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Environmental Problems of Lake Victoria in Relation to Human Activities: Lessons from another Great Lake

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MANAGEMENT PERSPECTIVE

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Current status: This paper was invited as one of two keynote addresses to open an East African regional workshop: "Towards Sustainable Development and Management of the Lake Victoria Basin: A Regional Workshop". The workshop was sponsored by the European Union's Lake Victoria Fisheries Research Project and the Canadian International Development Research Centre (IDRC). IDRC has been funding research on Lake Victoria fisheries and environment through the Fisheries Research Institute of Uganda since 1986 while the EU project has been active for a three year preparatory phase and is not ready to commence the first fish stock assessment since 1969. Both agencies are trying to help the riparian countries to define sustainable levels of utilization of the resources of Lake Victoria which has undergone substantial ecosystemic changes in the past 40 years. Both agencies are committed to identify community based mechanisms for defining the crucial attributes of the Victoria ecosystem and effective management actions to lead to sustainable use. All agree that current trends are not sustainable. The workshop attracted over 90 participants of which 60 were sponsored. It was a stakeholder workshop which tried to span the economic spectrum of the basin as well as the spectrum of actors from resource user to researcher.

Next steps: The proceedings of the workshop will be published for limited circulation and this keynote address has been sought for inclusion (text attached). The EU coordinator (Mr. Martin van der Knaap) and the directors of the national fisheries research institutes have requested that Dr. Hecky recommend a basic design for a limnological study in support of the planned fish stock assessment project for EU implementation. IDRC has agreed to provide training support through in country technical workshops, as well as in Canada counterpart training to ensure the limnology study can be implemented.

PEOPLE MAKE A DIFFERENCE

Many changes have taken place in and around Lake Victoria in the last 40 years. Some have been seen as positive by the peoples around the lake, e.g. the higher abundance of fish, others are certainly unwanted, e.g. loss of fish species, the excess algal growth and invasion of water hyacinth. Other changes are less noticeable but just as certain. There is evidence that the lake is somewhat warmer than it used to be, and the water level of the lake since 1960 has been higher than the period from 1900-1960. Any change in the character of such a large lake is cause for concern, but when so many obvious and important changes are occurring over the same, relatively short time period, then concern becomes alarm (Figure 1) as people naturally wonder what is causing these changes and what does the future hold for the lake. Is our current use of the resource wealth of the basin and its lakes sustainable? Will Lake Victoria nurture our children and future generations as it has ourselves? Are our actions and our use of the basin responsible for these changes? Must we change our behaviour and/or our expectations to insure sustainability? What can we do; can we do what is required? CAN THE PEOPLE OF THE BASIN MAKE A DIFFERENCE IN THE FUTURE OF THEIR LAKE AND THE BASIN ENVIRONMENT? These are some of the questions that this workshop must try to answer in the next few days. But the most important question is the last, and I will provide an answer so the workshop can get on with the difficult task of deciding what must be done.

I come from Canada, a land rich in lakes but poor in people. It is estimated that Canada has 10% of the world's supply of freshwater; yet, less than 0.006% of the world's population. If Canada's population were evenly distributed, its effect on its lakes would not be detectable; but such is not the case. Much of Canada's freshwater is found in four great lakes which it shares with the United States. One-third of the population of Canada and one-tenth or the U.S. population lives in the basin of the Great Lakes. Even within the Great Lakes basin, population is not evenly distributed. Less than 0.5 million people live in the basin of Lake Superior (6 persons per square kilometer of lake surface), the uppermost of the North American Great Lakes and the largest lake in the world. In contrast, 20 million people live in the immediate basins of Lakes Erie and Ontario, the smallest of these Great Lakes (450 persons per square kilometer of lake surface). In Canada, we can see great differences in these large lakes today, and we can see that their recorded histories of pollution and disturbance have been very different. Lake Superior remains in relatively pristine condition while Erie and Ontario have required substantial management intervention to restore some of their desired properties and to sustain desired use. People and their daily activities earning a livelihood, make a difference to the lakes and basins they occupy.

The recent history of Lake Erie provides perhaps the best comparison with the recent history of Victoria, and it may provide a hopeful guide to the future. Lake Erie is the shallowest of the North American Great Lakes while Victoria is the shallowest of the African Great Lakes (Table 1). The mean depth is about half, while it's area is somewhat less than half that of Victoria. It has been estimated that nearly 20 million people live in the Victoria catchment which is nearly double the number in the Erie catchment (11 million). Erie, in fact has a higher density of people living on the land surface (150 persons per km^2) while Victoria has approximately 100 per km^2. (However the density is increasing at 3% per year in Victoria while it is nearly static in the Erie basin). There are some important differences to bear in mind.

Central North America is well watered, and the volume of water in Erie is replaced every three years while it takes about 100 years for the Nile discharge to flush Lake Victoria. More importantly to the life of the lakes, Erie is in a cool temperate, climate. It's surface waters can get as warm as 25 C in summer, but it freezes over most winters and mean annual temperature of its water mass is on the order of 8 C. In striking contrast, Victoria's temperature range is narrow and warm with a mean annual water mass temperature of 25 C. These continuously warm temperatures have important consequences for the oxygen content of the tropical lakes (Figure 3) which have a high tendency to lose rapidly oxygen from deep waters with slight changes in temperature compared to temperate lakes. Oxygen is essential for higher organisms to live and its loss can dramatically affect the distribution and abundance of higher organisms including fish. Because of the long, flushing time, most material which enters Lake Victoria remains in it and is exposed to its continuously warm temperature. Consequently, Victoria retains more of its incoming materials and recycles them more efficiently than Lake Erie. This leads to high rates of organic production, but oxygen can quickly become a problem if organic material is produced more rapidly than consuming animals can assimilate it. In lakes, organic production is most often nutrient limited when light is available for photosynthesis. Increased rates of nutrient input cause increased rates of production, and excessive inputs lead to excessive organic production and then high rates of oxygen consumption. This process of excessive nutrient enrichment is referred to as eutrophication.

Fisheries managers on the North American Great Lakes sometimes proudly refer to Lake Erie as the world's most productive, commercial freshwater fishery. They are, of course, incorrect. When challenged, they will admit that it is the most productive of the North American Great Lakes and the most efficient (economic return on investment) in the world. Because this high economic return is maintained by a cooperative, self management system, it deserves global recognition. This was not always the case. In 1970 and for a few years thereafter, the Erie fishery was closed totally to commercial fishing because fish had become contaminated with the toxic compound methyl mercury as a result of industrial pollution. Steps were taken to remove Hg from industrial processes, and the lake has recovered. Prior to that, overfishing and increasing nutrient loading had eliminated the valued and endemic blue pike and reduced commercial stocks of whitefish to very low levels. Yields had been maintained and even increased by commercial fishers redirecting effort to underutilized stocks such as yellow perch and smelt (an introduced species).

The most productive freshwater fishery in the world is Lake Victoria largely because of the success of the introduced Nile perch. Yields from the lake are thought to exceed 500,000 metric tonnes in recent years. This is a huge and valuable fishery which has captured a large export market. But size can be deceiving and falsely reassuring. A cautious reminder should be taken from another Canadian example, a marine example, which is the northern cod fishery. This fishery had been exploited for generations by the people of eastern Canada and an international fishery from many countries and by the 1980's was yielding several hundred thousand metric tonnes. However, this fishery is now closed to all fishing for cod because the stocks collapsed in the early 1990's. This was a tragic and preventable loss which has caused economic devastation because of the huge loss of jobs from the region's primary industry and the loss of even subsistence fishing for cod. Fisheries must be well and wisely managed and the stocks husbanded, or catastrophic loss and economic deprivation (even in an economically developed country such as Canada) will follow. This collapse was caused by overfishing, and a similar fate must be avoided in Lake Victoria.

EUTROPHICATION AND RECOVERY OF LAKE ERIE

There were many dramatic statements made by stakeholders in the Lake Erie basin about the poor condition of Lake Erie and its fishery in the 1960's. Many of those statements would sound very similar to those made about Lake Victoria today (Figures 1 and 3). In fact the statements about Erie at that time were even more devastating. Lake Erie was "dead" or "dying". Many said it's condition was irreversible. Everyone agreed on the symptons, rotting algal scums, fish kills, spreading deoxygenation in the deep water, taste and odor problems with drinking water, sicknesses related to swimming in the lake, etc. (Figure 3). There was agreement about the general cause, population growth, because many other lakes in Canada where population density was low had remained unchanged over the same period of time that Erie changed so dramatically. The population had increased from 3.8 to 11.2 million between 1910 and 1960. Urbanization had allowed this increase to take place, but the growing cities could not handle the growing volume of sewerage and treatment was rudimentary. Increased industrialization accompanied this population growth which created toxic pollution problems mentioned above. The increasingly fewer farmers in the Erie basin resorted to increasing use of agrochemicals to boost productivity in order to maintain their economic viability and to feed the growing local market. This intense land pressure, soil erosion and nutrient mobilization, although unintentional, fed the increasing nutrient loading of Lake Erie (Figure 3). Finally in the mid-1960's, the public was sufficiently alarmed to press their governments for actions and solutions. Governments turned to the scientific community to explain these changes and to recommend solutions. Although there was general consensus that population pressure was the ultimate cause, there was not consensus about what aspect of population growth was directly causing the problem. After all, the people did not live in the lake; therefore, it must be some product of output from those people which caused the changes. A contentious and vehement debate ensued about which nutrient was fundamental to causing the problem..

The final resolution of the great nutrient debate was that phosphorus control on effluents to the lake was necessary. Binational agreements were achieved to reduce phosphorus loading into Lake Erie, and target concentrations were agreed upon. The agreement among many levels of government was to reduce point source effluent concentrations to 1 mg/L. As thousands of point sources came into compliance, the loading from point sources declined rapidly (Figure 4). Part of this decline came from the elimination or reduction of phosphate from detergents which became law in all jurisdictions within the basin. Non-point sources of phosphorus also were reduced through changing land use practice, reductions in fertilizer usage, and zero-till agriculture. In major rivers in western Ohio, 75 to 85% of the reduction in total phosphorus (Figure 5; Table 2) was achieved by reductions in non-point sources. This was accomplished without any targets being set for non-point sources; but this was, rather, a byproduct of improved land management by farmers to maintain their profitability. Reducing phosphorus lost to rivers meant that more phosphorus remained on the land for agricultural production. The microscopic algae in Lake Erie responded rapidly to the reduction of phosphorus inputs. Algal growth became more phosphorus limited and algal densities fell (Figure 6). There was also improvement in the composition of the algal community as the greatest reductions were in the most noxious species such as the nitrogen fixing blue-green algae. The targeted, desirable concentration of phosphorus in Lake Erie was set at 10 micrograms per litre, and this concentration was achieved by the late 1980's.

EUTROPHICATION OF LAKE VICTORIA

The recent history of the Lake Victoria basin has some striking similarities to that of Lake Erie. Population growth in the Victoria basin increased at a similar rate as that in the Lake Erie basin up to the mid-seventies at which time growth in the Erie basin leveled off. However, in Victoria basin growth continued and the population doubled again between 1970 and 1985. Such growth rates cannot be sustained although they are still current (Figure 7). The Victoria basin already has the highest population density of the African Great Lakes (Figure 8) especially in the highlands of Rwanda and Burundi and in Kenya. This high population density combines with the shallowness of Victoria relative to the other lakes in Figure 8 to increase phosphorus concentrations rapidly when loadings rise. Phosphorus loadings to the sediments of Victoria have risen by at least 50% (based on analyses of sediment cores from the deep water in Kenya) and the concentrations in the water have risen by 50-100%. The algal community has increased in productivity by a factor of 2 and standing crop by a factor of 5-8 (as shown by studies of Rosemary Mugidde of the Fisheries Research Institute of Uganda) and has shifted its composition away from dominance by diatoms to dominance by nitrogen fixing blue-green algae (Figure 9). The diatom maximum, which used to occur in August-September when the lake mixed, no longer occurs; and blue-green algae produce maximum crops from November until the lake mixes again in July-August. Similar shifts in the algal community of Lake Erie occurred when nutrient loadings were high. Excess algal growth resulted in increased rates of oxygen demand in the deep waters of Victoria with the result that waters below 40 m experience low oxygen concentration ((0-2 mg/L) for extended periods of the year. This is a significant change from 35 years ago when only the very deepest parts of the lake (>60 m) would experience only brief periods of low oxygen.

The poor oxygen conditions which now occur in Victoria in deep water profoundly affect fish distributions. Large areas of the lake bottom (Figure 10) now have insufficient oxygen to support fish life for much of the year. The area of the 40 m contour covers over 65% of the lake bottom. The last time a full stock assessment was taken (1969-1970) a substantial portion of the fish biomass, on average, were found below 40 m (Table 2). This loss of habitable space would have reduced stocks available if the fish community were the same now as it was in 1969-70. Of course, the community has changed completely. The catches then were dominated by hundreds of endemic species of haplochromines which constituted most of the biomass at all depths. Nile perch was rare and only occurred in shallower waters having been recently introduced in the late 1950's early 1960's. Nile tilapia was also rare, especially compared to the endemic *Oreochromis (Tilapia) esculentus.* Beginning in the late 1970's in Kenya and the early 1980's in Uganda and Tanzania, catches began to rise (Figure 11) to previously unknown levels. This rise was largely accounted for by Nile perch and to a lesser extent Nile tilapia, and it was accompanied by the disappearance of the endemic species of haplochromines from most catches.

The cooccurrence of the rise of Nile perch with the recognition that the lake had also undergone significant change raises the question of causation. Despite the loss of biodiversity of the haplochromines and reduction of some of the other endemic species, the Nile perch explosion was a great stimulus to the commercial fishery as catches rose by a factor of 5 after a long downward trend since the turn of the century. Increased effort is partly responsible for the higher catches as the fishing industry has responded to the abundance of marketable fish and has expanded to serve an export market. Most Nile perch is now sold to factories in the export trade, and this has raised concerns about the declining availability of fish for local markets. The reality is that the yield of landed fish in the early 1990's was around 500,000 metric tonnes which exceeded by a factor of two the estimated annul fish production based on the 1969 survey. Annual fish yields rarely exceed 0.4 of annual production for species living longer than one year. This major discrepancy together with the abundant evidence of eutrophication from limnological data suggest that the annual production of fishes has increased from earlier levels in response to increased primary production caused by higher nutrient loading. Current fish yields are readily supported by the amount of primary production currently measured in the lake.

When did Lake Victoria begin to become enriched. The answer to this can be found in the sediments of the lake where changes in abundance of the microfossils of algae record the changing nutrient history of the algal community. These sediments can be dated by natural radioisotopes and a time scale can be provided to assess when changes occur (Figure 12). Changes occur with the entry of European civilization into the Victoria basin when species of the diatom *Cyclostephanos* began to increase while other species of green algae e.g. *Botryococcus* began to decline. Change accelerated rapidly after 1960 as the formerly dominant large diatom *Aulacoseira* disappears from the sedimentary record while the diatom *Nitzschia* becomes dominant. The record of changes recorded by the algal record begins with the increase in human population which accompanied improved medical care and veterinary services and accelerated with population increase up to the present The plant commnity of the lake continues to respond to enrichment from nutrients as is shown by the recent successful colonization of the Lake Victoria by water hyacinth from the Kagera River. This weed needs high nutrient concentrations to grow and cannot compete with algae unless light is limiting algal growth and nutrient concentrations are very high. The current condition of Lake Victoria is a consequence of increasing human populations and their activities through their effect on increasing nutrient loading. The Nile perch introduced by humans in an attempt to boost sagging fish yields has also driven the change in the fish community.

To reverse the conditions of excess algal growth and deoxygenation would require actions to reduce the nutrient loading. Currently, information on point and non-point sources of nutrients are sparse, and only crude estimates of total nutrient and especially phosphorus loading are possible for Lake Victoria. Land disturbance, with consequent increased loss of phosphorus from the land surface, is the primary source of the phosphorus while municipal sources are secondary. The situation is somewhat similar to Lake Erie in the 1960's with the difference that anoxic conditions are widespread now in Victoria whereas low oxygen occurred only in a restricted area of Lake Erie for a short portion of the year. Anoxic conditions increase recycling of phosphorus from sediments and this feedback might delay recovery of Victoria. More study of the phosphorus budget is required to determine expected recovery time. The other nutrient of concern is nitrogen, but the atmosphere currently supplies much of the nitrogen required for algal growth through the activities of nitrogen fixing blue-green alga which now dominate the algae. Because current nitrogen loading is primarily from the atmosphere mediated by the nitrogen fixing blue-green algae, it is not controllable except through reducing the abundance of blue-green algae. Only phosphorus loading can be reduced through appropriate interventions in the watersheds from which it originates.

RESPONSE TO CHANGE

Lake Victoria has changed; we can all agree with this. More difficult to answer is why is this Great Lake changing, and what can be done about it. Change is part of life. When the pace of change is slow, living beings including humans can adapt. When the pace of change becomes too rapid, then many plants and animals less adaptable than humans can be lost from ecosystems; and the health and economy of humans can suffer. When the rates of change become exceptional and unexpected events affecting resources upon which we depend become normal (for example, frequent fish kills), then humans finally worry about sustainability. We must not let change create panic, but we must address it and understand causation. A hierarchical series of questions should be asked when the pace of change disturbs us. I suggest we ask these questions during this workshop about the sustainability of resource utilization in the Lake Victoria basin.

Is the perceived change positive or negative to our well being and that of our children?
Are we certain that the change is real, or could we be deceived?
If real, is the cause known of unknown?
Is the change due to natural or human causes?
If human induced, can the change be reversed?
Is the cause remote from us or local (can we here do something to reverse it or must we enlist assistance of others)?
Is the action required technically feasible (can it be accomplished)?
Is the required action socially acceptable (can people be motivated to the required action)?

When the world's second largest lake undergoes fundamental changes which may threaten our future use of its wealth, perhaps the biggest problem we have to overcome is the feeling of helplessness. I hope that I have convinced you that several of the changes in Lake Victoria are the consequence of population pressure on the land. I also hope that experience with large lakes in North America has demonstrated that these changes are reversible through concerted action when societies are motivated to address the causes. The questions above can all be answered for Lake Victoria except the last question. Perhaps, this workshop will start the process of answering it, and the most two important questions then remaining: WHO? and HOW?

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References: Full references to published literature and unpublished information are available from the author. The figures on Lake Erie recovery are from the *Journal of Great Lakes Research 13(4):1987.* The data on Lake Victoria stocks in 1969-70 are from A.W. Kudhongania and A.J. Cordone. *African Journal of Tropical Hydrobiology and Fisheries* 3:15-31.

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