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# Challenges for Management of the Fisheries Resources, Biodiversity and Environment of Lake Victoria



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## Fisheries Resources Research Institute


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IDRC CANADA

LAVEMP – Lake Victoria Environment Management Project – For Maximum Sustainable Benefits

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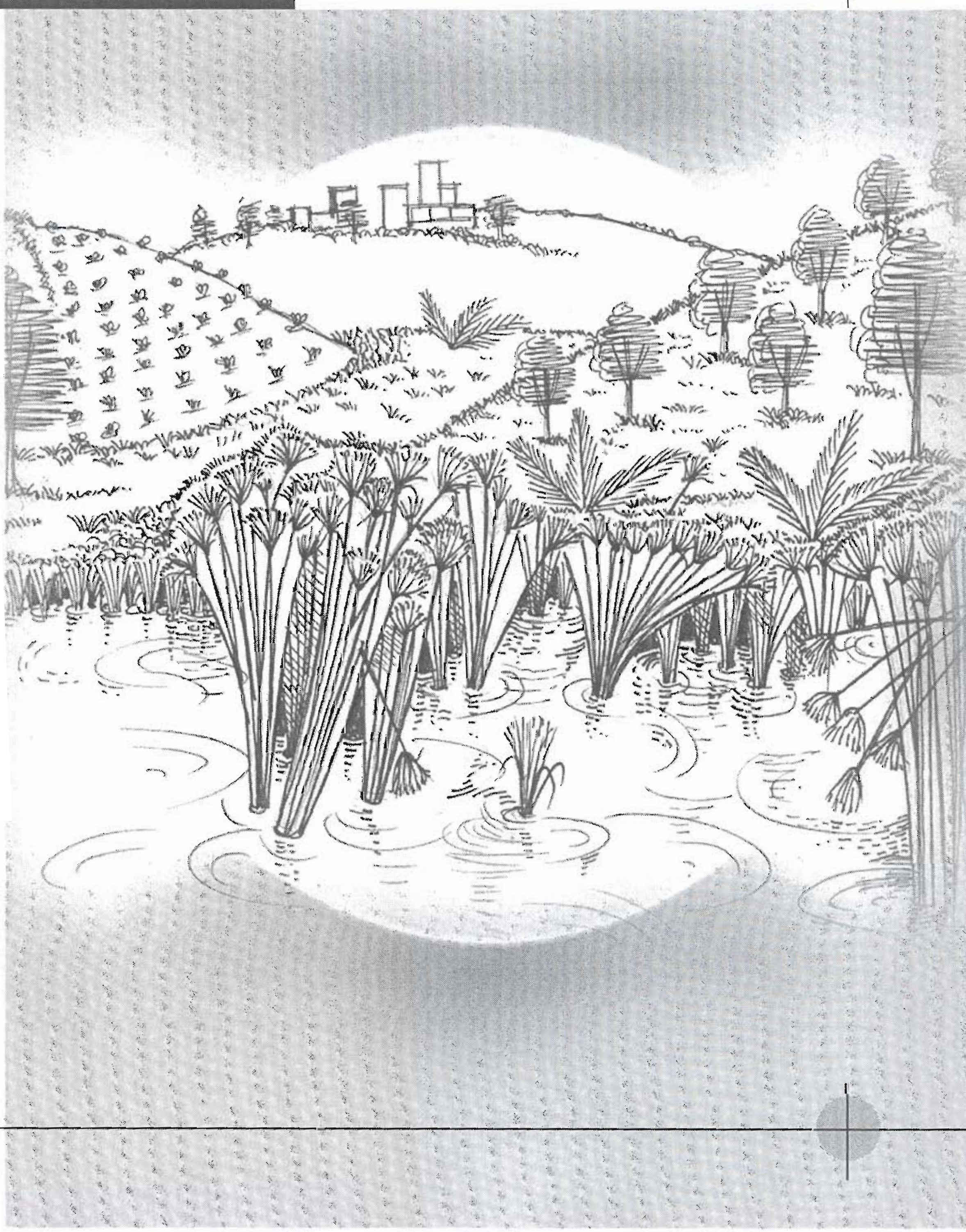
# CHAPTER EIGHT 8

## Management of Fish Quality and Safety



# 8.1. Potential Risks of Contaminants with specific reference to Mercury

*Linda M. Campbell*

## Introduction

Fresh water and fish are important to the people who live in the Lake Victoria region therefore the quality of the water and fish is of major importance (Johnson & Odada, 1996). It is well known that dirty water and spoilt fish can lead to poor health and lower standards of living, and that quality can be affected by the pollution in the environment.

Even though Lake Victoria is very large, it is relatively shallow and the water remains in the lake basin for a long time (Bootsma & Hecky, 1993). There are a number of environmental issues in Lake Victoria, including water hyacinth, over-population and increased farming causing problems with the lake ecosystem. All these factors combine to keep contaminants within the lake for long time, which will lead to gradually increasing concentrations in the lake.

Pollution is a term that covers a wide variety of chemicals and physical changes and their adverse effects on the environment. Here we focus on contaminants, which are unwanted chemicals introduced to the environment. Contaminants include a very wide variety of chemicals, both man-made and natural, for example, mercury, pesticides and herbicides, heavy metals, and natural plant and algae toxins. Many contaminants do not always lead to adverse effects immediately, but can gradually induce long-term problems leading to chronic illnesses and physical damage. A few contaminants have very rapid impacts resulting in immediately obvious changes such as death or injury.

Sources of contaminants are varied. Contaminants can get in the lake by the way of agricultural treatment of crops near the lake, industrial effluent, intentional introduction such as fish poisoning by fishermen, natural sources such as heavy metals from particular types of rocks, and even some plants naturally release their toxins. Contaminant sources are not always found near Lake Victoria. Because air has no boundaries, and can move from one country to another very quickly, air masses can carry contaminants from far away. For example, European and Middle Eastern industries can expel contaminants into the air, and the contaminants can be deposited far away in Africa or other continents. Another source that is of paramount concern in many countries is the automobile. Vehicles emit a nasty mixture of contaminants into the immediate air, including lead, mercury, nitrogen oxides, and organic contaminants, which can be breathed in by people around the car and also transported through the air into nearby lakes and agricultural crops.

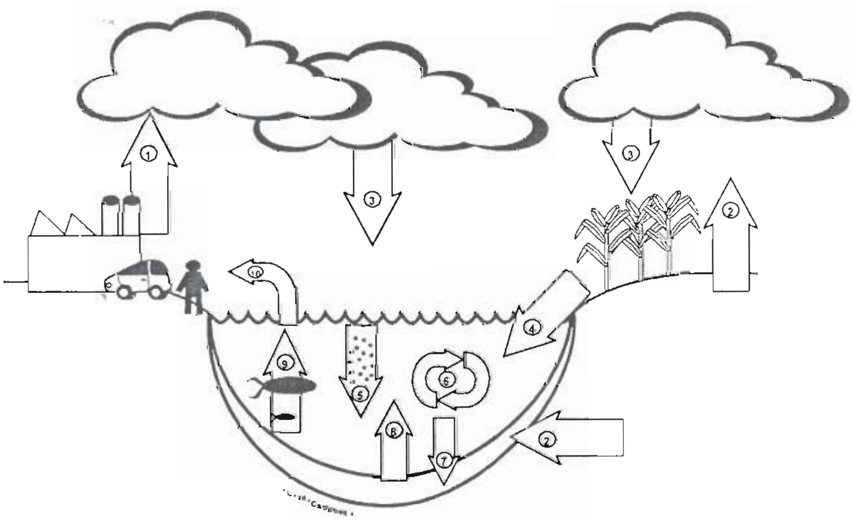


Fig. 8.1.1. Contaminant cycling. (1) is the emissions from manmade sources such as industries and automobiles, (2) is emissions from natural sources such as rocks and volcanoes, (3) is precipitation containing the contaminants, (4) is runoff from manmade sources such as fertilizers and natural erosion, (5) is the deposition of contaminants through the water, (6) is the chemical and bacterial transformation of the contaminants within the lake, (7) is the deposition of contaminants in lake sediments, (8) is the release of contaminants from sediment, (9) is the bioaccumulation through the food web, and (10) is the transfer of contaminants from water and fish to humans through diet and exposure.

Once contaminants enter the lake, they enter a complex cycle, which can be affected by the quality of the water, the type of organisms in the lake, and the interactions of different organisms and their environment. Bioaccumulation occurs when animals accumulate contaminants in their bodies from their diet and environment. A major concern for fish consumers is the amount of contaminants in the fish they eat because people can assimilate the contaminants into their own bodies that may lead to long-term problems. Different fish have different amounts of contaminants depending on their diet and where they live in the lake. Some fish such as Nile tilapia eat plant matter while other fish, such as Nile perch, feed on fish and insects. Food webs describe how fish and organisms feed within the lake, and what eats which. Within each food web, trophic levels can be determined by grouping organisms with similar feeding patterns. For example, plants and algae form the bottom trophic level, fish and insects that eat plants form the second trophic level, and fish that eat fish form the third trophic level. Other fish that feed upon the third trophic level are the fourth trophic level and so on. This has a very important bearing on how contaminants are bioaccumulated in organisms. Because individual organisms at a given trophic level must eat more than the lower trophic levels, they incorporate more dietary material, which includes contaminants. With increasing trophic level, it is very common to see increasing contaminants within the fish. As a result, large fourth-trophic level Nile perch will contain more contaminants than second trophic level Nile tilapia.

There have been very few studies done on contaminants in Lake Victoria, and most of them were done after 1980 (Campbell *et al.*, 2003). Thus there is no knowledge of the level of contaminants in Lake Victoria prior to 1980 especially in Uganda and Tanzania. Fortunately, there is a way to estimate the level of contaminants in the lake in the past and use this data to predict contaminant concentrations in the future (Ramlal *et al.*, 2003). Lake sediments have been laid down at semi-regular intervals since Lake Victoria was formed thousand of years ago, with the most recent layers near the top. In general, the deeper the layer is in the sediments; the older it is, and the specific age of these layers can be estimated using naturally occurring radioisotopes. It is possible to examine each layer and picture what the lake environment was when sediment layer was deposited. To collect many sediment layers, scientists lower special equipment with a hollow tube into lake sediments to obtain a narrow "core" of sediments. The core is then sliced and each slice can be analysed. For example, we can determine the contaminant concentrations in a layer within a core and correlate that to the age of the layer. This will provide a historical perspective of contaminant deposition in Lake Victoria, and help to determine if contaminant deposition to the lake has changed through time. Scientists can analyse other aspects, such as the hard parts of small organisms and plant matter, to determine if the lake environment has changed through time as well. All this data provides a valuable perspective on past changes and provides a means to predict future changes.

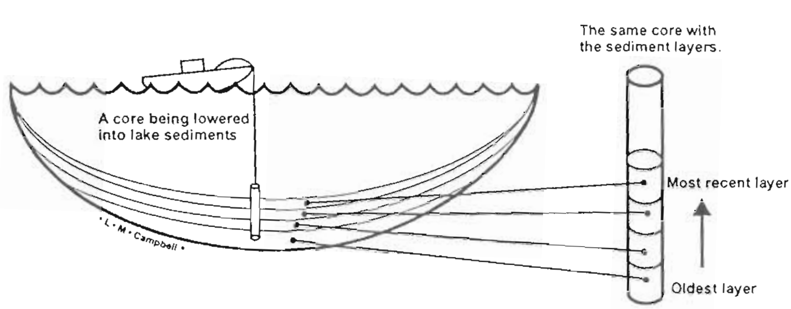



Fig. 8.1.2. How sediment cores are collected and the general age of sediment layer in a core.

When considering contaminants in water and fish from Lake Victoria, we must understand several important aspects:

1. Their chemistry and their effect on humans and animals
2. Their possible sources
3. Their behaviour in lakes and food webs
4. How much contaminants are found in fish and water?
5. What are the risks for human consumers? Will the risks increase or decrease in the future?

Table 8.1.1. The list of contaminants that have been analysed in and around Lake Victoria. We have listed what has been analysed (such as fish or water) and what is still unknown at the time of this publication

| Contaminant | Analysed in: | Not yet known for: |
|---|---|---|
| Mercury | Fish, soil, lake sediments, water, rain, and humans | Air |
| Pesticides and herbicides | Fish, invertebrates, lake sediments | Humans, air, water, rain |
| Heavy metals | Fish, soil, lake sediments, invertebrates, water | Humans, air, rain |
| Algal and plant toxins | Water, fish | Humans, invertebrates, lake sediments |

## Mercury

Mercury can be found in many forms in the environment, and fortunately, most forms are not toxic to humans or animals (World Health Organisation, 1989). However, methylmercury, the most common form found in fish and animals, is very toxic. When methylmercury reaches sufficiently high concentrations in humans, it strongly affects the brain and the nervous system, leading to permanent brain damage, blindness, and the inability to walk or use hands well (World Health Organisation, 1990). Consumption of methylmercury by young children under 15 years and pregnant women leads to the development delays in children and foetuses, and may lead to mental and physical retardation (WHO, 1990). Even at very low levels, methylmercury can affect the ability of children to learn as well as learning how to walk and talk. Methylmercury can cause these effects at extremely small doses: recent studies have indicated that regular diet consisting of more than 200 parts per billion (ppb) mercury may have negative effects. World Health Organization has suggested a recommended limit of 200 ppb for young and unborn children as a result of these studies (WHO, 1990).

Mercury is found both in natural and man-made forms. Rocks and soil worldwide naturally contain mercury compounds, which vary from one region to other. Volcanoes can emit mercury compounds which travel a long way through the atmosphere. Plants can take up and concentrate mercury from soil, and when burned, can release these mercury compounds to the atmosphere. Man-made sources include automobile emissions, battery manufacturing, and chloro-alkali water treatment plants. Mercury is found in a few anti-fungical applications, which have been banned in most countries (but is still in restricted use in Ethiopia and Sudan). A possible regional source of mercury is the goldfields in Tanzania and Kenya - gold workers use pure mercury to extract gold from ore, which leads to widespread mercury poisoning and illnesses among the workers. Locally, mercury compounds are found in some anti-bacterial soap and skin bleaching creams that should be avoided. Some Tanzanian goldfield workers and their families have been found to have high mercury concentrations in their blood, which are just below the threshold for serious poisoning effects (Ikingura and Akagi, 1996; Harada *et al.,* 1999). It is not known how developmentally delayed their children are.

Mercury compounds undergo a highly complex transformation cycle when they enter a lake, regardless of their initial form. Bacteria, water quality and algae all affect how mercury compounds transform and the balance of the different mercury compounds found in the lake. Some of the mercury is transformed to a gaseous form, which escapes the water surface, and some of the mercury is transformed to a dissolved form that cycles through the lake. When algae and plants incorporate mercury from the water, mercury can be transformed into methylmercury. This transformation and bioaccumulation process is continued through the food web, with the most methylmercury being found in predator fish such as Nile perch and eventually, human consumers of fish (Campbell *et al.*, 2003)

Recent mercury concentrations in most fish from Lake Victoria are below the safe threshold levels set by World Health Organization (200 ppb). At the moment, there is little concern about mercury poisoning in humans - even in young children from consuming tilapia or mukene. However, there is risk to young children and unborn babies if they eat Nile perch frequently. Small Nile perch below 5000 grams are probably safe, but large Nile perch over 5000 grams contain more than 200 ppb mercury, and should be avoided by pregnant women and young children (see Fig. 8.1.3).

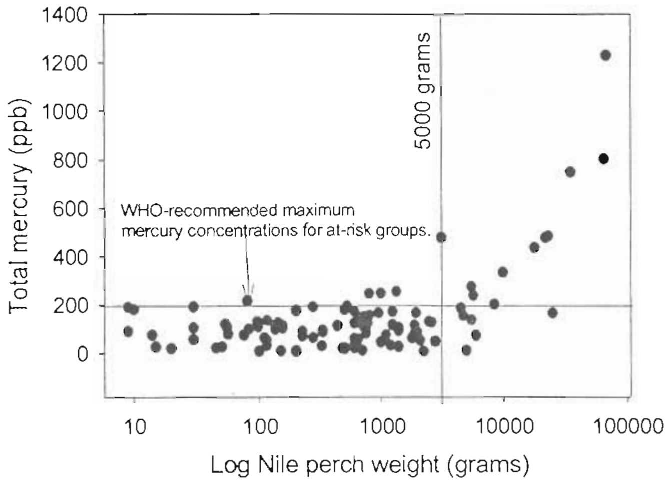



Fig. 8.1.3. This graph shows the mercury concentration in Nile perch from Ugandan, Kenyan and Tanzanian waters plotted against their weight. The data was compiled fro six different studies ( Campbell *et al.*, 2003). It shows that when Nile Perch reaches 5000 grams, their mercury concentration begins to exceed the World Health recommended Guidelines for risky groups including Women and children under 15.

Results from two cores taken in Ugandan waters of Lake Victoria suggest that mercury concentrations was low in lake sediments between 1900 and 1960, but started to increase steadily with maximum concentrations occurring between 1970 and 1980 (Ramlal *et al.*, 2003; Campbell *et al.*, 2003). Current mercury concentrations are similarly high levels in lake sediments, leading to concern that mercury may have increased in fish over time. The increases in mercury concentrations in the core coincide with increased industrial and economical development in East Africa around 1960's (Ramlal *et al.*, 2003; Campbell *et al.*, 2003). While mercury may be declining somewhat in more recent times, there is concern that with increased development, mercury concentrations in the lake will increase.

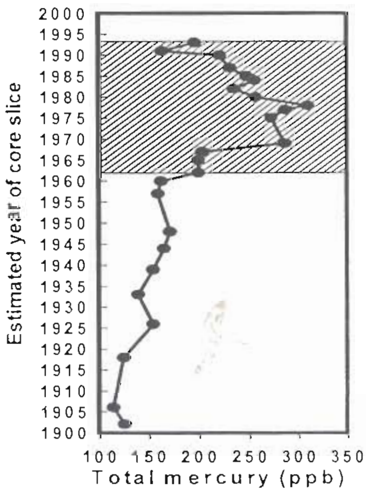



Fig. 8.1.4. Mercury concentrations from a core taken in northwestern Lake Victoria by Ms. P. Ramlal. The shaded area indicates when mercury concentrations increased after 1960. There is a decline in mercury after 1980, but concentrations are stil higher than before 1960.

## Pesticides and Herbicides

Pesticides and herbicides include a very wide range of chemicals, but the most commonly used pesticides and herbicides use chemicals called organochlorines and organophosphates. These organic compounds are highly effective against insects and unwanted weeds in agriculture and are used to control insects for public health reasons (i.e. mosquitoes, lice, termites, and other insects). Many of these compounds bioaccumulate very rapidly in fatty tissue of fish, animals and humans, and remain in these tissues for a long time. In addition, these compounds do not decay rapidly in the environment, and persist in soil, air and water for years. Persistent organic pollutants in lakes may transform to other forms; but this can be a slow process, and sometimes the new forms are even more toxic than the original form. In Uganda, there are no formal means of recording which type of pesticides are imported into the country, but it is known that legal pesticides consist about 29 % of chemical imports in 1992, which amounted to almost 3,000 metric tonnes (Kiremere, 1998). This value probably has increased due to increased modern agricultural practices in Uganda since 1992 (Kiremere, 1998).

Persistent organic pollutants (POPs) have a wide range of negative effects for exposed humans, including cancer, chronic illnesses, severely painful joints and other symptoms. Despite the many negative effects of POPs, the organic pesticides and herbicides are highly effective and allow for better agricultural yields and insect control than any other methods. Because of the highly useful nature of organic pesticides and herbicides, and their negative effects on human and environmental health, the manufacture, shipment and use of organic compounds are tightly controlled by international agencies. Many countries only allow the import and manufacture of a few organic compounds within their borders for specific purposes such as malaria control or protection of cash crops such as cotton. There are three sources of concern to Lake Victoria: farms and agricultural regions that use pesticides and herbicides, long-distance transport via air from other regions, and fish poisoning by fishermen who illegally use pesticide solutions to kill fish rapidly and cheaply (Kiremere, 1998). Table 8.1.2 outlines some of the pesticides and herbicides commonly used in East Africa for legal purposes.

Table 8.1.2. A list of selected common pesticides in East Africa, purposes and where used.

| Pesticide / herbicide | Used for: | Countries that allow this | Notes on usage since 1990 |
|---|---|---|---|
| DDT | Malaria-bearing mosquitoes | Kenya, Tanzania, Sudan, Ethiopia | Highly restricted, only for public health reasons |
| HCH compounds and Lindane | General insecticide | Uganda, Kenya, Tanzania, Sudan, Ethiopia, Rwanda | Restricted |
| Aldrin and dieldrin | Termite control | Uganda, Tanzania, Sudan, Ethiopia | Restricted, in some cases only used for emergencies |
| Heptachlor and chlordane | Termite and insect control | Tanzania, Ethiopia, Sudan | |
| Endosulfan | General insecticide | No data, probably allowed in all countries | No data, but may be used in Uganda for cotton crops |
| Round-Up (2,4,5-T) | Weed control | Tanzania, Uganda | Restricted in Uganda for research purposes |

A study in Germany showed that African immigrants had some of the highest concentrations of DDT and HCH compounds in their blood plasma when compared to immigrants from other countries (Schmid *et al.,* 1997). This is also true for fish from Lake Victoria: DDT and HCH compounds are most common in Nile perch from Kenya (Calamari *et al.*, 1995; Mitema & Gitau, 1990). This reflects the heavy use of DDT and HCH in most African countries. However, only one Nile perch out of 41 fish samples collected in 1988 was found to have DDT concentrations above the accepted threshold for human consumption (Mitema and Gitau, 1990). If one is concerned about exposure to organic contaminants in fish, then tilapia species and smaller Nile perch (less than 5000 grams) can probably be consumed safely, but the larger Nile perch should be avoided.

Fish poisoning with organic pesticides and herbicides was a serious issue in early 1999 when Uganda, Tanzania and Kenya faced the possibility of European Union fish bans due to contaminated fish. It is still a serious issue locally as some fish contain contaminant concentrations high enough to make any consumer ill or even dead. Common pesticides used include endosulfan, diothene and a pesticide mixture called "Ambush" originally intended for agricultural applications. In addition, Diazinon and Thiodan are used, mainly to collect Nile tilapia and Alestes spp - these chemicals can kill within 6 hours of being consumed by human beings. Poisoned fish exhibit a variety of symptoms based on what they were poisoned with, but in general, if the fish extrude reddish chemicals from the mouth and the anus, have very soft flesh or greyish or abnormally red gills, they should not be bought or consumed. Healthy fish have firm flesh, pinkish-red gills and clear eyes.

A core was collected near Kenya in Lake Victoria in 1990 for organic compound analyses. It was found that organic contaminants were fairly low in sediments, with the most contaminants being deposited between early 1950's and early 1990's (Lipiatou *et al.,* 1996). It is known that the use of organic contaminants has increased since 1970's, but in the early 1990's many organic pesticides, including DDT and HCH, were banned or highly restricted in many African countries (including Uganda, Kenya and Tanzania). It is expected that concentrations in fish will follow a similar pattern as seen in the North American Great Lakes. The North American Great Lakes suffered from a serious widespread DDT contamination for years before these compounds were completely banned in North America in the 1970's. However, DDT concentrations in fish continued to increase or remained at similar concentrations for many years. Only in the past few years, DDT concentrations in fish have declined and fish consumption warnings are still in effect in a few regions of the Great Lakes to protect local people. Given the persistent nature of these contaminants which remain in the environment for years, we may see an increase of organic contaminants in fish for a few years before decline is observed. An unfortunate aspect is that as development, industrialization and the use of automobiles increase in East Africa, there may be higher amounts of different organic compounds being introduced to Lake Victoria leading to higher organochlorine concentrations in fish in the future.

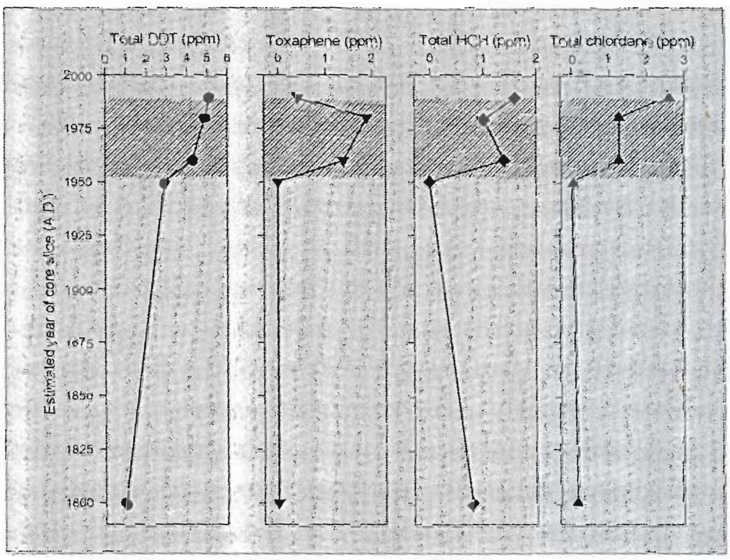



Fig. 8.1.5. Organochlorine concentrations in a core taken in Kenyan waters in 1990 by Dr Lipiatou and others (1996). The shaded areas indicate that organochlorines increased in the lake sediments just after 1950 which coincided with increased artmospheric transport and pesticides usage in the Lake Victoria region.Toxaphene was banned world-wide between 1970 - 1980 and there is a corresponding decrease in lake sediments. However, total HCH and Chlordane seem to be increasing in mordern sediments.

## Metals

Environmental metal and metalloid contaminants include arsenic, lead, zinc, iron, manganese, aluminium, copper and cadmium, and are commonly used in industrial and manufacturing processes. In large amounts, cadmium, arsenic and lead are highly toxic to humans and fish, and serve no useful biological function and can affect physical and mental functions (Nriagu, 1992; Biney *et al.,* 1994). Trace amounts of zinc, iron, copper, aluminium and manganese are important to the health of humans and fish, but can be highly toxic in very large amounts. Sources can include natural features such as volcanoes, rock formations, certain types of soil and disturbed earth resulting from human activities such as mining. However, man-made sources, including automobiles, manufacture of batteries, and metal processing factories are very important local sources of heavy metal contamination (Nriagu, 1992; Biney *et al.,* 1994).

Like mercury, metals can enter into a complex cycle in lakes and can undergo transformation that affects their toxicity and availability. However, unlike mercury and organic contaminants, most metals do not bioaccumulate easily in fish or animals through the food web. High concentrations in fish are only reached if there are high concentrations present in the lake sediments and in water.

Heavy metal concentrations in the Lake Victoria sediments in Kenya and Uganda are low (Mothersill, 1976; Onyari & Wandiga, 1987). Metals in sediments found in the highest concentrations include iron, manganese, zinc and copper in that order, and are not found at concentrations sufficient to warrant concern (Mothersill, 1976; Onyari & Wandiga, 1987). There is a higher amount of lead in sediments near Kisumu and Kampala, suggesting that lead contamination is a concern, probably due to the higher number of vehicles using leaded petrol and increased discharge of untreated wastewater in the region (Calamari *et al.,* 1995; Kiremire, 1998; Onyari & Wandiga, 1987). High copper concentrations in sediments have been found in Kenya near River Nzoia which has several paper processing factories and sugar refineries (Onyari & Wandiga, 1989). Aluminium and iron have been found in water at concentrations slightly higher than safe drinking water guidelines in Kenya, but with proper water treatment, these heavy metals should be reduced to safe levels (Onyari & Wandiga, 1989). Fish sampled in Kenya in 1987 were found to have safe concentrations for human consumption, including manganese, iron, copper, zinc, cadmium and lead (Wandiga & Onyari, 1987). Clams sampled in Kenya in 1995 showed high iron and copper concentrations, which were still below human safe thresholds (Onyari & Wandiga, 1989; Wandiga & Onyari, 1987). Fortunately, lead and cadmium, two of the most toxic heavy metals, were not detected in clam tissue. Coco-yam tubers sampled near sewage discharge plants in Kampala, Uganda in 1994 had high iron, lead, zinc and copper concentrations that were above toxicity thresholds, and should be avoided for human consumption (Kiremire, 1998). Considering the similarity of heavy metal concentrations in sediments between Uganda and Kenya, Ugandan fish is likely to have the same low concentrations of heavy metals as well and are probably safe for consumption by humans, but it is recommended that fish caught near sewage and waste discharge outlets be avoided.

## Natural Toxins

Algae are tiny plant-like cells that either float suspended in the water or grow along the bottom of the lake. Both algae and plants can produce toxins that can leach out into the water and affect any organism, fish or human that comes in contact with the contaminated water. These algal and plant toxins are found worldwide and can cause symptoms which can include, depending on the toxin type, skin rash, serious breathing difficulties if inhaled, nausea, headaches, and vomiting. In sufficient quantities, algal and plant toxins can cause death in fish and humans (Codd *et al.,* 1999). Blue-green algae toxins (microcystin toxins) have been associated with tumours in fish and humans and liver failure in humans (Falconer, 1999). One sub-group of algal toxins (lipopolysaccharide toxins) can cause malaria-like symptoms for 24 hours in exposed humans who drank contaminated water (Codd *et al.,* 1999). Such symptoms have been observed in people living near Winam Gulf when they showered in untreated hot water containing high amounts of algal toxins (Ochumba & Kibaara, 1989). Plant toxins are not common in Lake Victoria, but have been long associated with fish poisonings near shore where fishermen set out a container holding shredded terrestrial toxic plants to rapidly kill or paralyse fish in the water. These toxins disperse slowly, and may put nearby swimmers or bathers at risk.

Algal blooms have been associated with increasing nutrient content in the lake, and under the right conditions of nutrient supply and adequate light, can produce toxins . Excess nutrients come from increased agriculture leading to soil erosion and fertilizer entering the lake. Blooms have been increasing in recent years, and many are composed of three types of algae, *Cylindrospermopsis, Microcystis* and *Anabena* which all are known toxin producers. Research into the occurrence of algae blooms and algal toxins in Lake Victoria is still preliminary, but there has been detectable toxins occurring near algal blooms, some reaching concentrations high enough to affect fish. Dead fish have been found near the algal blooms in Uganda and Kenya, but fish kills have not yet been directly connected with algal toxin production.

Fishermen can also poison fish using natural plant toxins instead of organochlorine pesticides. For example, in Tanzania, fishermen use extracts from the following plants: the milk-plant, *Euphorbia tirucalli*, and the muluku plant (or "fish bean"), *Tephrosia vojeli* while Kenyan fishermen use the mbaraka plants *Cassia falla*cina or *Cassia didymobotra* and the nongo tree, *Albizia gummifera*. H.D.J. Mrosso of the Tanzania Fisheries Research Institute (Mwanza) and Kenneth Werimo of the Kenya Fisheries Research Institute (Kisumu), who have studied the fish poisoning problem, found the practice most serious in Tanzania, where a greater variety of poisons are used, especially around Musoma. It is only slightly less severe in Uganda and Kenya.

At this moment, it is difficult to determine the risk to humans because very little is known about these toxins in Lake Victoria. The best way to avoid toxin-related illnesses is to avoid eating dead fish from near algae blooms or fish poisoning sites, and avoid swimming in or drinking untreated water exposed to algal blooms or plant poisons. Fish that have died from algal toxins or fish poisoning are typically soft, with greyish or foamy gills, as opposed to firm flesh and red gills. The areas of the lake with algal blooms typically have a greenish scum on the surface and the water will have a strong smell and taste, either like grass or rotten garbage. At the moment, the only known way to control these toxins is to regulate the nutrients feeding the algae. It is possible to reduce excess fertiliser, nutrients and soil erosion entering the lake by maintaining proper agricultural practices and monitoring land use. If nutrient input into Lake Victoria increases, then it is predicted that toxic algal blooms will increase in the future.