundance. Many of the most dramatic changes in the algal community were completed by the late 1970's. Rapid growth of Nile perch populations and declines in haplochromines stocks began in the 1980's in Ugandan waters. The interplay of these two concurrent trends is controversial in attributing causation to the biodiversity decline. There is no doubt the Nile perch predation increased the rate of loss of species from the lake, but overfishing for some of the native stocks and the alteration of habitat by eutrophication have also contributed. Less likely to play a significant role in the species decline is a change in climatic conditions observed around the lake. Since 1962 the region has had well above average rainfall and somewhat warmer temperatures which have been recorded in the lake by deep water temperatures being on the order of 0.5 C warmer than earlier in the century. The extremely high rainfall of the early 1960's took the lake level two meters above the average recorded since the turn of the century and the lake has remained above the 1900-1960 mean level since then. The lake now has greater physical stability during its stratified season, and this increased stability together with higher rates of organic production contribute to the increased deoxygenation of the deep water.

The eutrophication is most directly linked to intensive land use by rapidly growing human populations based on paleolimnological interpretations and putative nutrient budgets which identify likely sources for the increased nutrient inputs. The phosphorus loading can be reversed through the application of better land management practices, changing livestock management and improved sewage treatment for growing urban centres. The Nile perch and other introduced species are now resident, but their populations can (will) be controlled with appropriate fishing effort. To what extent the endemic fish populations can recover is still an outstanding question. Systemic changes are still occurring as the water hyacinth has successfully invaded the lake in the early 1990's and is now creating havoc with many shoreline uses. The successful invasion of the water hyacinth into Lake Victoria, which has been in the region for decades, and its spread elsewhere in Africa is itself testimony to the degradation of and increased nutrient fluxes from watersheds under growing human pressure on the land and waters. Lake Victoria now requires intensive and expensive management to maintain water quality for its many domestic, industrial and natural resource uses by the 20 million people who live in its catchment. This management is unlikely to materialize without substantial investment from the international community. Action is required to restore Lake Victoria and to prevent a similar sequence of events from overtaking the other great lakes of Africa where the water quality and the endemic species flocks are still intact.

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