# LIMNOLOGY OF LAKES AND RIVERS (ZIMBABWE)

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## Contents



## Summary

Considerable limnological information for lakes Kariba and Chivero starting from their formation to the current state is available. For Lake Kariba the focus of the studies has been to understand the hydrobiological changes in a man-made impoundment with regards to water quality and the aquatic fauna and flora. This information is presented in this review. Interest on Lake Chivero has been primarily to understand the impact of pollution on a reservoir that serves as a major source of drinking water for the city of

Harare. Inadequacy of water and lack of a reliable water supply has led to the policy of reintroduction of "treated" municipal wastewaters into Lake Chivero. The introduction of treated effluent has resulted in enrichment and extremely high productivity in the lake. At present Lake Chivero is a system under extreme pressure both as a source of water and as a means of waste removal for the city of Harare, two diametrically opposing functions. Data on other systems are very scant and the future thrust in limnological research should focus on studying other lakes and rivers.

## 1. Introduction

Limnological studies in Zimbabwe are linked to the establishment of artificial impoundments in the country. These impoundments provided opportunities for studies of the limnology of reservoirs (Sanyanga & Mhlanga 2004). Since Zimbabwe has no natural lakes and very few perennial rivers this has necessitated construction of dams across main river systems in order to ensure adequate water supply. There are reservoirs of varying sizes, one of the largest being Lake Kariba that was built in 1958 to supply hydroelectric power to Zimbabwe and Zambia. Approximately 10 747 listed dams in Zimbabwe are 5 ha or less in surface area. Limnological studies have focused on large water bodies mainly Lake Kariba and Lake Chivero while other water bodies and rivers are less studied if at all.

## 2. Limonology of Lakes

Limnological studies on Lake Kariba and Lake Chivero have contributed to the knowledge on tropical reservoirs. For Lake Kariba, studies commenced immediately upon its impoundment with a focus of understanding hydrobiological changes due to the creation of the lake while for Lake Chivero it has been to understand the impact of anthropogenic pollution. There is paucity of data on riverine limnology except for affluent rivers to the two reservoirs with respect to their impact as sources of nutrients and pollutants.

### 2.1. Geographical and Ecological Setting of Lake Kariba

Lake Kariba (16º 28´ - 18º 06´S; 26º 40´ - 29º 02´E) is a tropical man-made reservoir that was created in 1958 by damming the Zambezi River at the Kariba gorge (Figure 1). It is situated on the border between Zambia and Zimbabwe and is shared by the two countries. It is 485 m above sea level (Balon & Coche 1974). The lake has an area of 5 820 km$^2$ at maximum storage level or 4 325 km$^2$ at lowest drawdown; stretches for 276 km in an East-West direction; has an average width of 19 km while the maximum depth is 120 m and the mean depth is 29.5 m. Some of the morphometric features of Lake Kariba are presented in Table 1.

| Parameter (unit) | Value |
|---|---|
| Length (km) | 280 |
| Mean breadth (km) | 29.4 |
| Surface area (km$^2$) | 5 500 |
| Volume ($10^6$ m$^3$) | 160.5 |
| Mean depth (m) | 29.2 |

| | |
|---|---|
| Maximum depth (m) | 120 |
| Shoreline length (km) | 2 164 |
| Catchment area (km$^2$) | 663 820 |
| Altitude (m) | 485 |

Table 1. Morphometry of Lake Kariba (Source: Coche 1974)

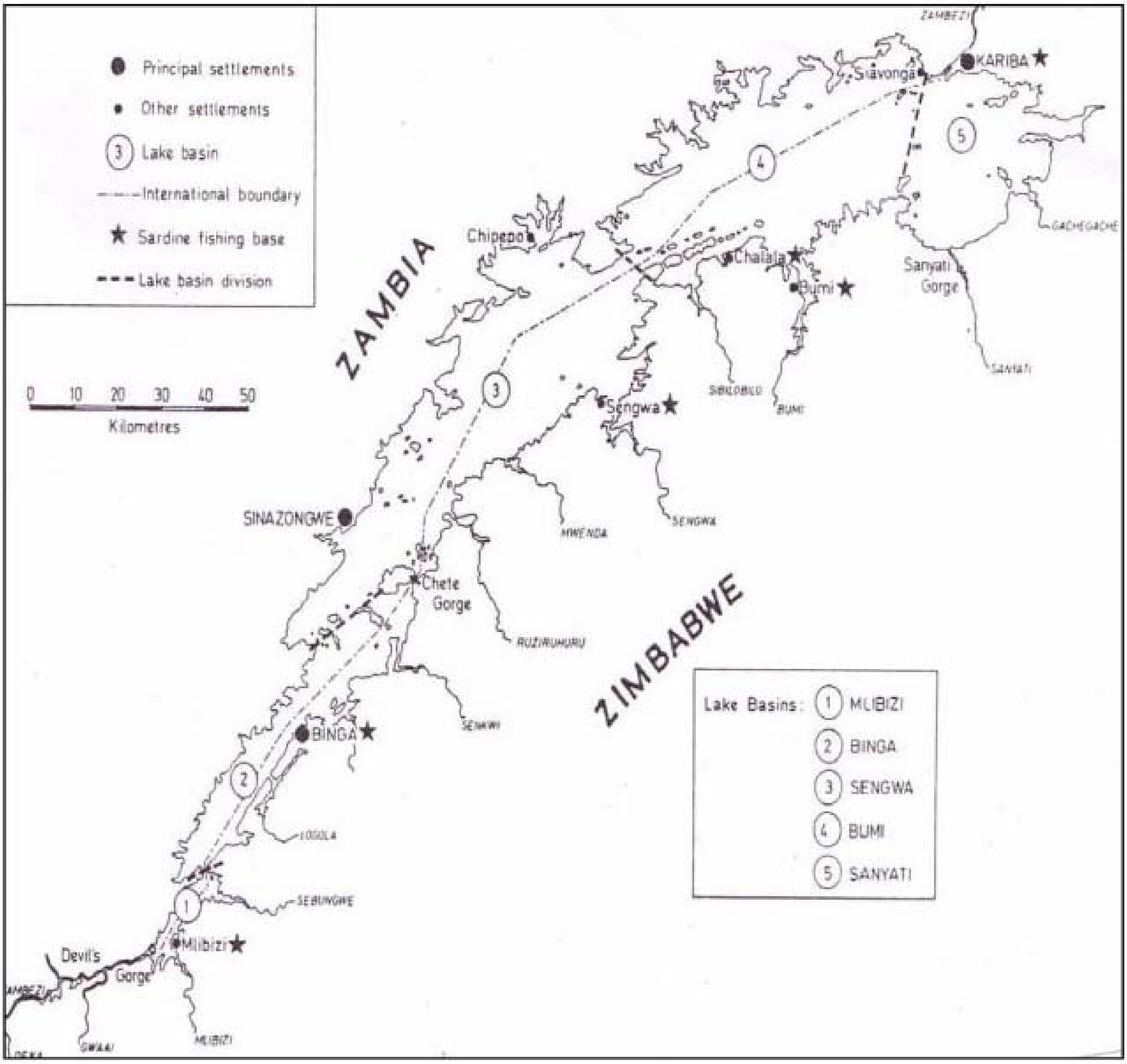


Figure 1. Location map of Lake Kariba showing division into 5 basins.

Lake Kariba can be divided into five geophysical basins along its long axis (Figure 1) (Coche 1974). Each of the basins is limnologically distinct and affluent rivers of each basin influence that part of the lake in the immediate vicinity of their entry (Begg 1969). Basins 1 and 2 have riverine characteristics for six months of the year (Moreau 1997) due to the strong influence of the Zambezi River. Basin 1 is riverine, turbid and richer in nutrients and thus has higher densities of phytoplankton and zooplankton. The flow of the Zambezi River creates strong water currents between February and April in Basin 1 and the upper half of Basin 2. Basins 1, 2, 3, 4 and 5 hold approximately 0.7%, 10.4%, 34.5%, 29.2% and 25.8% of the lake's total volume respectively and each covers 1.7%, 12.5%, 37.6%, 25.6% and 22.6% of the lakes surface area respectively (Table 2). The other 3 basins are lacustrine all year round since the influence of the Zambezi River is less in the lower reaches of the lake. These three basins are mainly influenced by local climatic conditions (Coche 1974) although the hydrology of Sanyati River strongly affects Basin 5 (Masundire 1997). Basin 3 is the largest of the five basins.

| Parameter | Basin 1 (Mlibizi) | Basin 2 (Binga) | Basin 3 (Sengwa) | Basin 4 (Bumi) | Basin 5 (Sanyati) |
|---|---|---|---|---|---|
| Length (km) | 23 | 56 | 96 | 59 | 46 |
| Mean breadth (km) | 4 | 12 | 21 | 23 | 27 |
| Surface area (km) | 91 | 677 | 2033 | 1386 | 1223 |
| Mean depth (m) | 13 | 24 | 27 | 33 | 33 |
| Volume ($10^6$ $m^3$) | 1 | 16 | 54 | 46 | 40 |

Table 2. Summary of basin morphometry of Lake Kariba

The Zambezi River, which covers a catchment area of about 1.19 X $10^6$ $km^2$ contributes 80% of the inflow into the lake (Coche 1974). Nutrient-poor Kalahari sandy soils cover most of its upper catchment and the river therefore brings in nutrient poor water causing low productivity in the lake. The main purpose for creating Lake Kariba was to generate hydroelectric power, but it now supports an open water fishery for the introduced sardine, *Limnothrissa miodon* (Boulenger) and an inshore fishery taking about eight native and one exotic (Nile Tilapia-*Oreochromis niloticus*) species, of which cichlids are the most important. The productivity of the lake is mainly influenced by nutrients released from the hypolimnion at turnover (June-August) and during the rainy season when nutrients are flushed into the lake from inflowing rivers and when nutrients are leached from the shore as the lake level rises (McLachlan 1970).

### 2.1.1. Limnochemistry

Lake Kariba is a warm monomictic lake of meso-oligotrophic character. It experiences wide seasonal fluctuations in water temperature (17$^o$C-32$^o$C) and undergoes turnover in July-August at a temperature of 20-22$^o$C with a period of maximum stability between December and April (Moreau 1997). The total mineral content of the pelagic surface waters is characterized by low total solids, salinity and conductivity (Balon & Coche 1974).

The lake has undergone two distinct phases since its creation, a post-impoundment eutrophic or nutrient-rich phase and an oligotrophic or nutrient-poor phase. The eutrophic phase caused by the decay of newly inundated organic matter (van der Lingen 1973) lasted for about five years. It was characterized by anoxic conditions in the hypolimnion that lasted for eight months of the year, conductivity levels of 111 µhmos and the highest concentrations of nitrogen and phosphorus ever recorded for Lake

Kariba (Thornton 1980). As the lake water chemistry stabilized from 1963 to 1967 it assumed characteristics of a slightly alkaline, warm monomictic impoundment and after 1967 the lake become mature. Physico-chemical characteristics of the lake have been stable since then. Dissolved oxygen levels range between 7.6 - 7.8 mg $L^{-1}$ in the epilimnion and 0.82-0.89 in the hypoliminion (ILEC 1998). Coche (1974) reported ranges of nitrate concentrations of 30-60 µg $L^{-1}$ in Basins 1 and 2 and 10-27µg $L^{-1}$ in Basins 3, 4 and 5. Masundire (1997) recorded concentrations of < 10 µg $L^{-1}$ from Basins 1 to 4 and in Basin 5 concentrations of approximately 10 µg $L^{-1}$. Phosphate-phosphorus concentrations ranged from trace to 50 µg $L^{-1}$ in Basins 1 and 2 and from trace to 72 µg $L^{-1}$ from Basins 3 to 5 (Coche 1974). Recently levels of 5.7 µg $L^{-1}$ (range 0.9- 13 µg $L^{-1}$) have been recorded (Mhlanga *et al*. 1999). Nutrient concentrations have remained relatively constant in the pelagic waters.

Lake Kariba is stratified from about August until May when overturn takes place and it becomes isothermal. Nutrients retained in the hypolimnion during stratification are released at turnover. The thermocline shifts from 20 m to 39 m as it develops from September to March and its depth varies from basin to basin ranging from 12 to 51 meters (Balon & Coche 1974). Conductivity ranges from an average of 95 µS $cm^{-1}$ in Basin 1 to 100 µS $cm^{-1}$ in Basin 5. The water in Lake Kariba is principally phosphorus limited for most of the year with a possibility of nitrogen co-limiting at other times (Moyo 1991).

Magadza (2000) noted a tight cycling of phosphorus and an estimated input of up to 1 025 tonnes of phosphate. Phosphorus however becomes barely detectable in the epilimnion by end of the dry season. High dissolved phosphorus levels occur following the rainy season (April) and at turnover where an internal release of phosphorus from deep waters occurs. Nitrogen content is estimated to vary from 1 500 tonnes at peak levels to about 900 tonnes towards end of the year and a minimum of about 150 tonnes in June. However there is rapid nitrogen utilisation in the photogenic layers throughout the year (Magadza 2000). Epilimnetic nitrogen ($NO_2$ +$NO_3$) ranges from 5 mg $L^{-1}$-30 mg $L^{-1}$ while hypolimnetic nitrogen is estimated at 100 mg $L^{-1}$ (Magadza 2000). Shallow inshore areas have higher levels of nitrogen than the deep open water. The general productivity of the lake is linked to nutrient fluxes during the rainy season and at turn over.

### 2.1.2. Phytoplankton

During the filling phase large algal species mainly desmids and benthic diatoms, relics from the riverine community (Conberg 1997) were dominant while the cyanobacteria *Microcystis* became dominant in the pelagic zone during the eutrophic phase (Mitchell 1969, Balon & Coche 1974, Thomasson 1980). After the lake attained an oligotrophic status blue-green algal blooms only occur in nutrient rich river estuaries. Phytoplankton species diversity in the lake only increased following the decline in nutrient levels as the lake assumed an oligotrophic status. *Microcystis* abundance also declined. Ten genera/species which included the blue-green algae *Anabaena* spp., *Microcystis* spp. and *Planktothrix agardhii*; the green algae *Eudorina elegans* and *Volvox* spp.; the diatoms *Melosira* spp. ( = *Aulacoseira*) and *Synedra* spp., the dinoflagellates *Ceratium* cf. *furcoides*, *Peridinium gatunense* and *P. volzii* var. *cinctiformis*; the chrysophyte, *Dinobryon sertularia*.were recorded between 1959-1964 (Cronberg 1997). The number increased to 150 algal taxa between 1986 and 1990, the dominant being green algae, blue-green algae, chrysopytes and diatoms. The blue-green algae were the most abundant with a representation of 40 taxa including *Aphanocapsa*, *Aphanothece*, *Chroccoccus* and *Microcystis*. Presently the most common phytoplankton is *Cylindrospermopsis raciborskii* and the diatom genera *Aulacoseira* and *Synedra* (Conberg 1997). The number of species recorded within the algal groups in Lake Kariba between 1986-90 is shown in Table 3.

| Algal group | Number of species |
|---|---|
| Cyanophyceae | 41 |
| Chlorophyceae | |
| Volvocales | 6 |
| Tetrasporales | 2 |
| Chlorococcales | 42 |
| Desmidales | 14 |
| Bacillariophyceae | 12 |
| Chrysophyceae | 16 |
| Haptophyceae | 1 |
| Cryptophyceae | 4 |
| Dinophyceae | 6 |
| Euglenophyceae | 8 |
| Raphidophyceae | 3 |
| Total numbers | 155 |

Table 3. The number of species recorded within the algal groups in Lake Kariba (1986-90) (Source: adapted from Cronberg 1997)

The blue-greens (*Cylindrospermopsis* and *Anabaena* ~ 80%) attain the maximum biomass during the rainy season (December –January) while diatoms (*Aulacoseira*, *Cyclotella*, *Synedra)* attain a maximum biomass at turn-over (June-July). The average biomass in 1982—83 was estimated to be 0.29 mg $L^{-1}$ about 60% being blue-green algae mainly genera *Cylidrospermopsis* and *Anabaena* (Ramberg 1984). Cronberg (1997) also observed that biomass rarely exceeded 1 mg $L^{-1}$ (range 0.2-0.9 mg $L^{-1}$) except when occasional blooms of *Anabaena* in Basin 1 attained a biomass of 7.8 mg $L^{-1}$. The mean biomass in the pelagic zone ranges from 0.5 –1.3 mg $L^{-1}$. The horizontal distribution shows a decrease of the proportion of blue-green algae from the inflow of the Zambezi River in Basin 1 to the outflow in Basin 5. With respect to phytoplankton the lake has reached stability and a regular seasonality pattern has been established (Cronberg 1997). Phytoplankton follow a cycle with a major peak in abundance in July following overturn and a smaller one during the rainy season when rivers are flowing. An average biomass of 4.5 $gm^{-2}$ (fresh weight), primary production of 0.42 g C $m^{-3}$ $d^{-1}$ or 4.2 g $m^{-2}$ $d^{-1}$ (fresh weight), daily turnover rate of 0.933 and annual P/B ratio of 340 have been estimated (Cronberg 1997). The annual phytoplankton primary production for Lake Kariba has been estimated to be 7.65 million tonnes (fresh weight) equivalent to 765, 000 tonnes of C (Cronberg 1997).

### 2.1.3. Zooplankton

Prior to the introduction of *Limnothrissa miodon* (1967-1968) larger cladocerans (*Diaphanosoma* and *Ceriodaphnia*) and calanoid copepods (diaptomids) were dominant while small cladocera, nauplii and rotifers were unimportant (Marshall 1997a). Due to predation larger crustaceans, the diaptomids, *Ceriodaphnia* and other daphniids declined in abundance and presently the zooplankton assemblage is dominated by two small species *Bosmina longirostris* and *Mesocyclops leukartii* (Masundire 1997). The dominance of small species has been attributed to predation by *Limnothrissa miodon* (Masundire 1989). Masundire (1989) recorded 57 zooplankton species from the pelagic zone of Lake Kariba, comprising 40 species of rotifers, 9 cladocerans and 8 copepods (Table 4). Later Masundire (1997) recorded 21 species in the pelagic zone and noted that crustacean species composition was uniform throughout the lake except for *Daphnia lumholtzii* recorded only in Basin 1. Similarly to phytoplankton, the biomass of the pelagic crustacean zooplankton is linked to nutrient dynamics, being characterized by two peaks of high density that coincide with periods of high nutrient fluxes (Masundire 1994). The first density peak in January-February dominated by *Mesocyclops leukartii* is associated with the rainy season and the second major one in June-August coincides with turnover and is dominated by *Bosmina longirostris*. *Bosmina longirostris* is the most dominant species in all basins (Masundire 1997). Zooplankton densities are highest in Basin 1 followed by Basin 2 and then Basin 5 in response to the gradient in nutrient concentration.

| |
|---|
| **Subclass Branchiopoda** |
| **Order: Cladocera** |
| *Alona* sp. Baird 1850 |
| *Bosmina longirostris* O.F. Muller 1785 |
| *Ceriodaphnia cornuta* Sars |
| *C. dubia* Sars |
| *Chydorus sphaerica* O.F. Muller |
| *Daphnia lumholtzii* Sars |
| *Daphnia laevis* Burge |
| *Diaphanosoma excisum* Sars |
| *Moina micrura* Kurz 1874 |
| |
| **Subclass: Copepoda** |
| **Order: Cyclopoda** |
| *Mesocyclops ooganus* Onabamiro 1957 |
| *Macrocyclops albidus* (Jurine) |
| *Microcyclops* sp. |
| *Thermocyclops emini* (Mrazek) |
| *T. neglectus* Sars 1901 |
| *T. hyalimus* (Rehberg) |
| |
| **Order: Calanoida** |
| *Thermodiaptomus syngemes* (Keifer) |
| *Tropodiaptomus kraepeline* (Pope and Mrazek) |
| *T.hutchinsonii* (Keifer) |
| |

| |
|---|
| **Order: Harpacticoida** |
| One unidentified species |
| |
| **Order: Ostracoda** |
| One unidentified species |
| |
| **Subclass: Malacostraca** |
| **Order: Decapoda** |
| *Caridina* sp. |

Table 4. Pelagic crustacean plankton of Lake Kariba (Source: Masundire 1997)

### 2.1.4. Aquatic Weeds

*Salvinia molesta* was the dominant floating aquatic weed during the eutrophic post-impoundment phase when the lake was filling (Marshall & Junor 1981) from 1958-1963. It grew rapidly during Lake Kariba's early years and, by 1963, it covered almost 22% of the lake's surface, approximately 1 003 $km^2$ (Mitchell 1969). In 1964 following a rapid drop in lake level there was a massive kill of *Salvinia* by stranding. In the mid-1970s its extent decreased as the lake assumed oligotrophic status and is now no longer an important species on the lake. The decline of *Salvinia* was partly attributed to biological control by a grasshopper, *Paulinia acuminata* whose introduction in the lake coincided with the receding of lake level and the decline in nutrient levels.

Following the decline of *Salvinia molesta*, submerged macrophytes colonised the lake (Mitchell 1969, Machena 1989). Submerged macrophytes appeared more slowly, beginning with *Potamogeton pusillus*, followed by *Lagarosiphon ilicifolius* in 1966, *Vallisneria spiralis* in 1969 and *Najas horrida* in 1971 (Donnelly 1969, Bowmaker 1973). These species are now the most important and widespread submerged macrophytes in the lake (Machena & Kautsky 1989).

Their earlier establishment had been suppressed by the exclusion of light to the bottom by mats of *Salvinia molesta*. A succession had been observed where *Potamogeton pusillus*, *P. schweinfurthii*, *V. aethiopica*, which were dominant in the early stages, were competitively excluded by *L. ilicifolius* which was first noticed in 1966 and is now the dominant submerged and rooted macrophyte (Machena & Kautsky 1989).

*Eichhornia crassipes* appeared in the late 1980s and is now the dominant floating macrophyte along the shoreline, although, unlike *S. molesta* in the 1960s and 70s, it does not form extensive mats or cover large areas of the lake's surface (Mhlanga 2001). It was first observed in estuaries in Basin 5 in 1988 and by December 1994 it had covered all the sheltered estuaries, bays and shallow waters of the lake.

However permanent mats did not occur in open water. The chemical 2,4D was used to control the potential spread over the whole lake in August and December 1988, although the weevil *Neochetina eichhorniae* had also been already introduced (Mhlanga *et*. *al*. 1999).

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