International Journal of Fisheries and Aquatic Studies 2017; 5(1): 490-495

E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.549
IJFAS 2017; 5(1): 490-495

www.fisheriesjournal.com
Received: 07-11-2016
Accepted: 08-12-2016

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Assessment of Lake Liambezi gillnet fishery in the Zambezi region, Namibia

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Abstract
Lake Liambezi in the Zambezi Region of Namibia, formerly known as the Caprivi Region, is shallow (< 6 meters deep) and characterised by cyclic episodes of filling and drying. When full the lake supports a highly productive fishery and when the lake is completely dry it is used for agriculture and grazing. In 2000 the lake filled, and between May 2011 and April 2012 catch landings were surveyed to obtain information for conservation and management recommendations for the fishery. An informal fishery has been established on the lake with more than 300 canoes and 120 fishermen using monofilament and multifilament gillnets. The annual average water temperature during the sampling period was 24.0 °C. Catch per unit effort (CPUE) was 15 kg/canoe/day and was significantly ($P < 0.05$) associated with monthly temperature and moon phase parameters indicating that in addition to fishing, the fishery of Lake Liambezi may be altered by climate and environmental factors. Annual catch from the lake was estimated at approximately 3193 tons with an estimated productivity of 106 kg/ha, suggesting that Lake Liambezi makes a significant contribution to the fish supply in the Zambezi Region and beyond. Recommendations were made to manage the Lake Liambezi fishery by imposing restrictions on effort (number of fishing boats), gear type, mesh sizes and access. Proper fisheries management and monitoring should incorporate climatic and environmental factors such as temperature and moon phase to meet the challenges of global climatic changes as well as other environmental issues.

Keywords: Lake Liambezi, fishery, gillnet, catch-per-unit-effort

1. Introduction
Lake Liambezi in the Zambezi Region of Namibia, formerly known as the Caprivi Region, is shallow (<6 m deep), about 300 km^2 in surface area, and is characterised by cyclic episodes of filling [1, 2] (Figure 1 & 2). It receives water from several sources [2]. The primary source is the Zambezi River, whose waters enter the lake in years of high flooding from two directions. Annually, when the Zambezi floods, the Chobe River reverses flow direction and enters the lake from the south-east, while the Bukalo Channel flows from the Caprivi floodplain of the Zambezi River into the north-east of the lake. The Kwando River flows south from Angola into the Linyanti wetlands to the west of the lake. Its waters percolate through the wetlands and out via the Linyanti Channels which flow eastward along the Namibia–Botswana border into the lake. Rainfall and runoff from the area north of the lake also contributes to water in the lake [1, 3]. When full the lake supports a highly productive fishery [3]. Early 2000, the fishery developed from scratch as the lake began filling. Initial catches in 2009 were dominated by *Clarias gariepinus* (Burchell, 1822), with few of the tilapiines [2]. In 2010 the rapid increase in the catch of large cichlid species inspired many fishermen to enter [3] and resulted in the development of the vibrant small-scale fishery at Shamahuka landing site. Catches quickly became dominated by large cichlids, with *Oreochromis andersonii* (Castelnau, 1861) and *Tilapia rendalli* (Boulenger, 1896) comprising approximately 90% of the total catch [2, 11]. Shamahuka is now the major landing site along Lake Liambezi from where catches are transported mainly to the urban fish market in Katima Mulilo (Figure 1). In November 2010, 125 fishermen, 91 canoes, and an average of two fishermen per canoe were registered by the fishery [3]. Fish trade begun in 2009 as an influx of Namibians, Angolans, Zambians, and Congolese settled at Shamahuka landing site for weeks or months at a time while topping up their target consignments of fish for sale (Simasiku, pers. obs.). Fish were caught mainly by the Namibian fishermen and sold to both local and foreign fish traders.

While at the lake, most of the foreign fish traders split and dried their fish or preserved them in salt before shipping them to Livingstone and Lusaka in Zambia, or further into the Democratic Republic of Congo (DRC) [3]. Alternatively, fish would be transported by taxi to local markets at Bukalo and the Katima Mulilo fish market [4, 5].

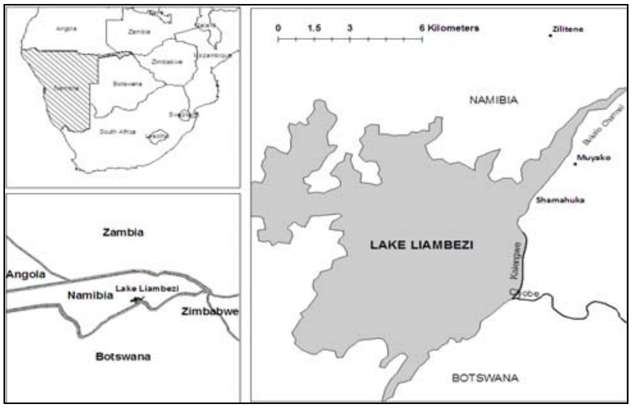

Fig 1: Map of Lake Liambezi, Namibia, showing the main source of water feeding the lake and Shamahuka landing site. (source: Peel, *et al*., 2015).

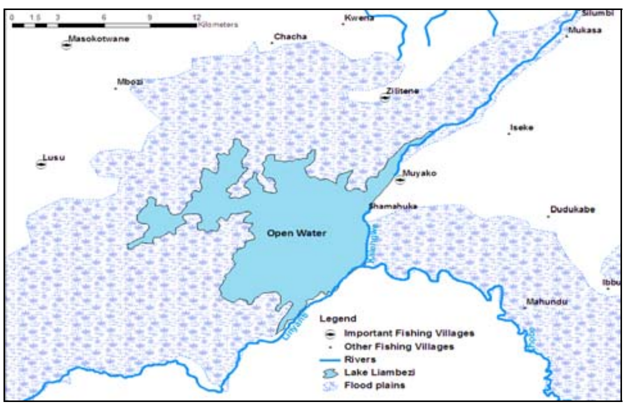

Fig 2: Map of Lake Liambezi showing the important fishing villages around the lake, generated using ArcGIS 9.3.

Catch data from a floodplain lake, such as Lake Liambezi are of variable quality, but the catch data are unreliable [5]. As a result, the true values of these fisheries are underestimated. Serious gap exists not only in the knowledge of the fishery structure, but also in our knowledge of the impact of such a small-scale commercial fishery on the fish community of the lake. Therefore, the aim of this paper was to assess the gillnet fishery developed on Lake Liambezi by accounting for statistical data at Shamahuka landing site with the objective to determine both harvesting patterns and annual catch rates of the local fishermen.

2. Materials and Methods

2.1. Water quality

Water temperature was measured using a digital thermometer and water transparency was estimated using a secchi disc. Hydrological data for the mean monthly water levels in metres were collected at a hydrological station situated in the mid-zone of the lake.

2.2. Catch assessment at Shamahuka

Catch Assessment Surveys (CAS) were conducted twice a week at Shamahuka landing site between May 2011 and April 2012 (Figure 1 & 2). Individual fishermen landing their catch were approached and questioned regarding their canoes, net types, stretched mesh sizes, net length and frequency of fishing activities. The daily catch of fish per canoe was weighed collectively using a hanging scale under a pole tripod with a large platform. The weighing station was strategically placed on the shore point where most fishermen landed their catch. Information on the number of fishermen was obtained by questioning the village headman. Responses regarding the frequency of fishing, gear type and mesh sizes were obtained directly from the fishers available and willing to participate in short interviews. In total, 106 fishermen operating on Lake Liambezi were interviewed during the course of the study. Effort was determined as the total number of canoes operating on the lake for five days in a week per month. A special attempt was made to count all the canoes at various landing sites along the lake between September and October 2012. Two teams undertook the surveys simultaneously, one supported by boat operating along the northern and central lake at Muyako and Zilitene, while the second team, supported by one vehicle, operated along the western lake at Lusu and Masokotwani (Figure 2).

2.3. Statistical analyses

Catch per unit effort (*CPUE*) was defined as the weight of fish caught per canoe.

CPUE was calculated as:

$$CPUE = \frac{\mathrm{C}i}{\mathrm{E}i}$$

where C*i* is the biomass of fish (in kg) and E*i* is the effort expressed per canoe.

Total Catch (*TC*) in kilograms (kg) was calculated as:

$$TC = \sum \overline{CPUE \times} F \times E$$

where CPUE is mean CPUE (kg/canoe/day), F = fishing days/year, E = effort (number of canoes).

The non-parametric Spearman's rank correlation coefficient was used to assess correlations between CPUE and three environmental factors: temperature, water level, and lunar phase. The lunar phase calendar was obtained from the link http://home.roadrunner.com/~davejessie/-MoonPhases/calenders/2012 jpg. As a quantitative way of describing the lunar phase, the authors decided to use the fraction of the moon's disk that was illuminated in a day. This quantity could take values between 0% (new moon) and 100% (full moon).

3. Results

3.1. Fishing craft and fishing gear

In total, 353 canoes were recorded on the lake between May 2011 and April 2012. The highest number of canoes (62%) were recorded from Shamahuka landing site (Muyako village), with the lowest being recorded from Zilitene (4%) and Lusu (4.4%) (Figure 2). During the study, 92.2% of the fishermen showed a high preference for monofilament gillnets over multifilament gillnets.

3.2. Frequency of fishing

Fishermen were asked how many days in a week they spent fishing. The results are summarized in Table 1. More than 60% of the fishermen indicated that they fish for five days in a week, while 16% indicated they fish for 7 days a week. As a result, an average of 5.2 fishing days per fishermen per fishing week was obtained during the creel surveys. All the fishers interviewed during the course of this study indicated that they fish every month of the year.

3.3. Fish landings per canoe at Shamahuka

Monthly fluctuations in monthly mean weight (CPUE) of fish from the lake between May 2011 and April 2012 are depicted in Figure 3. Average monthly catches increased from 15 ± 7.18 kg/canoe/net night in May 2011 to 44.6 ± 17.8 kg/canoe/net night in August; declined to 14.6 ±7.6 kg/canoe/net night in October and peaked at 53.1 ± 31.8 kg/canoe/net night in April 2012. The average catch rate per canoe per day trip was 35.8 ± 20.7 kg/day. Analysis of CPUE indicates that catches were lognormal distributed and that most (70%) of the time, a fisherman's daily catch would range between 11 kg and 50 kg (Figure 3 & 4).

Table 1: Percentage distribution of fishers in terms of fishing frequencies on Lake Liambezi, between May 2011 and April 2012

Status of fishermen	Number recorded	Percent
Once a week	0	0
Twice a week	0	0
Three times a week	4	4
Four times a week	5	4.7
Five times a week	70	66.0
Six times a week	10	9.4
Seven times a week	17	16.0
		100
Total	106	

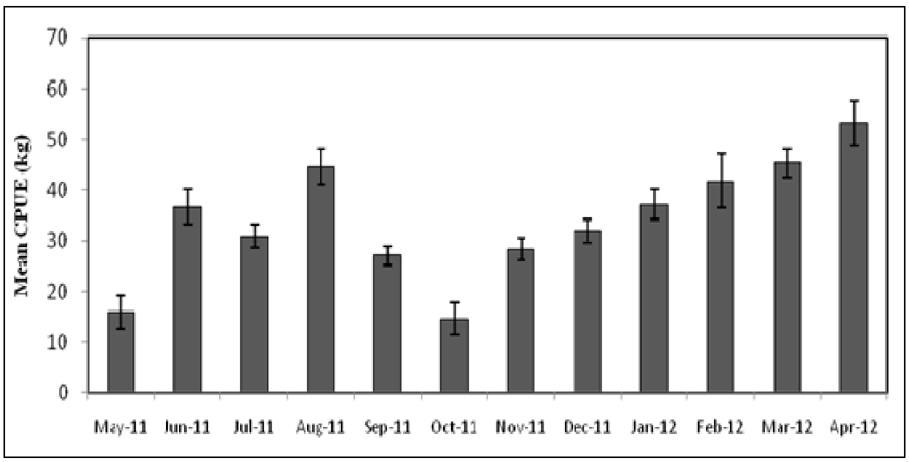

Fig 3: Monthly total catches per canoe per net night recorded from a sample of 602 canoes/days at Shamahuka landing site, on Lake Liambezi between May 2011 and April 2012. Columns are mean values and the lines indicates standard deviations

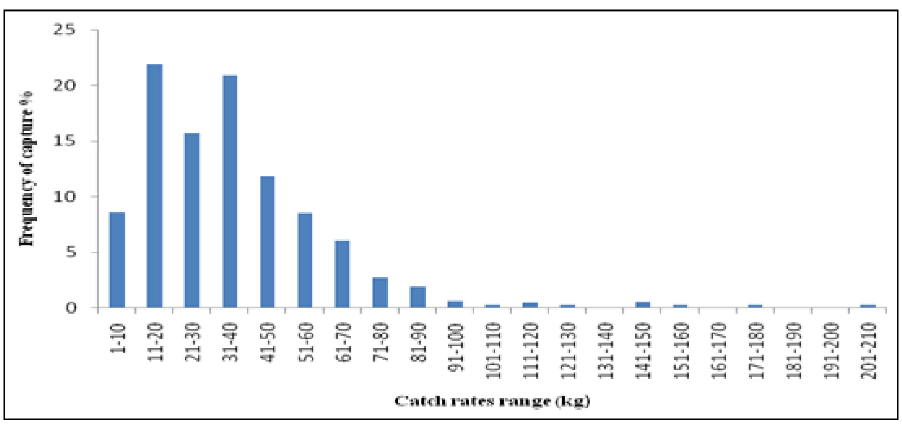

Fig 4: Frequency of capture per fishing day recorded from a sample of 602 canoes at Shamahuka landing site, Lake Liambezi, between May 2011 and April 2012.

3.4. Fishing effort and total catch

A total of 343 canoes were recorded from the entire lake with the highest record being 220 canoes from Muyako fishing village, which includes the Shamahuka landing site (Figure 2). Based on the above statistics, a total catch of 2219 ± 57 t/year was landed at Muyako landing site only, eastern lake side (Figure 2). This was computed from an average catch rate of 35.8 kg/fishermen/canoe/day, determined from an estimated number of 220 canoes recorded from Muyako village and 5/7 weekly fishing days of 365 days in a year (equivalent to 260 days) (May 2011 – April 2012). Total fish yield for the entire lake was approximately 3193 ± 88 t in a year computed from an average catch rate of 35.8 kg/canoe/day, determined from a total estimate of 343 canoes recorded for the entire lake.

3.5. Correlation between catches and climatic factors

Separate correlation analyses were performed to assess the relationship between the monthly catch rates at Shamahuka landing site with the three climatic factors of temperature, lunar phase and water level. A negative significant correlation between the monthly catch rates and temperature was found (r = -0.37; $P<0.01$). Similarly, a negative significant correlation between the monthly catch rates and lunar phase was also found (r = -0.14; $P<0.05$). However, no correlation between the monthly catch rates and water level (P>0.05) was recorded. A pair wise correlation analysis showed a positive significant correlation (r = 0.16; P<0.05) between the monthly catch rates with water level and lunar phase as a combined factor, whereas a negative significant correlation was recorded between the monthly catch rates with temperature and water level as a combined factor (r = -0.83; P<0.01). However, no significant correlation was recorded between the monthly catch rates with water level and lunar phase as a combined factor.

4. Discussion

A number of fisheries assessment methods are available. These include frame or inventory surveys [6], catch cards [7], angler diary [8], fisheries patrols [7], roving creel surveys [9], access point surveys [9] and aerial surveys [6, 10]. Statistical data collected on the lake in this study were collected using methods developed by Bazigos [6]. No major changes in harvesting patterns were observed before the lake dried up [1] and after it refilled in 2009 [11]. However, the gillnet fishery now uses monofilament gillnets (92.2%) rather than multifilament gillnets (7.8%) as it was observed by Simasiku, (2014) [11]. The change to monofilament gillnets in the Zambezi Region seems to have started in 2010. Modern gear increased in importance from mid-2011 to 2012 [11]. The reason for this change is attributed to the higher catch efficiency associated with the monofilament gillnets and the increasingly dominant market economy, and the creation of formal employment and urbanisation [2, 12]. Monofilament nets were three times more efficient than multifilament nets in catching fish in Lake Liambezi [11]. Monofilament and multifilament gillnets are selective towards the large cichlid species such as *O. andersonii*, *O. macrochir* (Boulenger, 1912), *T. rendalli* and *S. macrocephalus* (Boulenger, 1912) [2]. The drive by fishermen towards catching large cichlids is demand driven as they command a much higher market price than non-cichlid species e.g. *Hydrocynus vittatus* (*Castelnau,* 1861) and *Clarias* species [12]. In Malawi, fish trading has been increasing since the Second World War in response to the doubling of the population between 1945 and 1966 [13]. The introduction of machine-made nylon thread nets by a Blantyre factory instead of the fiber of local plants in 1958 was one of the most dramatic innovations of the fishing industry in Malawi [14]. Observations at fish landing locations and collection of metric data of landed fish are commonly used methods supporting fisheries management [15]. Monthly catch landings at Shamahuka per day increased over the study period and were related to climatic factors such as water level, temperature and lunar phase. Water temperature ranged between a winter minimum of 19.0 °C and a summer maximum of 28.0 °C. Secchi depth ranged from 0.6 m to 1.6 m while water level showed a slight declined from 6 m to 5.5 m [11]. Correlation analysis showed no significant relationship between the catches and water level. However, a significant negative correlation was found between average monthly temperature and monthly catches. Similarly, there was a significant negative correlation between lunar phase and monthly total catch. The observed negative relationship between catches and water level was a surprise in contrast to van der Waal, (1980) [1] who showed that low water lake levels produced high catches in Lake Liambezi. Welcomme, (1975) [16] also reported that for African floodplain fisheries, "variation in the intensity and duration of the floods and severity of draw-down conditions during the low water produces corresponding fluctuations in many biological parameters". Thus year-classes of fish from years of high water levels and slight-draw-down show greater growth and survival than year-classes from years of poor conditions. Similarly, Furse *et al*., 1979 [17] observed that the yield and species composition in the shallow Lake Chilwa (Malawi) varied as lake levels fluctuated. Hence the observed lack of correlation between water lake levels and monthly total fish catches in the present study could be attributed to slight seasonal changes in Lake Liambezi water level during the course of this study. Surveys conducted by van der Waal, (1980) [1] were very extensive (1973-1976) compared to the single year of data presented in this study. During the period covered by van der Waal's study, Lake Liambezi should have been through minor and moderately severe recessions resulting in significant impacts on the fish mortality.

This study showed a decline in fish catches with an increase in temperature and vice versa. There are three possible causes of this decline. Firstly, the fall in fish catches during the warmer months coincided with the spawning seasons for most cichlids, resulting in minimum migration in the lake as reported by Peel, (2012) [18]. Secondly, the twelve-month fishing season was further reduced by strong rainfall and wind experienced annually between October and April, which could have negatively influenced the fishing activities on the lake. Thirdly, a fall in catches may have been attributed to an increase in fishing pressure driven by increasing effort in the fishery. This has been shown in the Zambezi River where stocks of the larger, commercially more valuable cichlids species have been declining due to fishing [19]. A significant correlation between lunar phase and daily CPUE was also observed in this study. Lunar cycles are commonly observed in the movements, feeding and reproduction of marine and freshwater fish and invertebrates [20]. Both professional and recreational fishermen believe that catch per unit effort (CPUE) in many fisheries depends on lunar phase [21]. Catch rates were observed to decrease from new moon (0%) to full moon (100%) irrespective of fishing effort. A decline in fish catches during the full moon days can be attributed to an increase in the visibility of the netting as well as the influence of the moonlight on fish behavior and distribution of its prey [22]. The only exception to this pattern was observed in November – December 2011, when a relatively high catch rate was made over the full-moon periods. These observations agrees with (Lewis & Tweddle, 1990) [23] who pointed out that weather conditions influence catches during the rainy season, and concluded that overcast conditions would create good fishing conditions during periods of full moon, whereas periods of strong winds or thunderstorms on moonless nights would restrict fishing. However, it is noteworthy that the effect of lunar phase may vary, depending on the fish species. For instance, (Bigelow *et al*., 1999) [24] demonstrated that tuna (*Thunnus obesus*) catches using long lines peak during the full moon phase because predatory fish are better adapted to locate baited hooks in the moonlight. The contrasting effects of lunar phase on catchability of predatory fish illustrate the fact that lunar phases can have varying effects on CPUE,

depending on the nature of the fishery considered. The classification of “day or night” fisheries does not uncover any apparent patterns in respect to lunar phase effects.
Fish production per surface area of 3 193 t/year and 100 kg/ha was computed from the entire Lake Liambezi (size 300 km^2). The results obtained in this study are compared in Table 4 with statistics of other similar commercial fisheries on a number of African lakes.

Table 4: Fish yield from selected water bodies in Africa.

Lake name	Yield (kg/ha/year)	Surface area(km^2)	Reference
Kainji	4.7	1270	Balogun & Ibeun 1995
Kariba	57.0	5364	Machena 1995
Nasser	39.0	900	Rashid 1995
Volta	52.0	8300	Braimah 1995
Mweru	108.0	5175	Jul-Larsen *et al.*2003
Bangweulu	1.9	15100	Jul-Larsen *et al.*2003
Chilwa	160.0	750	Jul-Larsen *et al.*2003
Malombe	77.0	390	Jul-Larsen *et al.* 2003
Chiuta	100.0	199	GoM 2005
Liambezi	106.0	300	This study

The average production of the entire Lake Liambezi is comparable to the estimated figures which were computed in a similar way. The figure of 100 kg/ha is relatively low compared to Lake Chilwa (160 kg/ha) but within the range of other lakes such as Lake Chiuta, Lake Malombe and Lake Mweru (Table 4). The current Lake Liambezi fish production is higher than the 1700 t/year previously reported by Tweddle *et al*., (2011) [3]. It is possible that the preceding study had underestimated the yield computed based on the total number of fishermen on the lake, whereas the current yield in this study was computed from the total number of canoes. Information on the total number of fishermen on either side of the lake was obtained from headmen and this is usually undependable. It is also possible that catch rates were generally lower in 2011. An increase in fishing canoes, fish trade and export and the use of modernized efficient fishing gear are some of the innovations employed in boosting the current observed production from the lake.

5. Conclusions

Lake Liambezi supported a thriving tilapia fishery in the 1970s and has now become one once again. Monofilament and multifilament gillnets have been identified as the main gear used by most fishermen on the lake. This situation provided more economic fishing activity for the local fishermen with high risks of overfishing [2, 3]. Therefore the use of monofilament gillnets in the fishery should be discouraged.
Monthly landings (CPUE) at Shamahuka increased from 15kg to 53kg per standard net. An increase in CPUE over the study period was observed, possibly indicating that over-exploitation of fish caught in gillnets did not take place. Variation in monthly CPUE was relatively altered by climatic factors such as temperature and moon phase coupled with human induced effort. A yield of 100kg/ha was computed from the entire water surface of Lake Liambezi (size 300km^2). This confirms that Lake Liambezi is a productive lake with a significant input towards the nutritional requirement of the Zambezi Region. High floods for three years, 2009 to 2011, have ensured the lake is full and the surrounding floodplains now retain a lot of water throughout the year, thus it is likely that even without high floods, the lake will remain a significant water body for several years. This time span allows for management of a tilapia fishery.

6. Acknowledgement

We would like to thank the German Academic Exchange Service (DAAD) and the Ministry of Fisheries & Marine resources for funding this project. I extend my sincere thanks to the Namibian Nature Foundation (NNF) and the South African Institute for Aquatic Biodiversity (SAIAB) for their incredible guidance and logistical support.

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