INSHORE FISHERIES AND FISH POPULATION CHANGES IN LAKE KARIBA

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1. INTRODUCTION

Since the creation in 1958 of Lake Kariba, situated on the Zambezi River and shared between Zambia and Zimbabwe, substantial changes in both its fisheries and in the fish communities have been observed. Although probably one of the best studied fresh water systems in Africa (Karenge and Kolding, 1995a), the sustainable exploitation levels of its fish communities are still largely unknown (Anon., 1992; Kolding, 1994). Fear of overfishing, or at least indications of fully exploited resources, has repeatedly been expressed (Marshall, 1981; Marshall, Junor and Langerman, 1982; Kenmuir, 1982; Marshall 1985, Machena and Mabaye, 1987; Marshall and Langermann, 1988; Moyo, 1990; Scholz, 1993; Sanyanga, Machena and Kautsky, 1995; Sanyanga, 1995; Machena and Kwaramba, 1997), whereas other studies have contested these views (NORAD, 1985; Ramberg *et al*., 1987; Marshall, 1992; Machena, Kolding and Sanyanga, 1993; Kolding, 1994; Karenge and Kolding, 1995a). Most of the attempts to calculate sustainable yields (Marshall, Junor and Langerman, 1982; Marshall, 1985; Moyo, 1986, 1990) are from classic fisheries stock assessment models based on catch and effort variables, with the underlying basic assumption of ecological stability and constant regenerative capacity. Most of the results from these analyses have proven of dubious value (see Box 5.2 in Volume I).

Lake Kariba is not a stable system as most other small or medium sized lakes in Africa. Karenge and Kolding (1995b) showed that the environment, in terms of the changing hydrological regime, explains a large proportion of the variability in catch rates (CPUE). They concluded that Lake Kariba was an allothropic riverine lake where productivity was largely driven by the nutrient pulses carried by the annual floods. The question is therefore how much of the observed changes can be attributed to fishing activities and how much is due to natural environmental fluctuations. Another important management issue, particularly on the Zambian side, is the high fishing pressure and changing fishing pattern in terms of increased use of small mesh sizes and customary use of illegal fishing methods such as drive fishing (Kutumpula). It is widely believed that such uncontrolled development is a potential sign of overfishing and poses a threat to the biodiversity (FAO, 1992; Lowe-McConnell, 1994; Pitcher, 1995). On the other hand, in highly variable systems, susceptibility to increased fishing effort is thought to be low, while resilience is high and recovery potential is rapid.

Lake Kariba is a man-made grand-scale ecological laboratory with a unique chance to observe and monitor the intricate pathways of natural succession under exploitation, and a relatively good catch and effort monitoring scheme has been in place since its creation. In addition, the inshore fisheries of Zambia and Zimbabwe have evolved differently and have been subject to different types of management regimes (see Bourdillon, Cheater and Murphree, 1984; Malasha, 2003; Jul-Larsen, 2003 and Overå, 2003 for a detailed historical account and analysis). Since the overall fishing effort, catch rates and fishing patterns on the two sides of the lake are very different due to different management and enforcement, a comparative study may shed some light on the impact that these different fisheries have on each side of the same ecosystem.

After a brief description of the physical and biological environment, and the different management regulations in place, we will use the long-term time series of commercial and experimental catch rates available to describe and discuss the observed development and changes on both sides of the lake. From this comparison we will evaluate the impact of fishing on the fish stocks relative to their natural succession and fluctuations in the environment.

There are two distinct fisheries in Lake Kariba: the low cost, non-mechanized, multispecies, inshore artisanal fishery, and the highly mechanized, capital intensive, semi-industrial single-species offshore fishery on the introduced pelagic clupeid Kapenta (*Limnothrissa miodon*). The biological, technical, and socio-economic interactions between these two fisheries are so small (Karenge and Kolding, 1995a; Bourdillon, Cheater and Murphree, 1985) that the fisheries must be treated separately. As the particular problems of the industrial Kapenta fishery are not the main focus of this study, it will be described and analysed only cursorily.

2. BACKGROUND INFORMATION

2.1 The environment

Lake Kariba (277 km long; 5 364 km^2; 160 km^3; 29 m mean depth and 120 m max. depth) is located on the Zambezi River between latitudes 16° 28' to 18° 04'S and longitudes 26° 42' to 29° 03'E. It was the largest man-made reservoir in the world at the time of construction. Today it is the second largest reservoir in Africa by volume. The catchment area covers 663 817 km^2 extending over parts of Angola, Zambia, Namibia, Botswana and Zimbabwe. The dam wall (128 x 580 m) was completed in 1960 and the filling phase lasted from December 1958 to September 1963 when the water reached the mean operation level at 485 m above mean sea level. The lake is naturally divided into five basins (Figure 1) and is almost equally shared by the two riparian countries Zambia and Zimbabwe with 45 percent and 55 percent respectively. The impact of the artisanal inshore fishery on the two sides of the lake can be considered not to affect each other because of the deep channel in between the two shores along most of the lake.

Lake levels fluctuate annually from one to five metres (mean = 2.9 m) as a function of inflowing floods between December and June and continuous drawdown through the turbines and, before 1981, spillage through the sluice gates. Since 1982 the lake levels have declined due to a series of droughts and the lowest levels recorded was in December 1992 and January 1997 at 476 m (Figure 2). Since 1997 the lake levels have risen rapidly, and in April 2000 the sluice gates were opened again for the first time in 19 years.

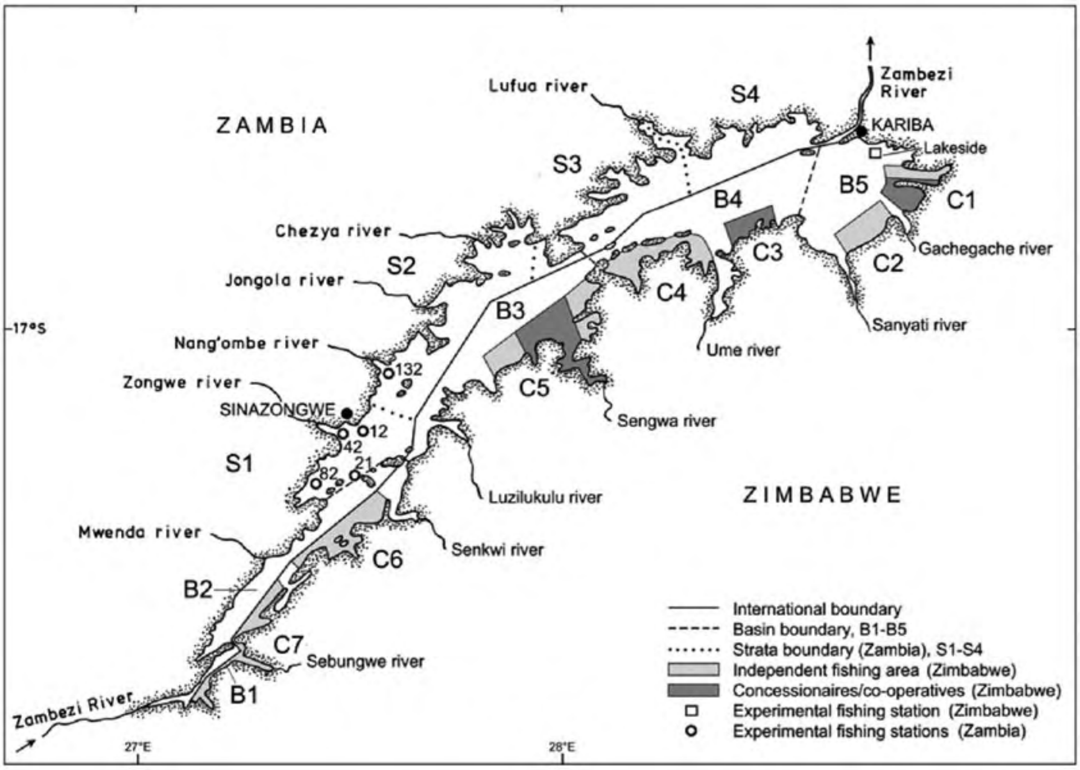

FIGURE 1. *Map of Lake Kariba showing the five natural basins (B1..B5), the designated inshore fishing grounds on the Zimbabwean side (C1..C7), the sampling strata in Zambia (S1..S4), the selected experimental fishing stations in Zambia around Sinazongwe (open circles), and the experimental fishing station (Lakeside) in Zimbabwe near Kariba town (open square).*

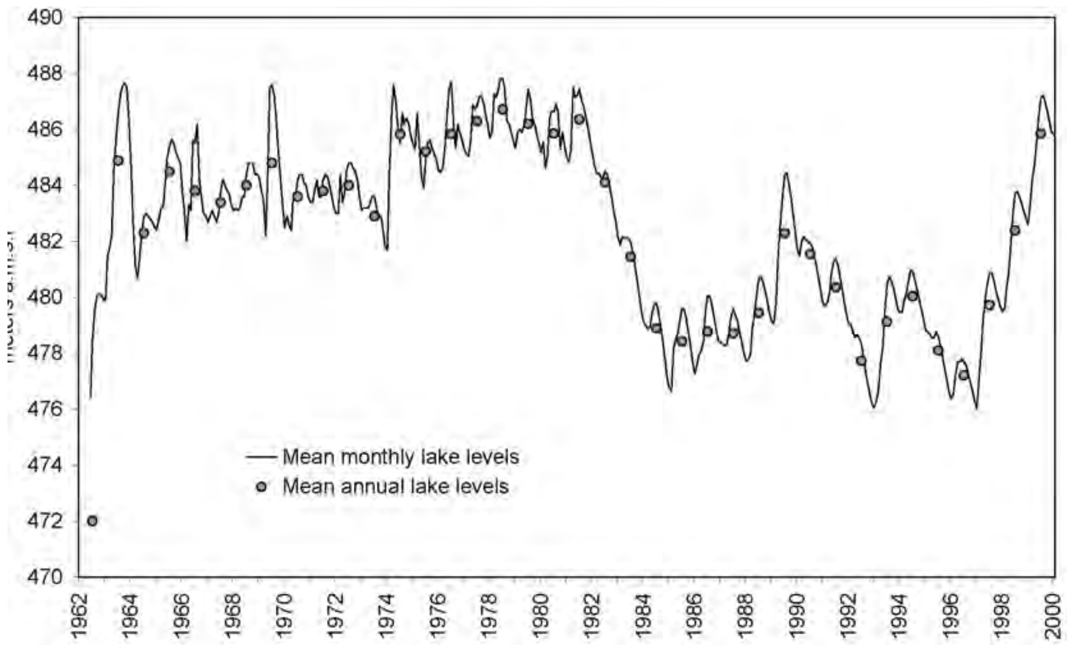

FIGURE 2. *Mean monthly and mean annual lake levels (m a.m.s.l.) in Lake Kariba from 1962 to 2000. Between 1981 and 2000 no surplus spillage through the dam wall floodgates have been performed.*

The limnological and various biological characteristics of Lake Kariba are well described elsewhere (see e.g. Coche, 1968; Balon and Coche, 1974; Marshall, Junor and Langerman, 1982; Marshall, 1984; Machena, 1988 and Moreau, 1997 for comprehensive reviews). The most salient features are a warm (mean surface temperature of 26°), oligotrophic, monomictic lake with overturn occurring in June–July. Stratification begins around September with a thermocline around 15 m depth which gradually moves down to around 35 m at the time of the turnover. The oxygen concentration in the hypolimnion declines steadily during the stratification period and often reaches a stage of deoxygenation. The volume to inflow (c. 50-70 km^3 per year) ratio is low giving a mean water retention time of only 2.6 years. The Zambezi River provides about 80 percent of the inflow and there is a natural gradient in the lake ecosystem from east to west. Basin 1 and 2 have more riverine characteristics gradually attaining a more lacustrine environment to Basin 5 near the dam wall.

The waters from the Zambezi River are very clear and low in plant nutrients. Phytoplankton blooms occur just after turnover and locally at the onset of floods from tributaries, but most of the year primary production may be very low. Zooplankton abundance shows variation in response to phytoplankton biomass (Begg, 1976; Marshall, 1997). Initially after filling, the lake was eutrophic due to the vast amount of dissolved nutrients through inundation of vegetation and land. From 1963 the lake became slightly alkaline with a marked decrease in phosphate and nitrates (Thornton, 1980). During the early eutrophic years the floating fern, *Salvinia molesta*, colonized large areas of the lake and retained vast amounts of plant nutrients (Mitchell, 1973). From the 1970s it has gradually decreased and been replaced by increasing amounts of rooted macrophytes down to a depth of around 10 m (Machena, 1989).

2.2 The fish fauna

The natural limnological gradient in the lake is also reflected in the fish communities which are dominated by potamodromous species in the east (cyprinidae and distichodontidae) and by more sedentary cichlids in the western basins (Begg, 1974). The fish community and biology of the fish species is well described in a number of reviews and research works (Balon and Coche, 1974; Mitchell, 1976a; Marshall, Junor and Langerman, 1982; Kenmuir, 1984; Marshall, 1984; Karenge, 1992; Machena, Kolding and Sanyanga, 1993, Musando, 1996; Karenge and Kolding, 1995a). Several of these discuss the observed biological succession in detail and only a brief update will follow. Most notable is that the number of fish species in Lake Kariba seems to be steadily increasing.

Jubb (1967) listed 55 species occurring in the Middle and Lower Zambezi River system, that is the portion of the drainage system from below the Victoria Falls to the mouth of the Zambezi River into the Indian ocean. In a pre-impoundment gillnet survey (Jackson 1961b), 28 fish species were caught in the Zambezi river at the location of the new lake (but very small mesh sizes were not used). Shortly after filling in 1964, Harding (1966) reported 33 species. In the early 1970s, Balon (1974a) recorded 39 species, later updated to 43 species by Marshall (1984). Since then five more species, the garpike *Hepsetus odoe* (Sanyanga and Feresu, 1994), the tilapias *Tilapia sparmanii* and *Oreochromis niloticus*, the chiselmouth *Varicorhinus nasutus*, and the largemouth bass *Micropterus salmoides* (Karenge and Kolding, 1995b; Anon., 1995) have been caught in the lake by the Lake Kariba Fisheries Research Institute. Bell-Cross and Minshull (1988) list 62 species in Lake Kariba area, defined by the Victoria Falls upriver and all south bank tributaries. Several of these have not been recorded in the lake itself.

2.3 Invasions, introductions and disappearances

The presence of non-introduced Upper Zambezi fish (i.e. above the Victoria Falls) in Lake Kariba a decade after creation, such as the cichlids *Sargochromis giardi*, *Sargochromis carlottae*, *Oreochromis andersonii*, and *Pseudocrenilabrus philander*, the mormyrid *Marcusenius macrolepidotus*, the cyprinid *Labeo cylindricus*, the schilbeid *Schilbe intermedius (mystus)*, and the small barbs *Barbus poechii*, *B. paludinosus* and *B. unitaeniatus*, caused some scientific debate when Balon (1974c) suggested that they survived the drop down the mighty Victoria Falls (e.g. Jubb, 1976a, 1976b, 1977). There are, however, indications that the so called "upper Zambezi invaders" may also have been present in the middle Zambezi before inundation but were missed in the sampling programs. They may also have been accidentally introduced or could have reached the lake through the Victoria Falls power station overflow (Jubb, 1976a; Kenmuir, 1984; Bell-Cross and Minshull, 1988). Whatever the origin, it seems that the new lacustrine environment give these species enhanced conditions to become established.

Presently 50 different fish species have been observed in the lake, five of which are introduced (Songore and Kolding, 2003). However, seven species have been reported just once (*Leptoglanis rotundiceps, Serranochromis angusticeps, Hepsetus odoe, Barbus radiatus, Labeo lunatus, Varicorhinus nasutus*, and the introduced *Micropterus salmoides*). Thus it can be is questioned whether they are stray specimens or have established viable populations in the lake. Two of the introduced species, *Tilapia rendalli* and *Serranochromis robustus*, may as well have invaded the lake naturally (e.g. Kenmuir, 1984). In fact *T. rendalli* was already caught by Jackson (1961b) during the pre-impoundment survey. Thus only three truly exotic species have established in the lake. One is the cichlid *Oreochromis macrochir*, which was stocked into the lake in 1959–62 from Chilanga, Zambia. It was never caught during Balon's (1974a, 1974b) intensive sampling programme and was believed extinct, but started appearing in the Lakeside sampling programme in 1974. It has since then been caught every year in the experimental surveys at Lakeside but only in very small numbers (on average about ten specimens per year out of 5–10 000 total sampled). In the Zambian experimental gillnet surveys it has been recorded only three times: in 1985, 1992 and 1996. The other true exotic is the small pelagic clupeid *Limnothrissa miodon* introduced from Lake Tanganyika in 1967–1969 (Bell-Cross and Bell-Cross, 1971). This introduction is a well-known success story (see section below) and there are no indications that this by far largest single stock in the lake with an annual total production rate around 125-150 000 tonnes, has had adverse effect on the other species (Marshall, 1991; Karenge and Kolding, 1995b). The third true exotic is the Nile tilapia (*Oreochromis niloticus*) which since 1993 has been caught in ever increasing quantities in gillnets by Lake kariba Fisheries Research Institute (LKFRI). This species was never introduced deliberately but is cultured at several farms along the lakeshore, which drain directly into the lake.

Some species have disappeared or have become rare (Kenmiur, 1984). The rheophilic species, *Chiloglanis neumanii*, *Opsaridium zambezense* (and possibly also *Leptoglanis rotundiceps*) are now confined to the tributaries or the two more lotic western basins (Balon, 1974a,1974b). Species diversity could be greater in the eastern effluent part of the lake than is assumed today (Begg, 1974), as Balon (1974a, 1974b) recorded 39 species in the Zinazongwe area (Basin 3) in a poisoning sampling programme. In a similar study in the Sanyati basin (Basin 5) only 27 species were recorded (Mitchell, 1976a). It was feared that the potamodromous mottled eel, *Anguilla bengalensis*, eventually would disappear from the lake, since the elvers coming up from the sea would not be able to mount the 128 m dam wall (Jubb, 1967). Marshall, Junor and Langerma (1982) considered the situation even more problematic with the construction of the formidable Cahora Bassa dam wall (160 m high) about 400 km down-river. However, some elvers still seem able to do so, although in low numbers, and eels have been recorded in the lake at all times (Marshall, Junor and Langerman, 1982). For instance, two mottled eel of around 60 cm TL were captured in March 1993 near the dam wall. If these have not ascended the two dam walls on their way up the Zambezi river, they were by then more than 30 years old (Anon., 1993).

2.4 Management and regulations:

The lake was primarily constructed to generate hydro-electricity but additional expectations were also derived from different estimates of the potential fish yields. Before inundation, an area of some 950 km^2 (about 18 percent of the lake area) was bush cleared at various places within the 20 m contour in order to establish inshore fishing grounds. Between 1959 and 1962, 26 tonnes of cichlid fingerlings (*Tilapia rendalli* and *Oreochromis macrochir*) were stocked into the lake to boost the fishery (Coche, 1971). From the very beginning the essential issue in the management of the fishery was the question “Who was to fish”? On this question the Zambian and Zimbabwean[1] authorities fundamentally disagreed, which eventually led to divergent policies that still mark the fisheries in the two countries today (Bourdillion, Cheater and Murphree, 1985). In Zimbabwe the authorities divided the shorelines into 14 areas, separated in spheres of white and black interest. Along the “Native Area” shoreline, black fishers, who were encouraged to become “professionals”, would exploit the inshore fishery. Therefore the 26 camps in which they were located were strictly for fishing: permanent settlement and shoreline agriculture were prohibited. The native areas were shared with white-owned concessionaires, who in addition to their own fishing concession areas, would also purchase the fish from the black fishers. The area demarcations and concessions allocated for fishing were changed in 1972 into eight larger areas and again in 1976 into the present seven areas (Figure 1), (Marshall, Junor and Langerman, 1982; Karenge and Games, 1995), mainly to conserve the stocks and to meet the demands for more recreational waters from the burgeoning tourist industry. Whilst the total area available for inshore fishing was reduced by these changes, the area allocated to local fishers was increased slightly. At present about 470 km^2 (63 percent) of the fishable water on the Zimbawean side is available to the inshore fishery (Marshall, Junor and Langerman, 1982) and the number of fishing villages has grown to about 40.

From the very beginning, the Zambian authorities took a different view. The interest of the local population was paramount and there was no racially based segmentation. The whole Zambian shoreline was designated as “Native trust land” and could not be utilized without consent of the local people. Furthermore, the Zambian authorities initiated infrastructure and institutions for developing the fishery. A large resettlement compensation was paid to the Gwembe Rural Council, mainly used for development of the fishery. In addition, a Fisheries Training Centre was build in Sinazongwe with harbour, boat building, and ice plant facilities. Up to 1994 there were about 270 fishing villages on the Zambian shoreline, but these were amalgamated into 67 villages in 1995 (Jul-Larsen, 2003). In Zimbabwe, preparations for the

[1] Before 1964 called Northern and Southern Rhodesia under the Central African Federation of Rhodesia and Nyasaland.

initial fishery were much more modest and little money was allocated for the fishery development. Since its beginning until today any kind of economic investment in the inshore fishery in Zimbabwe has been virtually absent (Marshall, Junor and Langerman, 1982; Bourdillon, Cheater and Murphree, 1985), in contrast with a relatively strong management regime and enforcement capacity.

In Zimbabwe the inshore fishery is controlled by the State through the Department of National Parks and Wildlife Management (DNPWM) who limits access, closes areas to fishing and restricts fishing gear methods. A permit system is in place whereby the DNPWM informs the two riparian local authorities, the Nyaminyami (west) and Binga (east) District Councils (separated by the Sengwe river in Basin 3), of the limits placed on the number of fishing permits that may be issued for the particular year. The Councils then issue these fishing permits to the individual fishers or fishing co-operatives. The distribution of permits per individual fisher can differ according to local authorities. For example for the greater part of the 1980s individual fishers in Binga were allocated 2.5 nets each whilst fishers in Nyaminyami were allowed five nets each. Fishing permits for fishers operation off state lands are issued directly from DNPWM. According to officially set limits there should be a maximum of 2 530 nets on the Zimbabwian side of the lake belonging to 771 fishers, independent fishers and cooperative members inclusive. It is however difficult to establish how these effort limits were arrived at since it proved impossible to obtain documentation on the method used (Songore, 2000). The official limit, however, has never been reviewed and the actual recorded number of nets and fishers, although fluctuating, for most of the time has been below these values (Figure 4).

The fishing patterns are very simple because only one type of gear (gillnets) are used throughout the whole Zimbabwean inshore fishery. Fishing is not permitted using nets with less than a four-inch (102 mm stretched) mesh size. In addition explosives, chemicals, poisons, intoxicating substances, scoop nets, jigging and fish driving may not be used to catch fish. Fishing is also not permitted along parts of the shoreline (about 20 percent, Figure 1) belonging to the DNPWM, notably all the Chete Safari Area, most of the Matusadona National Park and parts of the Charara Safari Area. Other restrictions are in place for river mouths, large population centres, harbours, and river estuaries. Fish net manufacturing is not permitted for persons who do not hold a valid manufacturer and dealer’s license and fishing nets can only be sold to holders of valid fishing permits.

Two institutions dealing with the fishery resort under the DNPWM: The Lake Kariba Fisheries Research Institute conducts research and collects data on the fish stocks, the fishers and their catches, while the management branch of the DNPWM is tasked with policing the fishery.

In Zambia access to the fishery is free in principle and fishers can fish anywhere. When the lake was created the management regulations were similar to the other fisheries in the country, but these were seen as interim to be revised after obtaining further information (Malasha, 2003). Initially, therefore, the legal minimum mesh size was set to four inches and a closed season was to be observed from 16 December to 16 March. In 1962 the Department of Game and Fisheries in Northern Rhodesia tried to abolish the mesh size regulation based on the results of experimental fishing. However, the authorities in Southern Rhodesia rejected this on the grounds that the Lake Kariba Fisheries Research Institute had not yet conducted sufficient experiments to support this move. From the independence of Zambia in 1964 to 1986 no mesh restrictions for gillnet existed and beach seines were allowed. After 1986 the minimum mesh size for gillnets was set at three inches (76 mm) and beach seining was prohibited. In practice, however, there has been little enforcement due to lack of resources (Musando, 1996). Also the kutumpula method (fish driving) is very popular among fishers although it is officially banned by the Fisheries Act (Scholz, 1993).

3. MATERIALS AND METHODS

3.1 Data: origin and treatment

Fish yield data collection in both Zambia and Zimbabwe has been in operation since the fishery started in 1961 (Zambia) and 1962 (Zimbabwe). In addition both the Lake Kariba Research Unit (LKRU) in Sinazongwe (Zambia) and the Lake Kariba Fisheries Research Institute (LKFRI) in Kariba town (Zimbabwe) (Figure 1) have carried out extensive monitoring with experimental gillnets. Very little data, however, are available from Zambia in the period 1974–1980 when the fishery was officially closed due to the Zimbabwean civil war.

Hydrological data were obtained from the Zambezi River Authority (ZRA) as daily lake level recordings, which were averaged on a monthly and annual basis (Figure 2).

3.2 Inshore fishery, Zimbabwe

Fisheries catch and effort data collection has been in operation since the fishery started in 1962 on the Zimbabwean side. Until 1992 a data collection system referred to as Catch Assessment System (CAS) was in place. From 1993 the CEDRS system, unified with Zambia, was introduced as one of the activities under the Zambian-Zimbawean SADC Fisheries Project. Artisanal fishing on the Zimbabwean shores of the lake is conducted in seven fishing areas (C1 to C7, Figure 1). A description of these fishing areas and changes that they underwent during the history of the fishery is given in Marshall, Junor and Langerman (1982) and Karenge and Games (1995). A compilation and partial analysis of the catch-effort data on the Lake Kariba artisanal fishery in Zimbabwe is given in Songore (2000). Methods of data collection differed according to how fishing activities were organized. Operators of concessions (fishing areas C1, C3 and part of C5) were required to submit monthly returns of their daily catches, effort, and sales. The annual catch of this group was worked out from the returns. Data from the remaining fishing areas operated by the local communities were collected through an enumeration programme. Staff from LKFRI carried out enumeration in two fishing areas (C2 and C4) while staff from the Binga District Administrator's office enumerated catches from the three other areas (part of C5, C6 and C7).

Prior to the intensification of the liberation war in Zimbabwe, data were collected from generally all the fishing areas. Later, during the period 1975–1979, when the war escalated, data collection operations were disrupted with some of the sampling areas being abandoned due to closure of fishing villages. This mostly affected data collection in fishing areas that were fished by local communities. The concessionaires continued sending in their catch, effort and sales returns undisrupted. Attempts to normalize data collection again were made in 1980 when the war ended. However, due to inadequate manpower and financial constraints, it was not possible for LKFRI to cover all the landing sites using its own resources. Hence the Binga District continued for some time to collect data from landing sites under their jurisdiction. But, data from these areas (C5 to C7) were sent in irregularly. From 1973 to 1984 total yield was estimated from mean monthly catch from all villages (where catches from villages not enumerated were estimated) through multiplication by 12 months and adding the reported catches from the concessionaires. From 1985 some of the concessionaires were transformed into cooperatives, and during the period 1985–1992 enumeration activities were scaled down to ten fishing villages which were all in the areas C2 and C4. Therefore yield estimates for the whole lake were based on extrapolation of data collected from C2 and C4.

A critical analysis of the sampling strategy and a number of recommendations were made by Sanyanga, Lupikisha and Thorsteinson (1991). This led to the introduction in 1993 of the CEDRS in order to unify the data collection systems of Zambia and Zimbabwe. As it was found impossible to sample either all villages or the total landings for any particular village for the whole year, ten representative villages were to be enumerated for ten days every month on each side of the lake. The sampled catch was to be raised to an estimate of the total catch by multiplying by the ratio between total number of days sampled and days in the year and the ratio between the number of fishers in the villages sampled and the total number of fishers. CEDRS only operated well for a short period, but broke down due to diminishing human resources. Enumerators who retired, resigned or died were never replaced. Furthermore, very few of the proposed strategies for improving were implemented. Hence the quality of data collected continued to be questionable in terms of representing the whole fishery (Songore, 2000).

Total yield estimates from 1985 to present have been calculated using the following formula:

$$\hat{Y} = \frac{sampled\ catch}{sampled\ \#\ fishers \cdot days} \cdot total\ \#\ days^{(1)} \cdot total\ \#\ fishers^{(2)} + reported\ cooperative\ catches$$

(1) total # days = 365 until 1993, thereafter = 360.

(2) from 1985 to 1992 total # fishers used in the calculation was constant (= 765), from 1993 the total # fishers was obtained from Frame surveys, keeping the number constant in between each survey.

3.3 Inshore fishery, Zambia

Scholz (1993) gives a detailed account of various sampling designs used and an analysis of the data from 1961–1990. Aggregated data from his thesis are used for the period 1961–1980. Data from 1980 to 1999 are based on a compilation and partial analysis of the catch-effort data on the Lake Kariba artisanal fishery in Zambia by Musando (2000). Two different systems of collecting catch-effort data have been used. From 1980 to 1993 the so-called CAS (Catch Assessment Surveys) was used, a two stage stratified random sampling system to estimate catch rates (*Cpue*) supplemented by a framesurvey to count total effort (f) and activity level (A), based on which total catch (C) could be estimated (). During three survey days at randomly selected sampling units (PSUs), fishers met at their landing sites were asked to report on catch, mesh sizes and number of nets set. Settings with no catch are said to have been reported as well. The catch was identified by fish family and weighed in kilos. The “CEDRS” (Catch and Effort Data Recording System) was introduced during 1993; in order to unify the data recording system with the Zimbabwean side of the lake. The CEDRS programme was designed to carry out the survey for ten days per month per stratum (Figure 1), in ten selected fishing villages, as well as record catch rate by species name other than the family name.

Unfortunately the execution of the sampling programme for both the CAS/CEDRS designs has been highly irregular due to budget shortcomings and lack of staff (Scholz, 1993, Musando, 2000). Moreover, it appears that the total estimated effort is made as a simple summation of strata sampled, irrespective on the number of strata actually sampled. In this way, the “effort” thus becomes a function of number of strata and on the number of times each strata has been sampled during a year (Musando, 2000).

3.4 Frame surveys on Lake Kariba

Lake wide frame surveys on Lake Kariba were initiated in 1990 under the auspices of the Zambia/Zimbabwe SADC Fisheries Project (ZZSFP) and repeated in 1993. Additional frame surveys have been conducted in 1995 and 1999 on the Zambian side and in 1998 and 2000 on the Zimbabwean side.

3.5 Experimental data

Since 1960 LKFRI in Zimbabwe has conducted an experimental gillnet fishery at Lakeside station close to Kariba town in the Sanyati basin (Basin 5, Figure 1). Here commercial fishing was only permitted between 1962 and 1972 (Kenmuir, 1984) and limited fishing took place from 1977 to 1980, but this probably had little effect on the fish stocks (Marshall, 1984). Experimental fishing during the early years was somewhat sporadic with few settings (Kenmuir, 1984). However, from 1970 to 1975 settings were done twice a month and since 1976 sampling has been done weekly, except for 1981 when no fishing took place (Karenge, 1992; Karenge and Kolding, 1995a). The sampling design has remained constant over the whole period and consists of multifilament nets in multimesh fleets with 12 panels ranging from 38 mm to 178 mm stretched mesh sizes with 12.5 mm increments. The fleet, 550 m in total length, was set overnight perpendicular to the shore with the smaller meshes inshore. Each individual fish caught was recorded for species, mesh size, weight, length, sex and maturity stage. All experimental gillnet data from 1969 to 1999 have been digitized into PASGEAR (Kolding, 2001) which now contains more than 185 000 individual fish records from 39 species and represents more than 14 000 panel settings. A detailed analysis of this data set up to 1992 is given in Karenge (1992) and Karenge and Kolding (1995a).

In Zambia, the Lake Kariba Research Unit (LKRU) under DoF, based in the former Fishery Training Centre in Sinazongwe, has carried out an experimental fishing with multimesh gillnets since 1980. Under this programme, every month three experimental localities (stations) were sampled for three consecutive days. Multifilament nets were in use during 1980 to May 1984 and also from 1992 to 1995, whereas monofilament nets were used between June 1984 to part of 1992 and 1993. Both gear types were set at a hanging ratio of 0.5. A fleet of nets with stretched mesh sizes ranging from 25 mm to 178 mm with 12.5 mm increments, were set. A detailed description and analysis of these data up to 1995 is given in Musando (1996). All experimental gillnet data from 1980 to 1999 have been digitized into PASGEAR. The database now contains more than 118 000 individual fish records from 36 species and represents more than 13 000 panel settings. Unfortunately, the choice in stations sampled during this programme has shifted repeatedly, the gillnet fleets were not always complete due to difficulties in replacing worn out nets while the sampling programme occasionally was not carried out because of fuel-shortages, net thefts and bad weather. For the present analysis, due to the irregular sampling design, only the most used sampling stations in close proximity to

Sinazongwe (Charlets Island (st.12), Samaria Island (st.21), Zongwe estuary (st.42), Ngoma (st.82), and Nang'ombe (st.132)), have been included (Figure 1). From 1994 to 1995 only Charlets Island and Zongwe estuary were sampled. From 1996 to 1999 only Zongwe estuary remained in the sampling programme. Furthermore, only the mesh sizes in the range 50 mm stretched to 152 mm stretched have been included as only this part of the fleet was more or less complete (except for 1989 when only mesh sizes from 89 mm to 152 mm were used).

Catch per unit effort (C/f) in the both the Zambian and Zimbabwean experimental fishery is expressed as catch (kilo wet weight or number of fish) per standard gear unit per setting. The standard gear unit of each mesh size is one panel of 45 m (50 yards) long.

3.6 Multiple regression of hydrology and fishing effort on catch rates

Multiple regressions were performed with mean annual total catch rates (CPUE) as dependent variable, and hydrological indices and effort as independent variables. From the monthly or annual mean lake levels five differently time-lagged indices for the hydrological dynamics in Lake Kariba were tested following (Karenge and Kolding, 1995b):

The absolute mean annual lake levels (m a.s.l.).
The annual amplitude (m), i.e. the difference between the lowest and highest recorded level within one year.
Delta (△) lake levels (m), defined as the difference between the mean annual lake levels of one year and the immediately preceding year. This will permit the estimation of the effect in change of lake level of one year on the catch rate the succeeding year.
A combination of 2) and 3) by adding the two figures (△ lake level + amplitude), thus taking into account the combined effect of two consecutive years.
The $\triangle_y + \triangle_{y-1}$ (m), which is the sum of the delta lake levels of one and the preceding year, thus giving the combined effect of three consecutive years.

Fishing effort was expressed as total annual number of nets or fishers (inshore fisheries) or total annual boat nights (Kapenta fishery).

Using cross-correlations, where all variables were made orthogonal by subtracting the mean from the original series, it was established whether there was a lag-phase between detrended annual mean water levels and detrended annual mean catch rates, and which of the hydrological variables was more informative. The rise in lake level normally terminates in May-June every year, whereas the lowest lake levels normally are found in late December–early January. The annual fishery statistics are the average of the whole year, but with generally higher catches in the latter part of the year during low lake levels (Marshall, 1988; Karenge, 1992).

The multiple regressions were always of the form:

$$CPUE_i = \mu_i + effort_i + hydrological\ index_{lag(x)} + effort \bullet hydrological\ index_{lag(x)} + \varepsilon_i$$

Where,

$CPUE_i$	= time series of annual mean catch rates
μ_i	= overal mean
$effort_i$	= total number of nets, fishers, or boat nights for $year_i$
$hydrological\ index_{lag(x)}$	= one of the 5 hydrological indices at lag(x), x = 0 – 5
$effort \cdot hydrological\ index_{lag(x)}$	= interaction of effort and hydrological index at lag(x)
ε_i	= residual error

In all cases non-significant explanatory variables were removed from the model using stepwise regression. The interaction effect is interpreted as reflecting possible changes in catch rate either as a result of changes in efficiency or of usage of gears in relation to water levels. In case of confounded effects between effort and hydrological variables (i.e. when both variables were significant alone, but one or the other fell out in the combined model) interaction was always high and cannot be interpreted. All statistical analyses were carried out using Statistica (StatSoft ®).

4. RESULTS AND DISCUSSION

4.1 Development of the Kapenta fishery

From a pre-impoundment study, Jackson (1961) predicted that the pelagic habitat of Lake Kariba would remain non-colonized since the species present in the Zambezi river had evolved in a riverine habitat and would therefore only inhabit the shallow littoral zones. Coke (1968) and Mitchell (1978) later confirmed this. Following Jackson's recommendation Kapenta, *Limnothrissa miodon*, (a small pelagic clupeid, which in Kariba reaches a size of around five centimetres) was introduced by the Zambian government into Lake Kariba between 1967 and 1969 from Lake Tanganyika (Bell-Cross and Bell-Cross; 1971, Junor and Begg, 1971). The introduction was a success and, although the colonial Rhodesian Government was not informed about the introduction, the researchers at the Lake Kariba Fisheries Institute observed the widespread presence already in 1969. Commercial Kapenta fishing, or the offshore fishery, began in July 1973 in Zimbabwe with a single purse-seiner. But effort grew rapidly (Figure 3) and from 1976 this fishery changed to using lift nets from pontoons at night with light attraction, which considerably increased the catch rates. From 1978 the fishery started to expand along the Zimbabwean shoreline to six different bases, and in 1981, after the termination of the civil war in Zimbabwe, this fishery started in Zambia (Overå, 2003). The predominantly white-owned, capital intensive Kapenta fishery has now developed into a million dollar industry, with between 20 and 30 000 t landed annually, economically vastly outstripping the inshore fishery, and with theoretical potential for further expansions (Anon., 1992; Machena, Kolding and Sanyanga, 1993; Marshall, 1992, 1993; Kolding, 1994). The Kapenta fishery alone, through its profitability, is according to Bourdillon, Cheater and Murphree (1985) directly responsible for most of the infrastructural development that has occurred on the Zimbabwean shoreline. Cheater (1985) gives a detailed account of the development of this fishery in Zimbabwe until the mid 1980s. From the early 1990s no new licenses were issued in Zimbabwe and the effort development seemed also to stabilize in Zambia around this time (Figure 3) with a corresponding stabilization in catch rates of 150-200 kg per rig per night in both countries. From 1998 there has been a decrease in the reported Zimbabwean effort.

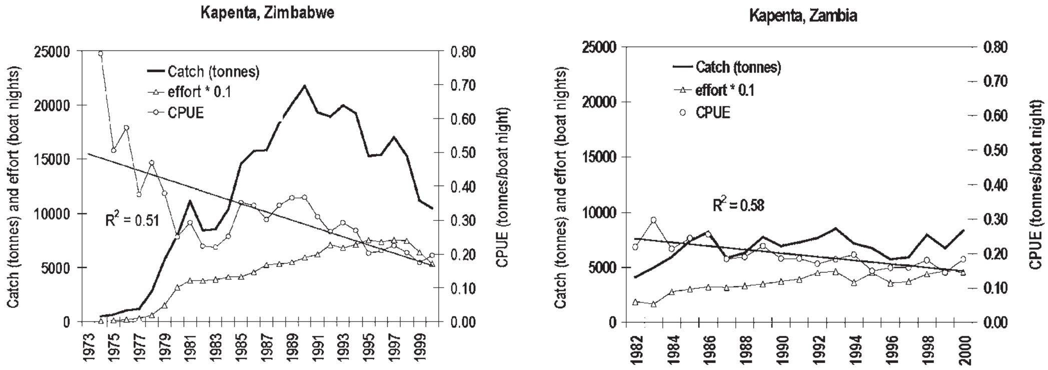

FIGURE 3. *Development in the offshore Kapenta fishery in Zimbabwe (1974-2000) and Zambia (1982-2000). CPUE in tonnes/boat night. Note effort values have been multiplied by 0.1 for scaling reasons. Source: Zambia-Zimbabwe Fisheries Joint Annual Statistical reports.*

4.2 Development in inshore fisheries

Commercial gillnet fishing started on the Zambian shore in 1958 immediately after the impoundment had begun, and from 1962 on the Zimbabwean side because the authorities wanted the filling and stocking complete before a fishery was initiated (Minshull, 1973; Bourdillon, Cheater and Murphree, 1985). Initially, the catches were very high due to the eutrophic state of the lake from the fresh inundation and the rapid colonization of opportunistic riverine detritus feeding species such as mudfish (labeo's) and distichodontids. In 1962 the catches started to decline in Zambia, followed by Zimbabwe four years later (Minshull, 1973). This initial boom and bust of the catches was reflected in the fishing effort. By 1962 about 2,500 fishers were operating on the Zambian side producing around 3 000 tonnes of fish, whereas by 1967 the number of fishers had decreased to less than 500 (Scudder, 1967; Jul-Larsen, 2003; Overå, 2003), (Figure 6). Similarly, on the Zimbabwean side the number of fishers peaked at just over 1 000 in 1966, subsequently declining to less than 500 in 1971 (Minshull, 1973) (Figure 4).

The number of fishers in Zimbabwe increased again during the 1980s with a subsequent decline during the 1990s to same low level as the 1970s (Figure 4). The number of nets per fisher in Zimbabwe, however, has remained relatively stable around an average value of 4±1.5 SD (Figure 4) with no significant development over time.

The overall decline in effort since the early 1990s (Figure 4) has taken place in all fishing areas, with the exception of fishing area C4 (Songore, 2000). For the fishing areas C1 and C3, which were once operated by white concessionaires, the effort has declined most, almost linearly since 1973. This can be attributed to a gradual exodus from fishing due to declining returns on investment (Marshall, 1984). Catch per unit of effort, however, has generally increased in all the fishing areas (Songore, 2000) also reflected by the overall rate (Figure 5).

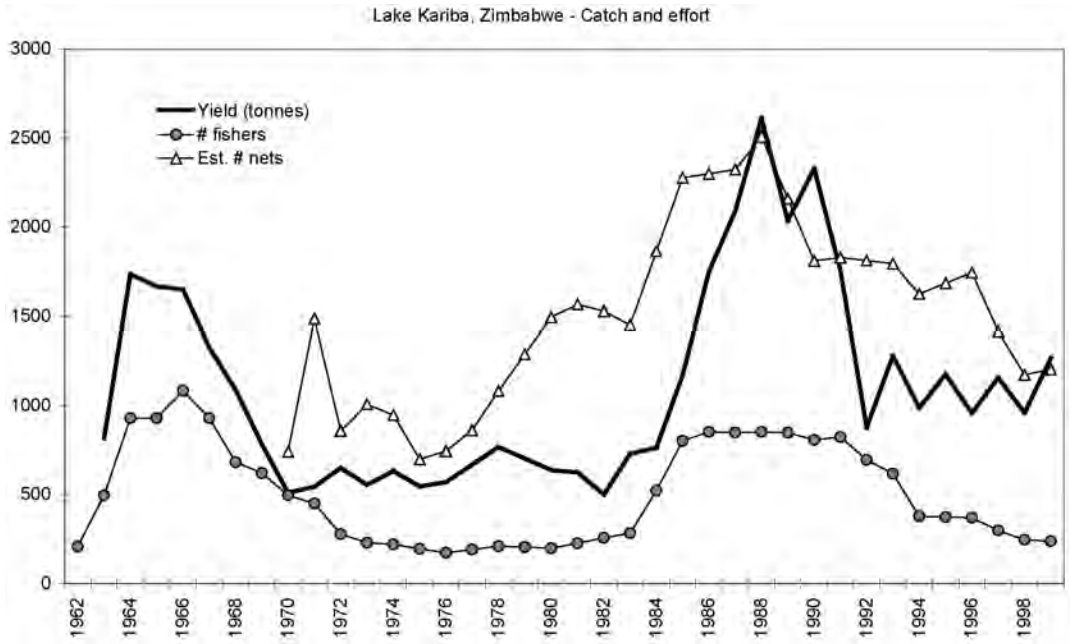

FIGURE 4. *Estimated total annual effort (numbers of fishers and nets) and reported annual yield (tonnes) from the Zimbabwean inshore fishery between 1962 to 1999. Source: Songore (2000).*

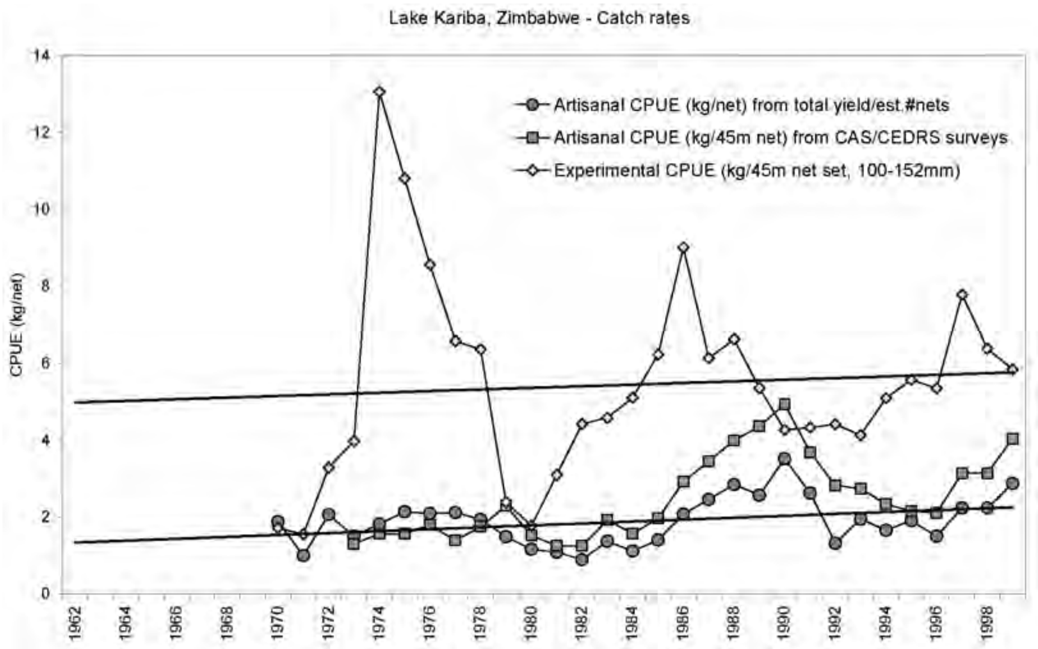

FIGURE 5. *Development in catch rates (kg/45 m net) of the Zinbabwean inshore fishery. Straight lines are linear regression on the experimental catch rates and the artisanal catch rates (kg/net) between 1980 and 1999. The trends (slopes) are not statistically significantly different from 0 (Experimental: Slope = 0.02, SE = 0.06; Artisanal: Slope = 0.02, SE = 0.01), but indicate a slight increase over time. The artisanal catch rates are on average one third of the experimental.*

Both the artisanal and experimental catch rates in the Zimbawean inshore fishery show the same overall trend since 1970 (Figure 5). Since the Lakeside station is in an unfished area, this indicates that the overall development in the inshore biomass appears to be independent of the change in fishing effort. It also indicates that the efficiency of the fishers (catchability coefficient) has not changed much over time which does not sustain the general notion that the fishers are increasingly under-reporting the number of nets used (e.g. Sanyanga, Lupikisha and Thorsteinson, 1991). Mean annual fishing effort (Figure 4) consistently has been operating below the maximum legal limit of 2 530 nets. This may be due to fishers being unable to secure fishing gear or some fishers being passive, keeping their licenses so as to utilize them in times of hardships. Fishers have always indicated that it is very difficult to acquire fishing gear (Songore, 2000). The average catch rates in the fished areas, however, are generally only one third of the experimental catch rates: this difference could be attributed to fishing.

The number of fishers in Zambia increased from around 1 000 during the 1980s reaching almost the level from the heyday in 1962, but has subsequently declined to around 1 200 fishers in the latest frame survey in 1999 (Figure 6).[1] The fluctuations in the number of Zambian fishers largely follows those in Zimbabwe (Figure 4) although initially the latter had a four year time lag due to a later start of the fishery. Since 1980 the ratio between the Zimbabwean and Zambian number of fishers has been remarkably stable with a mean of 0.3±0.1 SD. The average number of nets per fisherman in Zambia, however, has almost linearly increased during the whole period from around two in the early 1960s to around ten in the late 1990s (Figure 6). This means that the actual effort, although fluctuating in concert with the numbers of fishers, has increased much more rapidly and is today almost five times higher than at beginning of the fishery.

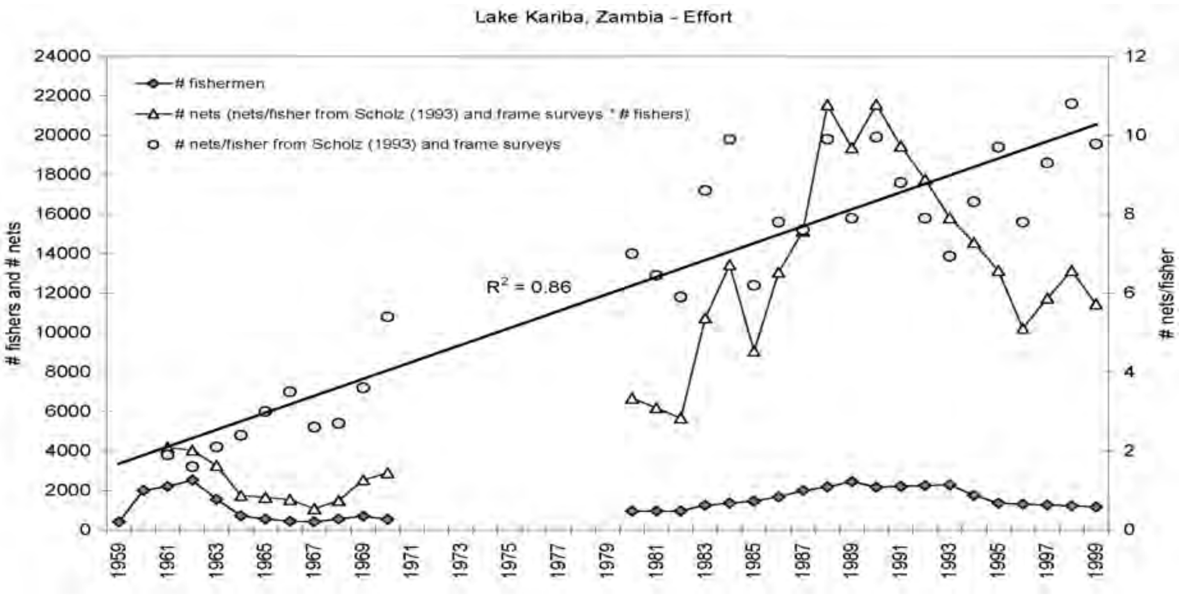

FIGURE 6. *Estimated effort development in the Zambia inshore fisheries. Number of nets are calculated from nets/fisher·#fishers. Straight line is a linear regression on the nets/fishers. Sources: Number of fishers: 1959-61 from Scudder (1967); 1962-89 from Scholz (1993); 1990, 1993, 1995, 1999 from Frame Surveys; 1981, 1991-92, 1994-95, 1996-98 interpolated. Nets per fisherman: 1961-89 from Scholz (1993); 1990, 1993, 1995, 1999 from Frame Surveys; 1996, 1999 from Jul-Larsen (2003); 1981, 1991-92, 1994, 1997 interpolated.*

1 No effort data are available between 1971 and 1979 but from 1980, after the Zimbabwean civil war, the fishery re-opened and data collection resumed.

Between 1980 and 1999 the reported yield from the Department of Fisheries statistics (Figure 7) is almost identical (only 1.4 times higher) to the estimated yield on the Zimbabwean side (Figure 4) despite the much higher effort in Zambia – on average three times more fishers and eight times more nets – and with approximately the same catch rates from 1980 onwards according to the CAS/CEDRS statistics (Figures 5 and 8).

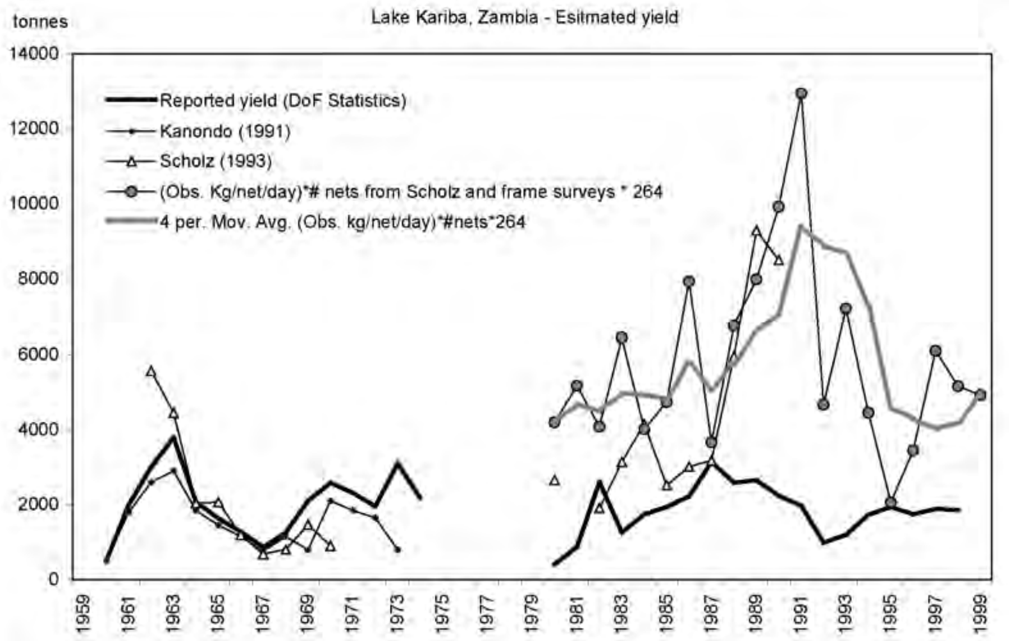

FIGURE 7. *Estimated yield in the Zambia inshore fisheries from various sources and from this study (1980–1999, solid circles and four year moving average).*

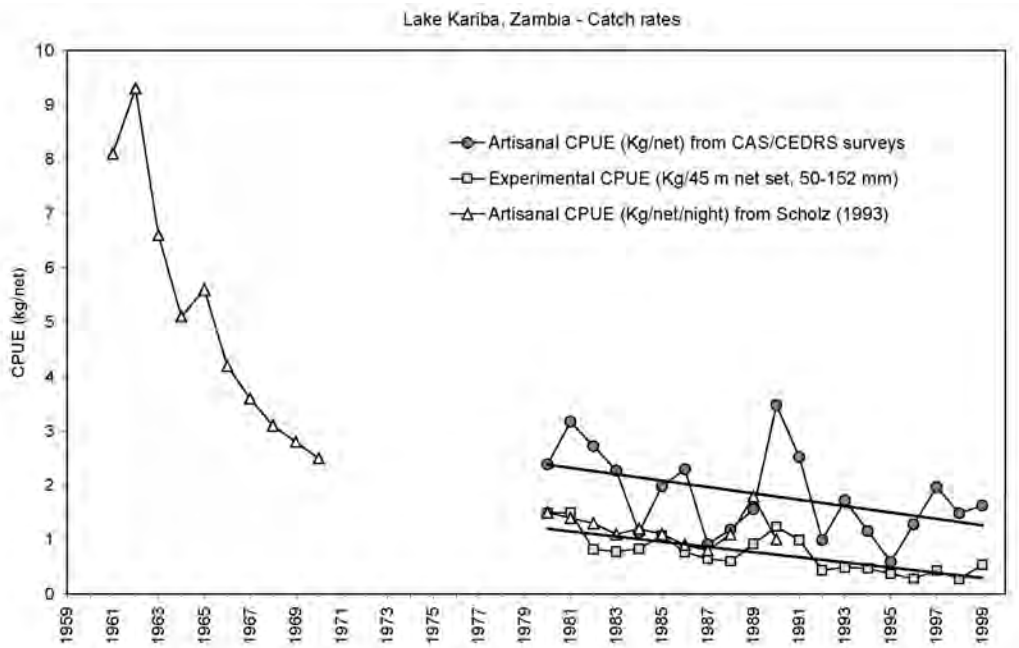

FIGURE 8. *Development in catch rates (kg/45 m net) of the Zambian inshore fishery. Straight lines are linear regression on the experimental catch rates and the artisanal catch rates (from CAS/CEDRS surveys) between 1980 and 1999. The trends (slopes) are not statistically significantly different ((Experimental: Slope = -0.05, SE = 0.01; Artisanal: Slope = -0.06, SE = 0.03), but the artisanal catch rates are on average 2.5 times higher than the experimental.*

These data strongly suggests that the reported Zambian yield is seriously underestimated, as was concluded by Scholz (1993) and Scholz, Mudenda and Moller (1997) as well. By using Scholz's (1993) figures of average active fishing days per fisher of 264 per year times the observed catch per net per day from CAS/CEDRS (Musando, 2000), and the estimated number of nets, a re-calculated estimate of the annual yields in the Zambian inshore fishery has been made (Figure 7). For the period 1980–1999 these recalculated yield estimates are on average three times higher than the reported yield.

After the initial boom in the Zambian fishery a strong decrease in the catch rates between 1962 and 1970 occurred (Figure 8). From 1980 to 1999 the trend continued to decline, although at a much lower rate. The experimental and artisanal catch rates follow the same trend, but in contrast to the Zimbabwean side, the enumerated artisanal catch rates are on average 2.5 times higher than the experimental (Sinazongwe area) for the same range of mesh sizes. This difference could be attributed to the different experience and ways of setting the nets between fishers and research personnel. A similar much lower catch rate of the research personnel compared with the full-time fishers was observed in Bangweulu (Kolding, Ticheler and Chanda, 1996, 2003).

4.3 Seasonal and geographical differences

Catch rates in winter (May–October) are significantly lower than in summer (November–April), both in the experimental and artisanal fisheries. Furthermore, the mean monthly catch rates is strongly correlated with the mean monthly rainfall ($r = 0.92$). (Figure 9).

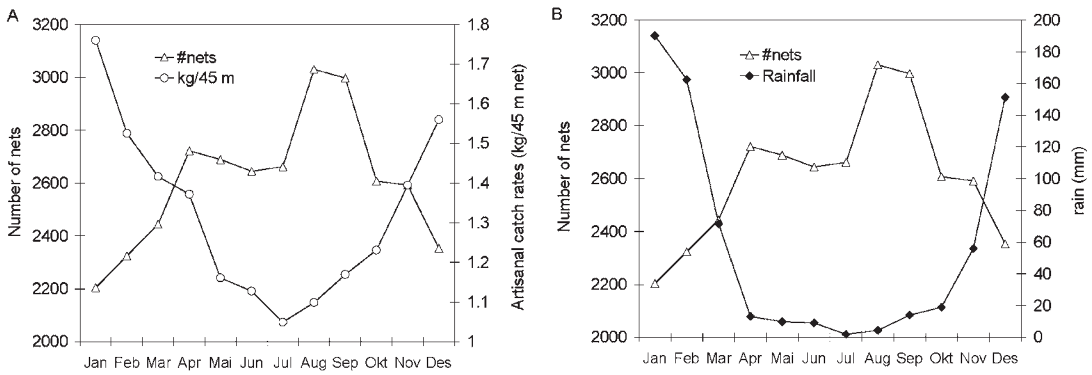

FIGURE 9. *The negative relationship between A: mean monthly effort (number of nets) and mean monthly catch rates (kg/45 m net), and B: mean monthly effort (number of nets) and mean monthly rainfall (mm) in the Zimbabwean inshore fishery*

Effort for the whole Zimbabwean side of the lake fluctuates during the year with low values in January, a stabilization during April to July and a rise to a peak in August after which it starts declining until December. Catch rates display a negative relation with effort (Figure 9A). This pattern can be interpreted in two ways. The first explanation is that the fishers increase their effort during the cold season when catch per unit of effort decreases. However, the alternative explanation is that the overall effort is low during the warm agricultural season which starts in October when land preparation and planting starts and extends to April when harvesting is completed. The second argument supports the "two home condition" (Songore, Moyo and Mugwagwa, 2000) of the fishers, characteristic for the inshore Zimbabwean fishery where permanent settlement and shoreline agriculture is prohibited. The "two home condition" and seasonally fluctuating effort clearly indicates that the original intentions of making the Zimbabwean inshore fishers "professionals" has never succeeded and that fishing is for many only one of several activities.

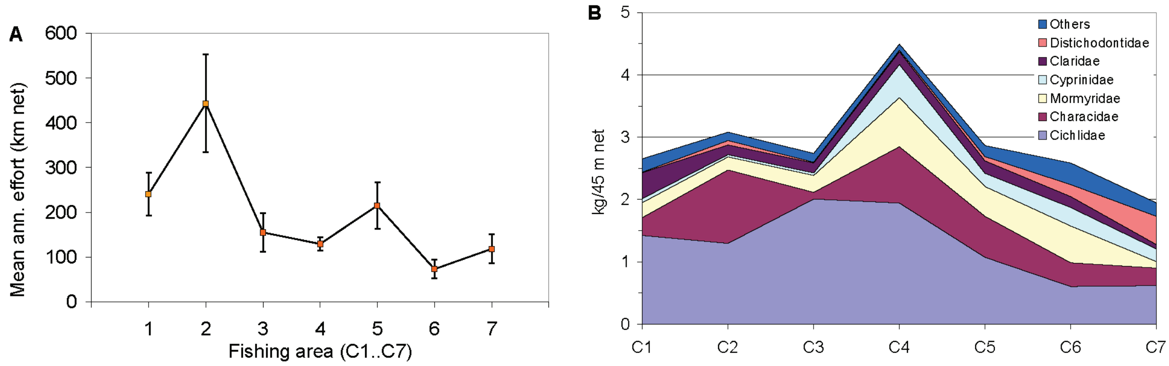

FIGURE 10. *A: Mean annual effort (km net) with 2·SE error bars, and B: mean annual catch per unit effort (kg/45 m net) by major families in fishing areas C1..C7 in the Zimbabean inshore fishery for the period 1980 to 1999.*

The mean annual effort and the mean annual catch rates are not uniform along the east-west gradient of the lake (Figure 10). Fishing area C2 between the Gachegache and Sanyati rivers has in general had the highest average effort, but also the highest variation. Otherwise there is a general decline in effort from the lacustrine eastern basin to the more riverine west of the lake. However, the average catch rates in each fishing area (Figure 10B) shows no apparent relation with the overall effort. This indicates that the effort distribution is more a result of vicinity to markets and the better infrastructure in Basin 5, and that catch rates and effort are largely independent. The catch composition, however, reflects the natural gradient in the lake ecosystem where cichlids are dominant in Basins 4 and 5 whereas large cyprinids and distichodontids become increasingly important towards Basin 1 concomitant with overall lower catch rates. The characids, dominated by tigerfish (*Hydrocynus vittatus*) are more uniformly distributed, but with higher catch rates in fishing areas associated with larger tributaries into the lake, such as the Sanyati river (C2) and the Bumi river (C4).

4.4 Changes in fishing pattern and species composition

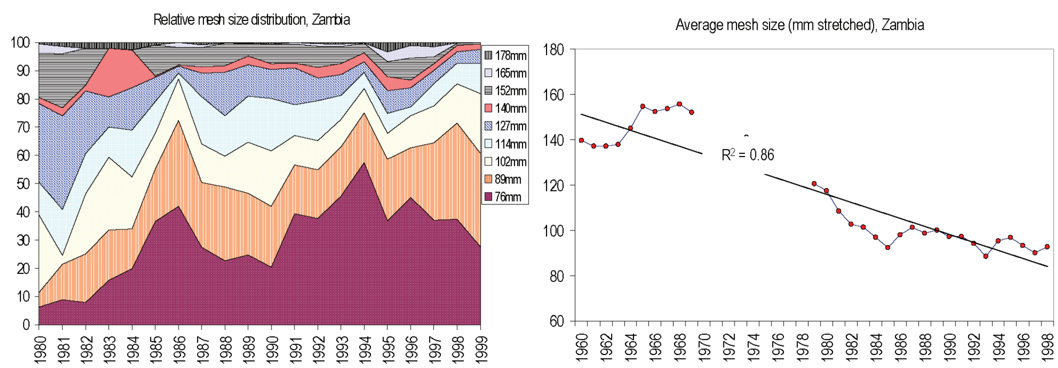

FIGURE 11. *Changes in recorded mesh size distribution in the Zambian inshore fishery. A: relative distribution of mesh sizes from 1980 to 1999, and B: average mesh size from 1961 to 1999. 1961-1970 data from Scholz (1993), 1980-1999 data from Musando (2000).*

During the first decade of the Zambian fishery the average mesh-size ranged between 140-152 mm (Scholz, 1993, Figure 11). From 1980, when monitoring resumed, to 1999 the average mesh-size in the inshore fishery decreased from 120 mm to 90 mm (Figure 11). In addition to a significant decrease in the mesh sizes used, the Zambian inshore fishers are reported to extensively use fish driving techniques (Kutumpula) to catch bream (Scholz, 1993; Malasha, 2003). In Zimbabwe most fishers initially used 150-175 mm mesh until around 1970. As the catches of the large migrating fish (labeo's and distochodontids), remnants from the first inundation period, decreased, the use of smaller mesh sizes increased gradually and by 1978 about 60 percent of the nets were in the range 112–125 mm (Marshall, Junor and Langerman, 1982). In the frame surveys of 1993, 1998 and 2000, the average mesh sizes were 128, 115 and 118 mm respectively (Songore, 2000). In general there has been no significant changes in the fishing pattern of inshore Zimbabwean fishery since the 1970s.

In the inshore fishery about ten species make up more than 90 percent of the catches and of these only three (the cichlids *Oreochromis mortimeri* and *Tilapia rendalli* and the characid tigerfish *Hydrocynus vittatus*) contribute more than 50 percent (Figure 12).

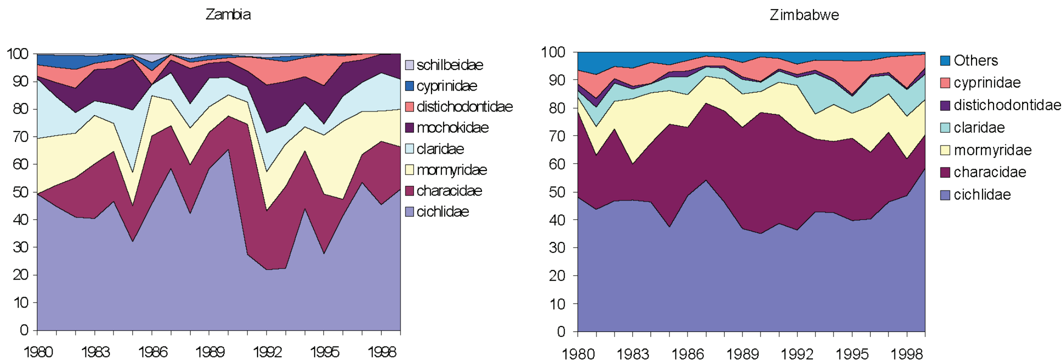

FIGURE 12. *Relative catch composition (% weight) in the inshore fishery between 1980 to 1999 by major families in Zambia and Zimbabwe based on CAS/CEDRS. Sources: Musando (2000) and Songore (2000).*

The changing fishing pattern on the Zambian side is not reflected in the overall species composition of the catches, neither are there any major differences in the overall catch composition between the two countries, which are both dominated by cichlids (Figure 12). In the Zambian inshore fishery relatively less tigerfish and more distichodontids are caught compared to the Zimbabwean side. This difference, however, can be explained from the distribution of the fishers where the majority on the Zambian side is in the western part of the lake, while in Zimbabwe the majority is in the eastern part. For both countries the relative species composition has changed remarkably little since 1980.

A comparison of mean weights and catch rates of the commercially important fish species from two fished areas and the non-fished Lakeside experimental fishing area (Table 1) showed no systematic differences although the overall experimental catch rates are about three times higher than the overall artisanal catch rates (Figure 8).

TABLE 1. *Comparison between mean weight (grams) and mean CPUE (kg/45 m net) for the most important species in the Zimbabwean fishing areas C2 and C4 and the experimental fishing station at lakeside (=LS, mesh sizes 102 to 173 mm) for the period 1980 to 1999. C2 and C4 were chosen because they represent the areas with high and moderate fishing intensity, and because they are the fishing areas enumerated by the same LKFRI staff that is conducting the experimental fishing at lakeside. Below each variable are given the other sites only if these are significantly different at p<0.05).*

	C2		C4		LAKESIDE (LS)	
SPECIES	Mean Weight	CPUE	Mean Weight	CPUE	Mean Weight	CPUE
Hydrocynus vittatus	1460 **C4, LS**	0.95 **C4, LS**	1284 **C2, LS**	0.37 **C2, LS**	993 **C2, C4**	0.36 **C2, C4**
Oreochromis mortimeri	640 **C4**	0.36	532 **C2, LS**	0.33	620 **C4**	0.50
Serranochromis codringtoni	419	0.05 **LS**	384 **LS**	0.10 **LS**	471 **C4**	1.40 **C2, C4**
Tilapia rendalli	543	0.18	533	0.27 **LS**	537	0.14 **C4**
Clarius gariepinus	956 **C4, LS**	0.09 **LS**	1129 **C2**	0.05 **LS**	1190 **C2, C4**	0.46 **C2, C4**
Momyrus longirostris	1801 **C4**	0.09 **LS**	1474 **C2, LS**	0.23 **LS**	1756 **C4**	1.31 **C2, C4**

For two of the species (*H. vittatus* and *T. rendalli*) the catch rates were actually higher in the fished areas than in the non-fished area and for tigerfish also the mean weight was higher in the fished areas. For tigerfish the higher catch rates and mean weights can be explained by location of fishing area C2 and C4 in vicinity to larger tributaries where this species migrate upstream to spawn. For the redbreast tilapia (*T. rendalli*) the higher catch rates could be explained from the use of fish driving as this species is notorious for evading stationary gillnets (Kenmuir, 1984; Karenge and Kolding, 1995a). However, the overall non-systematic difference between the fished and the non-fished areas do not indicate that the observed differences are due to fishing.

4.5 Development of catch rates in the experimental fishing nets

The development of catch rates in the experimental fishing nets on the Zimbabwean side (the unfished Lakeside station) and the Zambian side (Sinazongwe area) show clear differences (Figure 13). In 1980 when the Zambian fishery reopened after the closure due to the war, catch rates on the two sides were almost similar. After this first year, however, the two time series rapidly separated with an increasing trend at Lakeside and a decreasing trend in Zambia. The trends in the two countries are similar to the trends in the inshore fisheries respectively (Figures. 5 and 8). However, the average experimental catch rate in Zambia is about seven times lower compared to Lakeside from the mid 1980s.

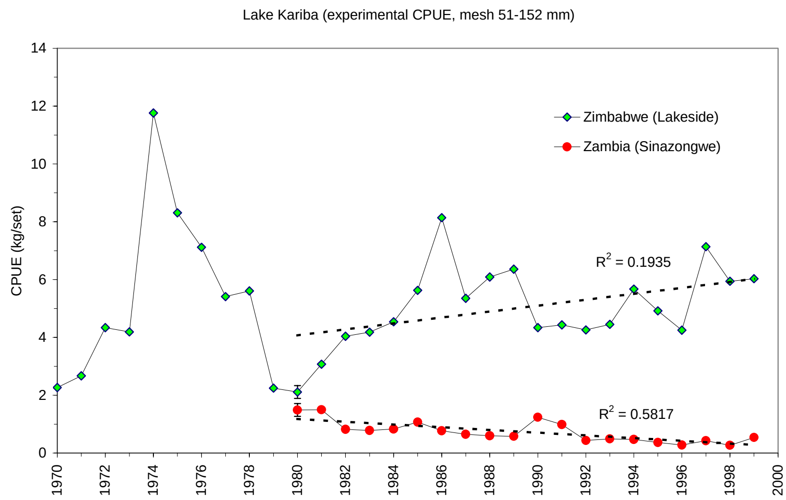

FIGURE 13. *Mean catch rates (kg/set) in the experimental fishery (mesh size range 52-152 mm) on the Zimbawean and the Zambian side of Lake Kariba. 95 percent confidence intervals are indicated for 1980 when the Zambian inshore fishery reopened and the trend lines (both significantly different from 0) represent the period 1980 to 1999.*

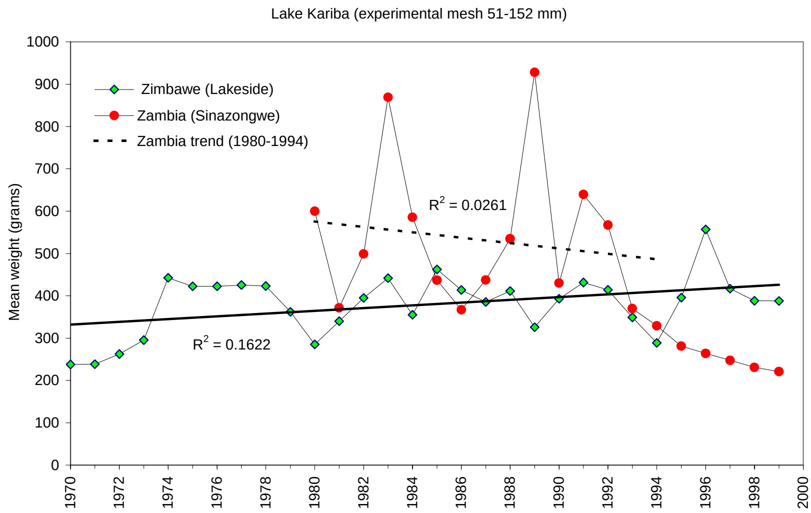

FIGURE 14. *Development in the mean weight of individual fish in the experimental gillnets on the Zimbawean and the Zambian side of Lake Kariba. The trend line for Zimbabwe (1970-1999) is significantly different from 0, whereas the trend line for Zambia (1980-1994) is not significantly different from 0.*

Although the development in the mean weights of the experimental catches (Figure 14) show the same trends as catch rates (increasing in Zimbabwe and decreasing in Zambia), the actual values were higher in Zambia until 1994 when the sampling areas were limited to around the Zongwe estuary (Figure 1). The higher mean weight in the Zambian experimental gillnets can be attributed to the much higher proportion of tigerfish and distichodontids than the Lakeside data dominated by cichlids. Similarly the strong decrease in the Zambian mean weight after 1994 is due to the predominance of squeakers (*Synodontis zambezensis*) in the Zongwe esturay (Figure 15) which means that the experimental gillnet data series in Zambia is not mutually representative before and after 1994.

4.6 Catch composition and species changes in the experimental gillnets.

Most of the published research on the changes and development of the fish populations in Lake Kariba has been from the Zimbabwean side of the lake (Donelly, 1970, 1971; Kenmuir, 1984; Marshall, 1984; Jackson, 1986; Karenge, 1992; Karenge and Kolding, 1995a, 1995b; Sanyanga, 1996). Comparatively little has been published from the Zambian side of the lake, particularly since the study of Balon and Coche (1974). Recently, however, Scholz (1993) and Musando (1996) did analyses on the long-term development of the inshore fish populations in the Zambian waters of the lake.

In contrast to the artisanal catch compositions which show a remarkable stability in the species composition and are dominated by cichlids on both sides of the lake (Figure 12), the relative species composition in the experimental gillnets show a systematic successive development over time (Figure 15). This would indicate that the experimental catches are not representative of the fishery, and that the selectivity (or fishing pattern) is not comparable although gillnets are the main fishing gears used. The Bangweulu case study (Kolding, Ticheler and Chanda, 1996, 2003) also showed that the experimental catches were not representative for the fishery, mainly due to different methods, and even for the same methods (gillnets) different ways of setting the nets. The divergence between the observed succession in the experimental nets and the catch composition in the fishery strongly indicates that the fishers are not passively harvesting the resources, but actively use the different methods and experience available to select and target particular species. In Zambia, for example, the high prevalence of cichlids in the artisanal catches, in contrast to the dominance of tigerfish in the experimental nets (Figure 15), and the large proportion of *Tilapia rendalli* on the Zimbabwean side, both supports the notion of a widespread use of fish driving (Kutumpula) as also observed by Scholz (1993) and Malasha (2003).

Most of the observed changes in relative species composition of the experimental catches can be attributed to the natural species succession that Lake Kariba has undergone since its creation as a new pristine environment (Karenge, 1992; Karenge and Kolding, 1995a; Musando, 1996). Shortly after filling, the large potamodromuos cyprinids *Labeo congoro*, and *L. altivelis*, and characins *Distichodus shenga* and *D. mossambicus*, were abundant in the lake and sustained for a large part the initial boom in the inshore fishery. After a few years they declined, particularly in Basins 3-5, and cichlids gradually became more important (Marshall, Junor and Langerman, 1982).

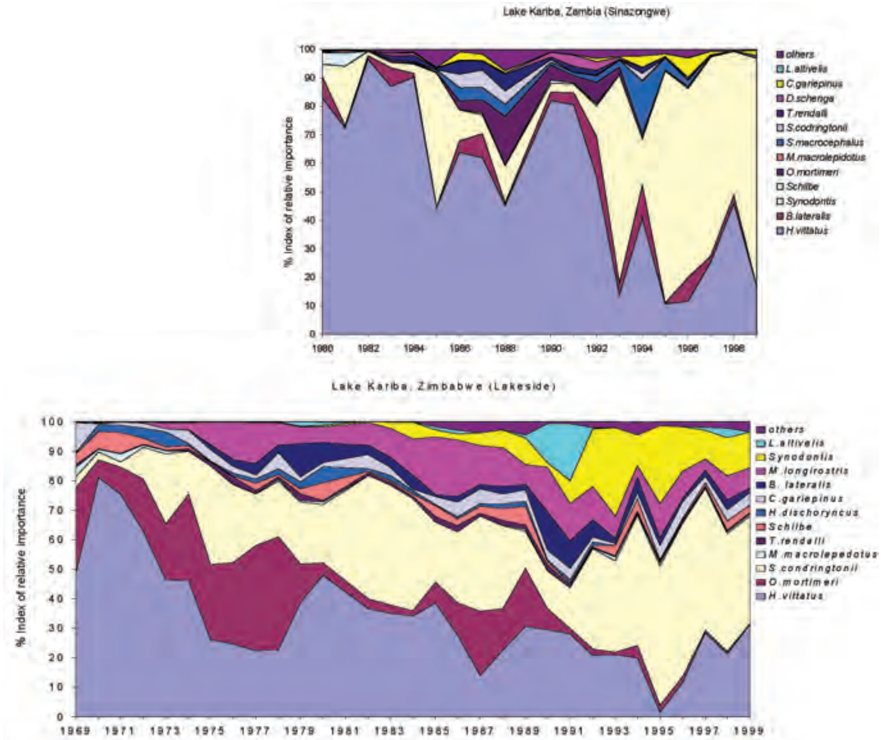

FIGURE 15. *Relative species changes in the experimental surveys represented by Index of Relative Importance (Karenge and Kolding, 1995a). Above Zambia from the Sinazongwe area (Basin 3) and below Zimbabwe from the Lakeside experimental station (Basin 5). From 1994 sampling stations in Zambia were reduced to only cover the Zongwe estuary which are not fully representative for the main lake (see also Figure 16).*

The successive development in species diversity, and particularly the relative evenness, seems more pronounced at Lakeside in the most lacustrine part of the lake (Basin 5) than in the Sinazongwe area (Basin 3). During the 1970s the relative abundance of *Hydrocynus vittatus* gradually declined after which it stabilized (Karenge and Kolding 1995a). Among the cichilids, *Serranochromis condringtonii*, which was not common in the lake in the early years (Kenmuir, 1984), has gradually replaced the Kariba bream (*Oreochromis mortimeri)* in Basin 5. *Oreochromis macrochir*, which had been reported to have disappeared completely shortly after stocking (Balon, 1974a) has been caught in low, though regular, numbers since 1975. This period was also marked by the gradual decline of *Marcusenius macropidotus* and *Hippopotamyrus discorhynchus* but with a substantial increase of the larger mormyrid species *Mormyrus longirostris*. From around 1980 the squeaker *Synodontis zambezensis* gradually became important in the inshore system, while the "Upper Zambezi invader" *Serranchromis macrocephalus* appeared in the lake and increased in abundance.

The tigerfish (*Hydrocynus vitattus*), due to its important recreational value as an angling fish, has always attracted particular attention in the management regulations of Lake Kariba. Its relative decline (Figure 15) has been subject to repeated concern. This species is considered particularly vulnerable to fishing with small mesh sizes (Kenmuir, 1973; Marshall, Junor and Langerman, 1982; Langerman, 1984; Scholz, 1993). Sanyanga (1995) even considered it presently endangered in Lake Kariba and recommended to give it conservation status. However, taking into account that the Lakeside catch data are from an unfished part of the lake and that the Zambian experimental catches are from an area with a continuously increasing level of fishing effort with decreasing mesh sizes, it is a paradox that the mean Index of Relative Importance for 1980-1994 for tigerfish in Zambia was 57 percent while at Lakeside it was only 26 percent. (Figure 15). Thus, while tigerfish has decreased in absolute abundance on the Zambian side since 1980, this decrease is proportionally following the same trend as all the other species in the inshore fishery (Figures 8 and 13). From the available data it is difficult to support the notion that tigerfish is particularly vulnerable to fishing with small mesh sizes, neither that it is an endangered species in the Kariba ecosystem. Karenge and Kolding (1995b) found that the relative lake level changes were the most important factor for the abundance of tigerfish. Lake Kariba experienced a serious drought between 1982 and 1998, with a subsequent rapid rise to full capacity in 2000 (Figure 2). It is expected therefore that the catch rates will increase from 1999 which has been confirmed during 2001 (Patrick Ngalande, pers. comm).

4.7 Diversity

The appearance of new species and the increasing abundance of other species (like *L. altivelis* and *S. zambezensis*, which were common in the Zambezi River before inundation) have resulted in steadily increased fish species diversity (Figure 16).

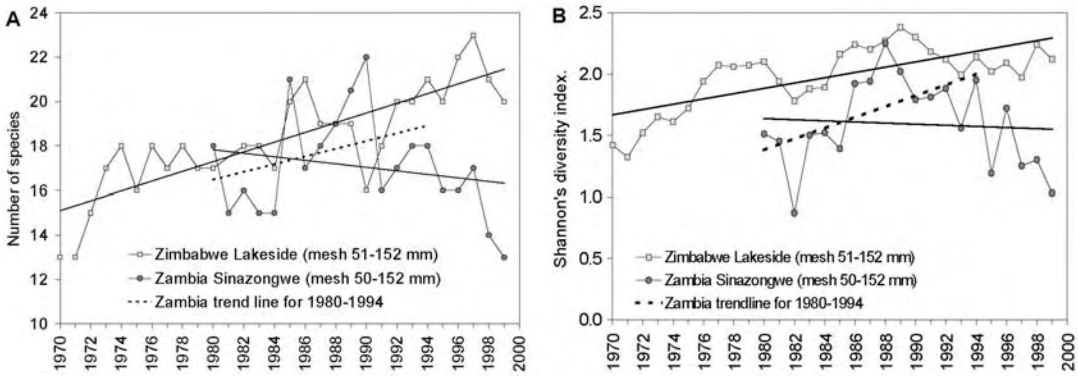

FIGURE 16. *Development in species diversity in the Kariba experimental gillnets (mesh sizes 50-152 mm) represented by* ***A****: annual mean number of species caught and* ***B****: Shannons's diversity index (H'). Continuos trendlines are for the whole period of observations (1970-1999 and 1980-1999 in Zimbabwe and Zambia respectively). Broken trendlines are from the period 1980-1994 in Zambia. The broken trendlines for Zambia (****A****: Slope = 0.21, SE = 0.15;* ***B****: Slope = 0.05, SE = 0.020) and the trendlines for Zimbabwe (****A****: Slope = 0.22, SE = 0.03;* ***B****: Slope = 0.02, SE = 0.004) are statistically not significantly different at 95 percent confidence intervals.*

An overall increase over time in the both the number of species caught and the Shannons diversity index can be observed at Lakeside, whereas around Sinazongwe an increase in the 1980s was followed by a decrease after 1993 (Figure 16). The decrease in Zambia, however, is believed a sampling artefact because from 1994 only the stations within the Zongwe estuary were sampled which due to the habitat has an overall lower diversity. The total number of species caught over the period 1980-1994 is 32 in Zambia and 29 in Zimbabwe in the experimental fleet of 50-152 mm mesh sizes. The average Shannon diversity index, however, is significantly different between the two countries due to a higher relative evenness among the species at Lakeside in Basin 5 (Table 2, Figure 15).

Comparing the period 1980-1994 in Zambia with the whole period in Zimbawe the successive development in species diversity (slopes) is not significantly different on the two sides of the lake (Figure 16). The lower mean values in the Zambian experimental catches can be explained from the different habitats in Basins 3 and 5 and the overall composition gradient along the lake.

	mesh range	# fleet settings	# species	H'	J'
Zambia	51-152	869	32	1.90±0.04	0.57±0.02
Zimbabwe	50-152	592	29	2.29±0.03	0.69±0.02

TABLE 2. *Comparison of the species diversity in the Zambian and Zimbabwean inshore gillnet catches between 1980 and 1994. Shannons diversity index (H') and evenness index (J') with confidence limits of 2·SE from bootstrapping.*

4.8 Biomass-size distribution

The difference in the mean experimental catch rates between Zimbabwe and Zambia (Figure 13) is reflected in the overall biomass-size distribution of the two areas (Figure 17).

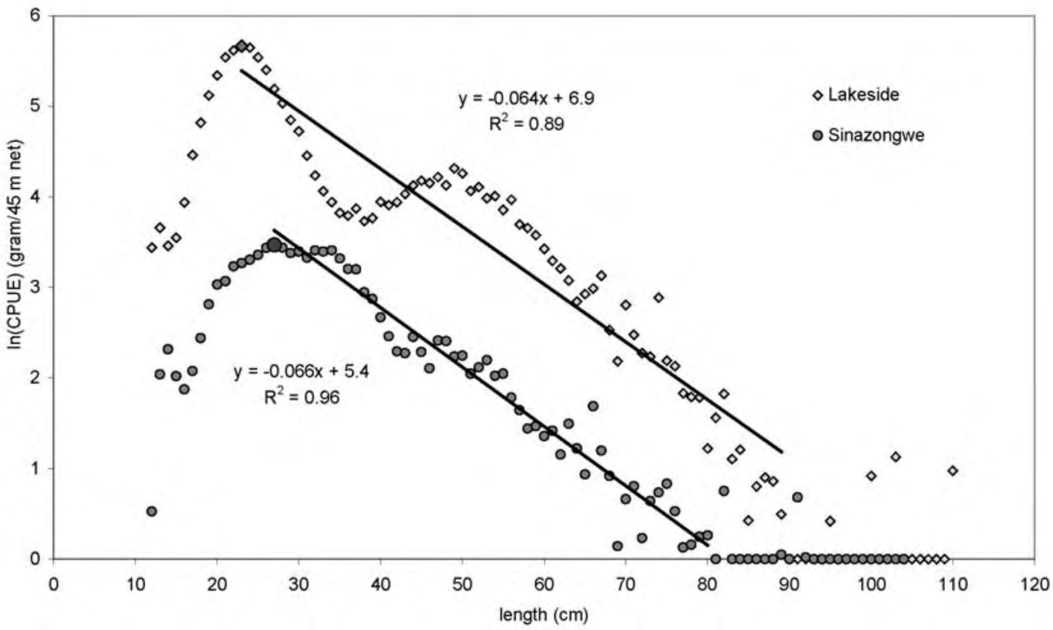

FIGURE 17. *Relative biomass-size distribution with linear regression from Zimbabwe (Lakeside) and Zambia (Sinazongwe) experimental fisheries during the period 1980-1994 for all fish caught in mesh sizes 50-152 mm. Linear regressions on ln-transformed standardized mean catch rates (gram/45 m net set) were made from length range 23-89 cm (Zimbabwe) and 25-78 cm (Zambia) (from the highest value to first 0-observation). The SE of the slopes are 0.0028 and 0.0019 for Zimbabwe and Zambia respectively which means the slopes are not significantly different at 95 percent confidence level.*

Although the means of the biomass-size distributions (intercepts) are significantly different it is interesting to note that the slopes are not. This indicates that although the absolute stock abundance is clearly different between the unfished and fished areas, the overall community size structure is relatively the same. Comparing the biomass-size distributions with the relative inshore catch composition (Figure 12) and the development in species diversity (Figures. 15 and 16), it appears that the much higher fishing intensity in Zambia with smaller mesh sizes only are affecting the overall biomass of the stocks, whereas the community structure and composition seems not affected. There are no indications that the present fishing level and fishing pattern in the Zambian inshore fishery show any potential threat to the biodiversity of the lake. As the overall yields have not declined (Figure 7), the lower catch rates are not a sign of overfishing in a biological sense, but simply a sign of fishing. Furthermore, by decreasing the mesh sizes, and thereby increasingly exploiting the smaller species/sizes in the biomass-size spectrum, the Zambian fishers are not only able to largely maintain their individual returns (CPUE) despite overall increasing effort, but also maintain the same relative size spectrum in the community which ecologically speaking only makes sense (see Jul-Larsen *et al.* 2003, Chapter 5).

4.9 The relative impact of the environment

Both experimental, inshore, and offshore catch per unit of effort (CPUE) fluctuated synchronously with mean annual lake level fluctuations with a remarkably high correlation (Karenge and Kolding, 1995b). The question is therefore how much of the observed variation can be attributed to fishing and how much to the changing environmental conditions.

TABLE 3. *The relative effect of hydrological changes and effort on catch rates in the Kariba fisheries. The statistical regression model used is: Annual mean catch rate*$_{ijk}$ *= overall mean + effort*$_i$ *+ lag(hydrological variable*$_j$*) + effort*$_i$*·lag(hydrological variable*$_j$*) + residual variation*$_{ijk}$*. Only significant effects are retained in the model and shown here as positive (+) or negative (-) effects. In some instances the hydrological variables and effort were confounded meaning that both parameters were significant alone, but in the total model one or the other became non-significant depending on the order they were entered into the model. In such situations it is not possible to quantify the relative effect of both parameters simultaneously. N= number of years in the model.*

Dependent variable		Independent variables								
Annual mean catch rate		Hydrology				Effort			Interaction	
System Variable	N	Lag	Variable	Sign	%	Variable	Sign	%	Sign	%
Zimbabwe										
Artisanal CPUE (Kg/net)	27	0+1	ΔLake levels	+ (**)	29	# Fishers	- (**)	44	Ns	
Artisanal CPUE (Kg/net)	27	0	ΔLake levels	+ (**)	19	# Nets	- (**)	26	Ns	
Exp. CPUE (kg/net)	29	0	Amplitude	+ (**)	39	# Fishers	Ns		Ns	
Exp. CPUE (kg/net)	29	0	Amplitude	+ (**)	39	# Nets	Ns		Ns	
Kapenta CPUE(t/night)	26	0	Lake levels	Confounded		Boats	Confounded		- (**)	56
Zambia										
Artisanal CPUE (Kg/net)	20	0	Lake levels	+ (**)	32	# Fishers	Ns		Ns	
Artisanal CPUE (Kg/net)	20	0	Lake levels	+ (**)	32	# Nets	- (*)	9	- (*)	8
Exp. CPUE (kg/net)	20	0	Lake levels	+ (**)	31	# Fishers	Ns		Ns	
Exp. CPUE (kg/net)	20	0	Lake levels	+ (**)	34	# Nets	- (**)	23	- (*)	11
Kapenta CPUE(t/night)	18	0	Lake levels	Confounded		Boats	Confounded		- (**)	60

The results of the multiple regression analyses between the various time series of catch rates, effort, and hydrological variables (Table 3) indicate that the lake level fluctuations have a significant effect on the overall stock sizes in both the unfished area, the inshore, and the offshore Kapenta. The fishing effort had no effect on the experimental catch rates in the unfished Lakeside area, which supports the notion that a closed area could act as a sanctuary. The fishing effort however had significant effect in all the exploited areas. In the Zimbabwe inshore fishery both the number of fishers and the number of nets were significant, reflecting the relatively constant number of nets per fisherman over time in this fishery. In the inshore Zambian fishery, however, only the number of nets were significant, reflecting the ever increased number of nets per fisherman (Figure 6) in this fishery.

Most interestingly, however, fishing effort had a higher relative effect in the lightly fished inshore Zimbabwean inshore fishery (44 percent and 26 percent for the number of fishers and number of nets respectively) compared to the higher exploited Zambian inshore fishery (9 percent for the number of nets). Conversely the environment had a higher effect in the inshore Zambian fishery than the inshore Zimbabwean fishery. Everything else being equal, this seems to indicate that as the fishing effort increases and the stock levels are reduced, the annual catch rates become more and more dependent on the changing environmental conditions. In other words, in an unstable environment with a high exploitation level, the fishery will develop more and more into a boom and bust fishery with the changing environmental conditions (see Figure 5.8, Volume 1). This situation would explain the much more variable annual catch rates and relative species composition in the Zambian inshore fishery compared to the less exploited Zimbabwean side (Figures 8 and 12).

5. CONCLUSIONS

The inshore fisheries on the Zimbabwean and Zambian side of Lake Kariba have ever since the creation of the lake undergone different management regimes. The Zimbabwean side is, compared to the Zambian, much more regulated and enforced resulting in a fishing pressure and fishing pattern which has not changed much over time and where the fish stocks are only moderately exploited. In contrast, the Zambian inshore fishery, with virtually no enforcement of regulations, has experienced a much higher fishing intensity and a changed fishing pattern towards increasingly smaller mesh sizes resulting in a higher exploitation level and reduced stock sizes. In both countries effort has been fluctuating over time. However, in Zimbabwe the effort in general has shown a decreasing trend while CPUE has increased, whereas in Zambia effort generally has increased with a corresponding decreasing trend in CPUE. The overall fishing effort, in terms of number of nets, is about seven times higher in Zambia than in Zimbabwe, while the average experimental catch rates are seven times lower. However, the artisanal catch rates are not very different on both sides of the lake (1.8 and 2.8 kg/net in Zambia and Zimbabwe respectively). This would indicate the Zambian fishers somehow are able to maintain the catch efficiency by decreasing the mesh sizes (Figure 11) and, probably through increased use of fish driving.

Nevertheless, there are no indications of biological overexploitation in the Zambian inshore fishery in terms of reduced total yields or changed fish communities. This leads to the conclusion that the Zimbabwean inshore fishery is underutilized.

Lake Kariba, as a man-made artificial environment, is slowly but constantly changing in terms of biological species succession indicating that it has not yet reached its final maturity stage 40 years after its creation. Both sides of the lake appear to undergo the same trends in diversity development, irrespective of fishing pressure and fishing pattern. The slopes of the biomass-size distributions are equal on both sides of the lake, although with significantly different intercepts. This indicates that the relatively high fishing pressure on the Zambian side does not have any negative impact on the community structure, only that the stock sizes are reduced presumably due to fishing.

The seasonal inputs of nutrients (through the river and through inundation of shores) into the system has a significant effect on the regenerative capacity of the stocks, indicating that Lake Kariba is a naturally fluctuating environment where effort limitations has limited effects on the conservation of stock size levels. In such a system the notion of sustainable long-term yields becomes very difficult to define. Furthermore, there are indications that with increased fishing pressure the relative effect of the environmental changes become relatively more important than the fishing mortality resulting in an increased variability of the catch rates but reflecting the high degree of resilience in the ecosystem. In such a situation, the fishery must adapt to the natural fluctuations by taking advantage of the good flood years, and, by a diversified economy, be able to survive the lean periods. Management regulations such as limited entry and restricted mesh sizes as in Zimbabwe would result in a higher stability for the individual fisherman, but on the other hand in a severe underutilization of the potential yields.

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