CHAPTER 09

THE IMPACT OF CLIMATE-CHANGE AND FISHING EFFORT ON KAPENTA CATCHES IN LAKE KARIBA

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ABSTRACT

Climate-change is negatively affecting ecosystems globally, and freshwater ecosystems are greatly susceptible. Lake Kariba, a man-made reservoir shared by Zambia and Zimbabwe, was created in 1958. In 1967/68, the Lake Tanganyika sardine, Limnothrissa miodon, was introduced into the lake, and by 1974 was being commercially exploited. The total annual catch steadily rose from 1974 to 1990, but has since undergone a gradual decrease. A number of recent studies have attributed the decrease in catches to climate-change with some disagreeing and attributing the decrease to fishing effort. The purpose of this study was to assess the relationships of L. miodon catches with climate variables, lake level and fishing effort and determine the effects of climate-change and fishing effort. We analysed trends in rainfall, temperature and lake water level data from 1964 to 2018, and fish catches data (total annual catch, fishing effort, and catch per unit effort (CPUE) from 1974 to 2018. Between 1964 and 2018, maximum atmospheric temperature around Lake Kariba increased at a rate of 0.117°C/year, whilst minimum temperature and water levels decreased by 0.051°C/year and 0.015 m/year respectively. Fishing effort increased by 4578.83 nights-fished/year, whilst CPUE decreased by 0.0078 tonnes/night-fished/year. Our analysis shows that fishing effort, maximum temperature and water level had a significant negative impact on catches. We conclude that the increase in fishing effort has been a major factor in the decline of L. miodon catches in Lake Kariba, which has been worsened by warming of the climate.

Keywords: Climate, Lake Kariba, Fisheries

INTRODUCTION

Climate-change is one of the most critical and urgent global challenge of this millennium. The Earth's climate is changing much faster than normally occurs naturally, primarily due to human activities (Intergovernmental Panel on Climate Change [IPCC], 2013, 2014). Rapidly rising temperatures, new precipitation patterns, and other changes are transforming ecosystems at fast rates, affecting biodiversity and many aspects of human society. People, whether in rural settings or in cities, have a close relationship with nature and biodiversity, which involves food, living space, recreation, spiritual connectedness, health, clean air and water. The benefits that people everywhere get from nature are numerous, interlinked in complex ways and have proven difficult to quantify. Understanding the impact and effects of climate-change is essential since climate-change alters the relationships between people and nature. The present chapter investigates the effects of climate-change and fishing pressure on the *Limnothrissa miodon* fishery on Lake Kariba, a man-made reservoir shared by Zambia and Zimbabwe.

Fresh-water ecosystems and their constituent species are greatly vulnerable to climate-change, because warming, volatility, sea-level rise, and acidification, directly affect fresh water organisms in some profound way (Kaufman, 2019). The impact of climate-change on freshwater ecosystems, especially fish production, is of great concern due to potential disruption of the livelihoods of communities dependent on fisheries resources. Fisheries are important sources of food, nutrition, income and livelihoods for hundreds of millions of people globally (Food and Agriculture Organization of the United Nations [FAO], 2016a). Inland capture fisheries are an important source of fish for several countries in Africa, which accounts for 25% of global catches (FAO, 2018). In 2016, fish production from inland capture fisheries was 11.6 million tonnes, which was 12.8% of total marine and inland catches (FAO, 2018). In terms of employment, de Graaf and Garibaldi (2014) estimated that the fisheries sector employs more than 12 million people either as full-time or part-time fishers and processors.

Fresh waters have over the years experienced decline in biodiversity, much greater than those in the most affected terrestrial ecosystems. Dudgeon *et al.* (2006) review and list the major threats under five headings: (i) over-exploitation, (ii) water pollution, (iii) flow modification (iv) destruction or degradation of habitat and (v) invasion by exotic species. Reid *et al.* (2019) note the further deepening of the fresh-water biodiversity crisis, and documented twelve more emerging crisis, comprising, (i) changing climate; (ii) e-commerce and invasions; (iii) infectious diseases; (iv) harmful algal blooms; (v) expanding hydropower; (vi) emerging contaminants; (vii) engineered nanomaterials; (viii) microplastic pollution; (ix) light and noise; (x) fresh-water salinisation; (xi) declining calcium; and (xii) cumulative stressors. Globally, many fish stocks have undergone population declines, with over-exploitation identified as a major driver (Reynolds, Dulvy, & Robert, 2002). Thus, the effects of climate-change can deepen the burden to fisheries that are currently being threatened by many other stress factors.

Lake Kariba was created by the damming of the Zambezi River at the Kariba Gorge in December 1958. The lake reached its maximum retention level in September 1963 (McLachlan & McLachlan, 1971). *Limnothrissa miodon* (locally known as kapenta) was introduced into Lake Kariba in 1967/68 from Lake Tanganyika (Bell-Cross & Bell-Cross, 1971), so as to fill the pelagic niche of the newly-created lake since none of the indigenous Zambezi riverine fish fauna show potential to occupy the pelagic environment (Mandima, 1999). After its introduction into the lake, kapenta quickly established commercially fishable stocks, commercial exploitation commencing by 1974 and according to the FAO (2016b), the kapenta fishery accounts for over 90% of Zimbabwe's total capture fishery landings. Early catches were so spectacular to such an extent that many viewed the fishery as a guaranteed source of quick profit. However, over the last two decades, there have been a sharp decline in kapenta catches, and the fishery is no longer as lucrative as it used to be. Several reasons have been advanced to explain the decline in kapenta catches which include over-capitalisation and the effects of climate-change.

Climate-change projections for Sub-Saharan Africa point to a warming trend, particularly in the inland subtropics, frequent occurrence of extreme heat events, increasing aridity, and changes in rainfall, with a particularly pronounced decline in southern Africa and an increase in East Africa (Serdeczny *et. al.*, 2017). Unganai (1996) who analysed ambient temperature data from nine stations across Zimbabwe, obtained over a 60-year period from 1933 to 1993, found that the national annual minimum temperature trend decreased, whilst there was a warming trend in maximum temperatures. At national level, maximum temperatures increased by up to 0.8°C, with maximum temperature for most stations increasing by 0.4 to 0.6°C, and minimum temperature decreasing by 0.2 to 0.4°C (Unganai, 1996). These changes are likely to have an impact on fish production.

The impact of climate-change has been reported in some African lakes. According to Cohen *et al.* (2016), the ongoing declines in fish catches in Lake Tanganyika can be explained by climate warming. Similarly, on Lake Kariba, the decline in fish catches, especially those of kapenta, have, according to Magadza (2010, 2011) and Ndebele-Murisa, Mashonjowa and Hill (2011a, b) were as a result of climate-change. Ndebele-Murisa *et al.* (2011a) analysed rainfall, lake level, and temperature data from 1964 to 2008, and data on evaporation from 1963 to 1999. Using moving averages analysis, they report that rainfall declined at a rate of 0.63 mm per year, which equated to a decrease of about 27.1 mm from 1964 to 2008. Furthermore, they report that there were significant increases in both minimum and maximum atmospheric temperatures around Lake Kariba, which increased by about 3.29°C and 3.58°C respectively, and a significant increase in the evaporation rate of 0.14 mm per year. Using general linear models, Ndebele-Murisa *et al.* (2011a) note that all climatic factors (rainfall, temperature, and evaporation) and lake level could explain the decrease in kapenta catches in Lake Kariba, with water levels having the greatest impact, followed by maximum temperature, evaporation and rainfall. Moreover, since they found that water levels were significantly associated with temperature and rainfall, they concluded that nutrients, which are influenced by water levels, and climate particularly maximum temperature, are the primary determinants of kapenta production in Lake Kariba.

Magadza (2011) used linear regression to analyse temperature data from 1965 to 2000, and found that both minimum and maximum atmospheric temperatures for the September/October/November season increased significantly, at a rate of 0.0446°C and 0.0526°C per year respectively, which were used to give an estimate of mean increase in temperature of 0.048°C per year. This was then used to give a 100-year warming estimate of 4.8 °C for the Lake Kariba area. Magadza (2011) concludes that there has been a warming trend around Lake Kariba, with seasonal rates 2 °C above the 1990 baseline that according to Parry *et al.* (2007) is likely to cause significant ecosystem changes. Furthermore, Magadza (2010, 2011) notes that the changes in climate have resulted in Lake Kariba warming at a rate of 0.62 °C between 1965 and 1990, resulting in a reduction in the depth of the epilimnion, the upper and generally more productive water layer of the lake, as well as a strong and stable stratification. Magadza (2011) suggests that due to global warming-induced thermal changes to the lake, the phytoplankton community has changed from one dominated by green algae (Chlorophyceae) to one largely comprised of blue-green algae (Cyanophyceae). Cyanophycea, unlike green algae, are quite resistant to digestion by zooplankton grazers (Porter, 1973; Haney, 1987; Lampert, 1987), can suppress the growth of other algae (Keating, 1978) and some strains produce toxins that adversely affect a broad range of organisms including protozoa, plants, invertebrates and vertebrates (Oberemm *et al.* 1999; Falconer, 2013). Thus, according to Magadza (2011), the likely dominance of Cyanobacteria due to warming has resulted in reduction in entomostracan zooplankton that graze on phytoplankton and are the principal food of kapenta, and consequently the decline in kapenta catches.

There are some who have disagreed with the findings that climate-change has had a significant impact on African fisheries, with Sarvala *et al.* (2006) arguing that the declining trend in fish catches on Lake Tanganyika are largely due to changes in fishing practices and not climate. Likewise, Marshall (2012) has argued that the decrease in kapenta catches on Lake Kariba has not been due to the effects of climate-change but rather due to increase in fishing pressure. Fishing is one of the major factors that has modified aquatic ecosystems (Jackson *et al.*, 2001), and high fishing pressure can enhance the risk of a population collapse (Shoener, Spiller, & Losos, 2001). The studies by Magadza (2011) and Ndebele-Murisa *et. al.* (2011a, b) argue that fishing effort/pressure has had no significant impact on kapenta catches on Lake Kariba. Ndebele-Murisa *et al.* (2011a, b) rule out fishing pressure on the basis of kapenta catch and effort data from the Zimbabwean side of Lake Kariba. They note that between 1992 and 2002, there was a decrease in the number of fishermen on the Zimbabwean size of Lake Kariba, and hence a reduction in fishing effort. Magadza (2011) analyses catch data from 1979 to 2000 and suggests that there was no trend in relation between effort and catch per unit effort.

Thus, the debate on the effects of climate-change and fishing effort on kapenta catches in Lake Kariba is still to be resolved. This study explored trends in climate variables (minimum and maximum temperature, rainfall) and lake level since the early years of Lake Kariba, as well as trends in total kapenta catch, fishing effort and catch per unit effort since commercial exploitation of kapenta began. The aim of the study was to assess the relationships that kapenta catches on Lake Kariba have with climate variables, lake level and fishing effort, and hence determine the effects of climate-change and fishing effort on kapenta catches.

DESCRIPTION OF THE STUDY AREAS AND METHODOLOGY

Study Area

Lake Kariba lies on the international boundary between Zimbabwe and Zambia and its main axis runs in a South West–North East direction (Figure 1). The lake, which is among the largest man-made reservoirs in the world, has a surface area of 4 364 km² at the normal operation level of 484 m a.s.l, a length of 276 km, an average width of 19 km and an average depth of 29 m. The Zambezi River, the main water source for the Lake, drains a catchment area of 1 193 500 km² above the Lake. It receives water from much of Zimbabwe, Zambia, eastern Angola, and a small part of Botswana (Marshall, 1982). The lake hosts two important commercial capture fisheries which are the inshore gill net-fishing industry and the pelagic semi-industrialised fishing industry. The latter is based on the exploitation of *L. miodon*.

Research Methods

Data Sources and Collection Methods

Climate data from January 1964 to December 2018 comprising monthly averages for rainfall, minimum and maximum temperature were obtained from the Meteorological Services Department of Zimbabwe. Average monthly lake level data for the same period were obtained from the Zambezi River Authority (ZRA), whilst the data for Kapenta fishing effort and annual catches for both Zambia and Zimbabwe were supplied by the Lake Kariba Fisheries Research Institute, a research unit of the Zimbabwe Parks and Wildlife Management Authority (ZPWMA). Commercial kapenta-fishing on Lake Kariba commenced on the Zimbabwean side of the lake in 1974, and in 1982 on the Zambian side. Thus, the fishing data obtained was from 1974 to 2018 and 1982 to 2018 for the two countries, respectively. The data from the two countries was combined to obtain the total kapenta catch (in tonnes) for each year and the total fishing effort (nights of fishing). The annual total fishing effort was obtained by calculating the total time of night-fishing by all the kapenta fishing rigs for that year.

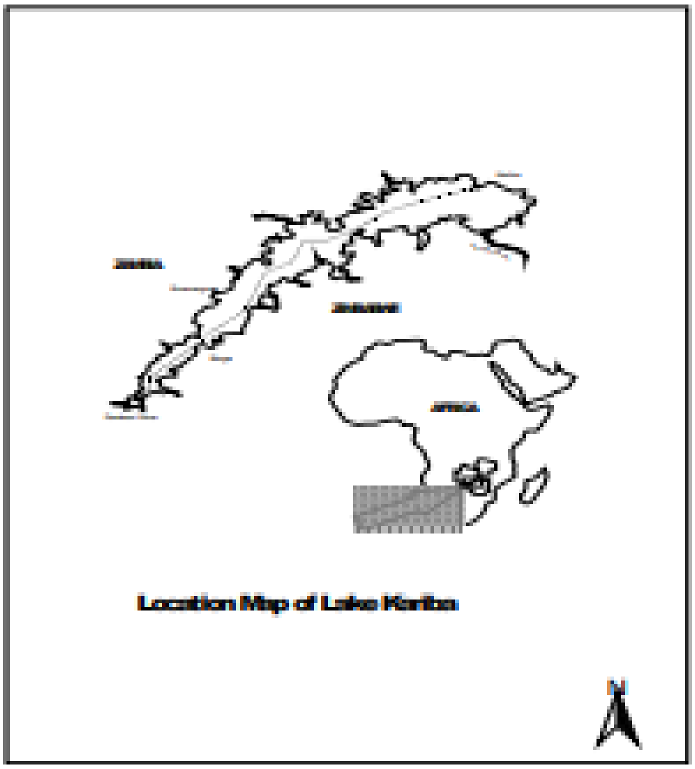

Figure 1: Map of Lake Kariba

2.2.3. Data Analysis Procedures

The data was analysed using R version 3.6.1 (R Core Team, 2019). We used the TTAinterfaceTrendAnalysis (v 1.5.5) package (Devreker & Lefebvre, 2019) to perform temporal trend analysis for rainfall, minimum and maximum temperature, lake level, total catch, fishing effort, and the catch per unit effort (CPUE) and obtain a Sen's slope for the estimate of linear rate of change. The change-point package (Killick, Haynes, & Eckley, 2016) was used to detect change-points in the seven variables. Generalised additive modelling (GAM) was applied to determine the relationships that Kapenta CPUE had with rainfall, lake level, temperature and fishing effort using the gam package (Hastie, 2019).

RESULTS AND DISCUSSION

Changes in climatic conditions in Kariba environs

Rainfall trend

The observed monthly rainfall and trend in annual means for Kariba from 1964 to 2018 are shown in Figure 2. Although there were periods of relatively low rainfall such as 1983 – 1984 and 1995 – 1996 (Figure 2), there was no change in overall trend in rainfall during the 55-year period (Table 1), and generally, the mean annual rainfall for the period was 61.3 mm.

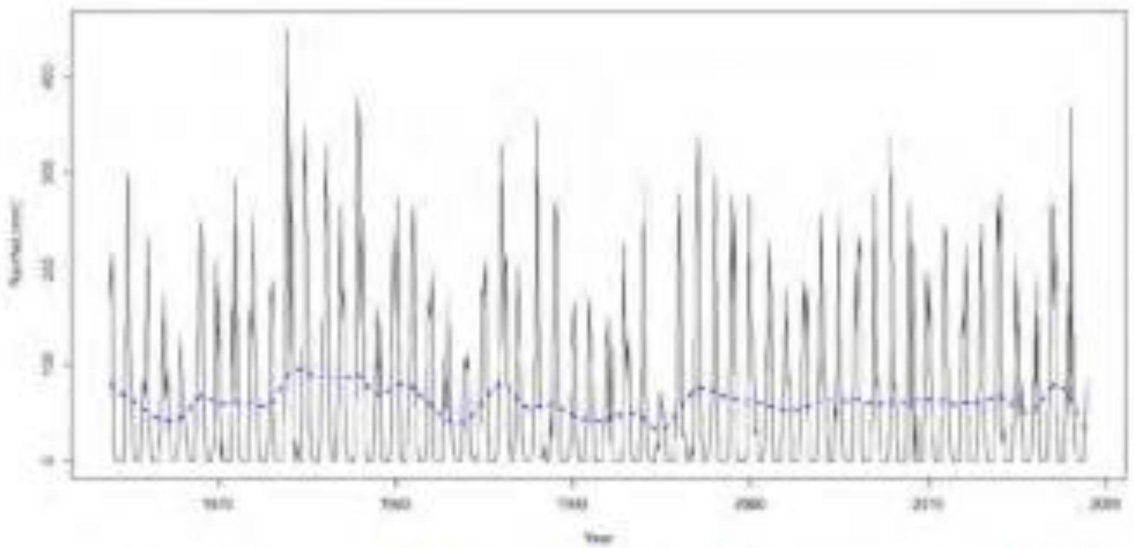

Figure 2: Time series of observed monthly rainfall and the trend in annual mean rainfall (dashed line) for Kariba from 1963 to 2018.

Table 1. Lake Kariba trend in rainfall, minimum and maximum temperatures from 1964 to 2018.

Variable	Trend (sen slope)	p value
Rainfall (mm)	0.000	>0.05
Minimum temperature (ºC)	-0.0511	0.0009
Maximum temperature (ºC)	0.1174	0.0000
Lake level (m)	-0.0149	0.0187

Temperature changes

Figure 3 shows the observed monthly minimum and maximum temperatures as well as the trends in annual means for the two variables. There were significant changes in trends ($p < 0.05$) for both minimum and maximum temperature over the 55-year period (Table 1). Minimum temperature decreased at a rate of 0.051 °C/year (or -0.0029% °C/year), whilst maximum temperature increased at a rate of 0.117 °C/year, which was equivalent to an increase of 0.0037% °C/year. Thus, between 1964 and

2018, the minimum temperature decreased by about 2.8 °C, whilst maximum temperature increased by about 6.4 °C. Change-point analysis showed that for both minimum and maximum temperatures, the change occurred around 1984 and 2014. The average minimum temperature for the period 1963 to 1984 was 18.28 ± 4.52 °C, whilst for the period 1985 to 2014 it was 15.32 ± 4.61 °C, and 19.51 ± 4.28 °C from 2015 to 2018. The averages for maximum temperature were 30.43 ± 2.85 °C for the period 1963 to 1984, was 35.73 ± 3.30 °C for 1985 to 2014, and 32.33 ± 3.06 °C from 2015 to 2018.

Lake water level

Trend analysis shows that from 1964 to 2018, lake level (Figure 4) underwent a significant decrease ($p < 0.05$) of about 0.015 m/year (Table 1). Generally, from 1964 to 1982, there was an increasing trend in lake level, followed by a sharp decrease and low levels from 1983 to 1998. Low lake levels were also recorded from 2005 to 2007 and 2015 to 2018, whilst periods of high-water levels were 1964 to 1982, 1999 to 2004 and 2008 to 2014 (Figure 4). The mean annual lake level for the period 1983 - 1998 was 479.56 ± 1.74 m compared to 485.9 ± 1.04 m and 485.08 ± 1.33 m for the periods 1974 - 1982 and 2008 - 2014, respectively.

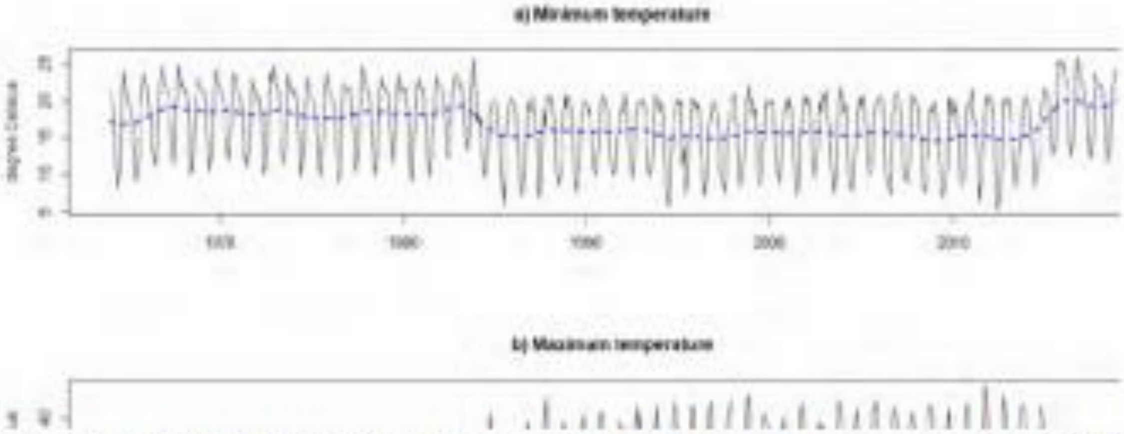

Figure 3: Time series of observed monthly minimum (a) and maximum (b) atmospheric temperatures and their annual mean trends (dashed line).

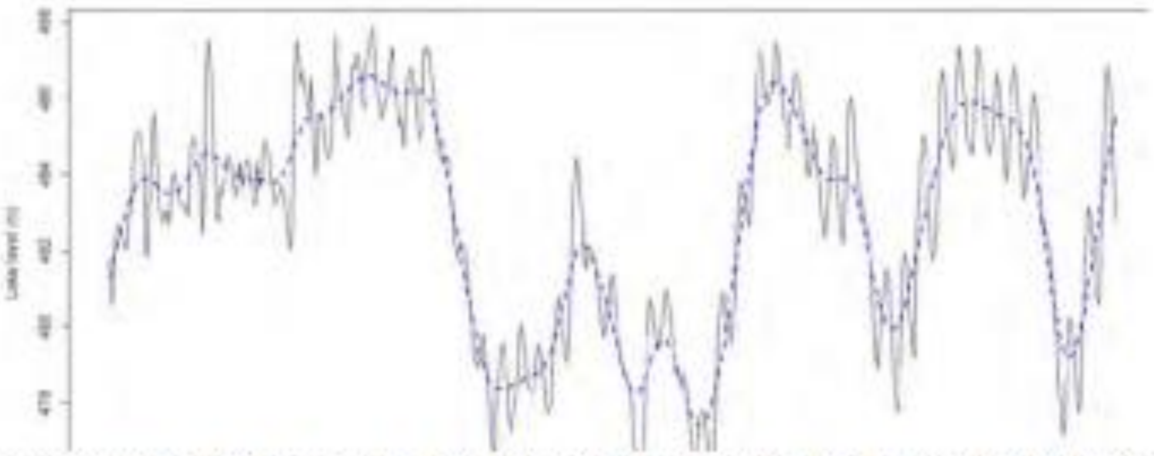

Figure 4: Time series of observed monthly lake levels and the trend in annual mean (dashed line) from 1964 to 2018.

Change in kapenta catches

The trends in total catch, effort and the catch per unit effort for kapenta in Lake Kariba from 1974 to 2018 are shown in Figure 5. The total catch increased gradually from 1974, with peak catch obtained in 1990, followed by a gradual decrease (Figure 5). Change-points in total catch occurred in 1977, 1979, 1984, 1994, and 1998. The period with the lowest average total catch (840.50 ± 279.67 tonnes) was from 1974 to 1977, with the highest mean catches (27,826.00 ± 2,130.90 tonnes) obtained from 1985 to 1994. From 1995 to 1998, the mean total catch was 24,231.75 ± 822.35 tonnes, which then fell to about 17,980.09 ± 2,354.64 tonnes between 1999 and 2018. The overall trend in total catch for the 45-year period was not significant ($p > 0.05$) (Table 2).

Kapenta-fishing effort increased from 1974, with change-points recorded in 1977, 1979, 1983, 1986, 1990, 2009 and 2013 (Figure 5). The mean fishing effort was 1,713.25 ± 915.15 nights fished between 1974 and 1977, had risen to 80,520.33 ± 4,201.22 nights fished between 1984 and 1986, and was 172,161.25 ± 3,478.64 and 245,721.40 ± 27,977.07 nights of fishing for the periods 2010 to 2013, and 2014 to 2018, respectively. Generally, there was a significant ($p < 0.05$) positive trend in fishing effort of 4,578.83 nights of fishing per year from 1974 to 2018 (Table 2). Over the same period, the change in the trend in CPUE was significant ($p < 0.05$), and decreased at a rate of 0.0078 tonnes/nights of fishing/year (Table 2). Change-point analysis showed mean CPUE from 1974 to 1979 was 0.517 ± 0.020 tonnes/nights of fishing/year, had decreased to 0.269 ± 0.031 between 1980 and 1992, and was 0.066 ± 0.008 tonnes/night/year from 2015 to 2018 (Figure 5).

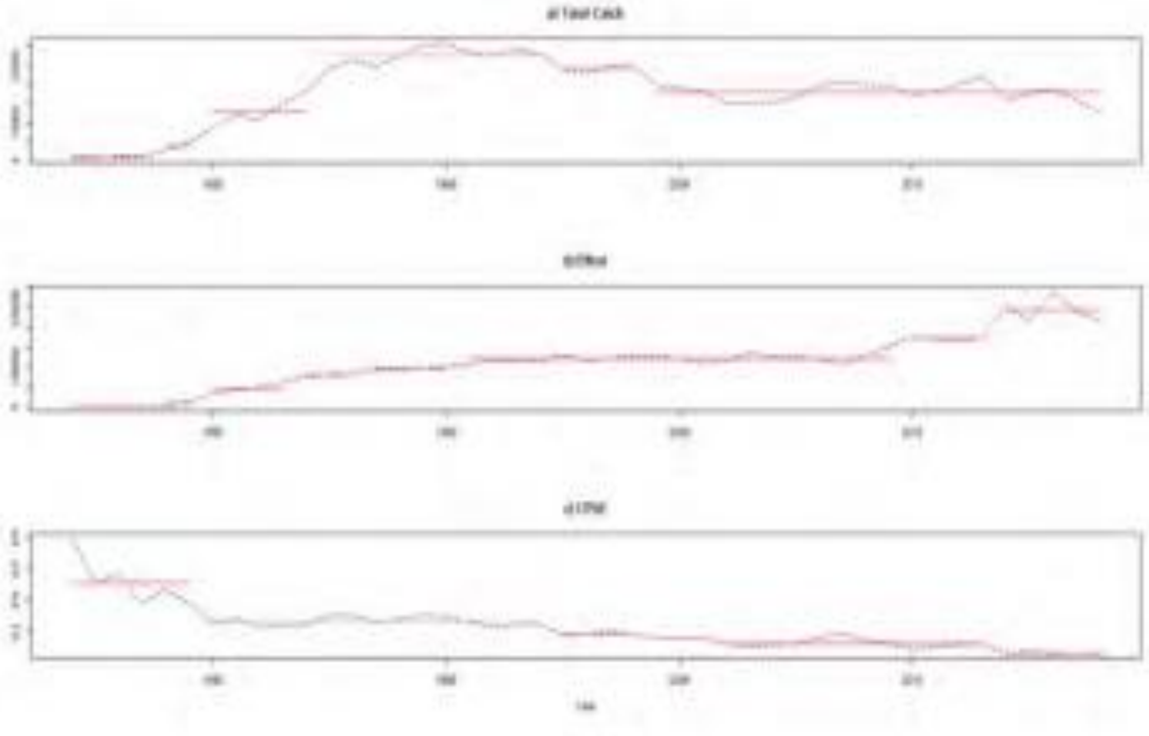

Figure 5: The trends in total catch (tonnes), effort (nights of fishing) and the CPUE (tonnes/night) in Lake Kariba from 1974 to 2016. The breaks in the horizontal lines show change-points in the trends.

Table 2. Trend in total catch, fishing effort and the catch per unit effort for kapenta in Lake Kariba from 1974 to 2018.

Variable	**Sen's slope (trend)**	**p value**
Total catch (tonnes)	145.15	0.3044
Effort (nights fished)	4578.83	0.0000
CPUE (tonnes/night)	-0.0077	0.0000

Kapenta-catches and relationship with fishing effort, lake level, rainfall and temperature

Analysis of the relationship between kapenta CPUE with fishing effort, lake level, rainfall and temperature using Generalised Additive Modeling showed that the CPUE was significantly related to fishing effort, lake level and maximum temperature (Table 3). Fishing effort and lake level had significant parametric linear relationships with CPUE, whilst fishing effort also together with maximum temperature had significant non-linear relationships with CPUE. As fishing effort increased to about 150,000 nights of fishing, there was a significant quadratic decrease in CPUE, but increase in effort beyond 150,000 nights of fishing was associated with a significant but linear decrease in CPUE (Figure 6). An increase in maximum temperature from below 30 °C to about 32 °C was associated with quadratic decrease in CPUE, which was followed by another quadratic but slower rate of decrease in CPUE as temperatures rose beyond 35 °C (Figure 6). Below lake levels of about 481 m, the CPUE was relatively constant, but underwent a comparatively fast but linear decrease as lake levels increased from 482 to 484 m, which was followed by a much slower and still linear decrease as lake levels continued to rise (Figure 6). Thus, this study shows that kapenta-fishing effort had strong and significant negative impact on kapenta catches, with increasing maximum temperatures and lake levels also associated with significant decrease in catches.

Table 3: Results of the GAM test for the relationship of kapenta CPUE to fishing effort, lake level, rainfall, and temperature (maximum and minimum).

Anova for Parametric Effects					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
s(Effort)	1	0.45516	0.45516	256.8122	**2.552e-14**
s(Max_temp)	1	0.00216	0.00216	1.2168	0.2809328
s(Min_temp)	1	0.00149	0.00149	0.8398	0.3685821
s(Lake_level)	1	0.02758	0.02758	15.5607	**0.0006059**
s(Rainfall)	1	0.00009	0.00009	0.0529	0.8199577
Residuals	24	0.04254	0.00177		

Anova for Nonparametric Effects			
	Npar Df	Npar F	Pr(F)

(Intercept)			
s(Effort)	3	6.1623	**0.00294**
s(Max_temp)	3	11.0805	**9.304e-05**
s(Min_temp)	3	0.5170	0.67457
s(Lake_level)	3	1.0227	0.40006
s(Rainfall)	3	1.9872	0.14278

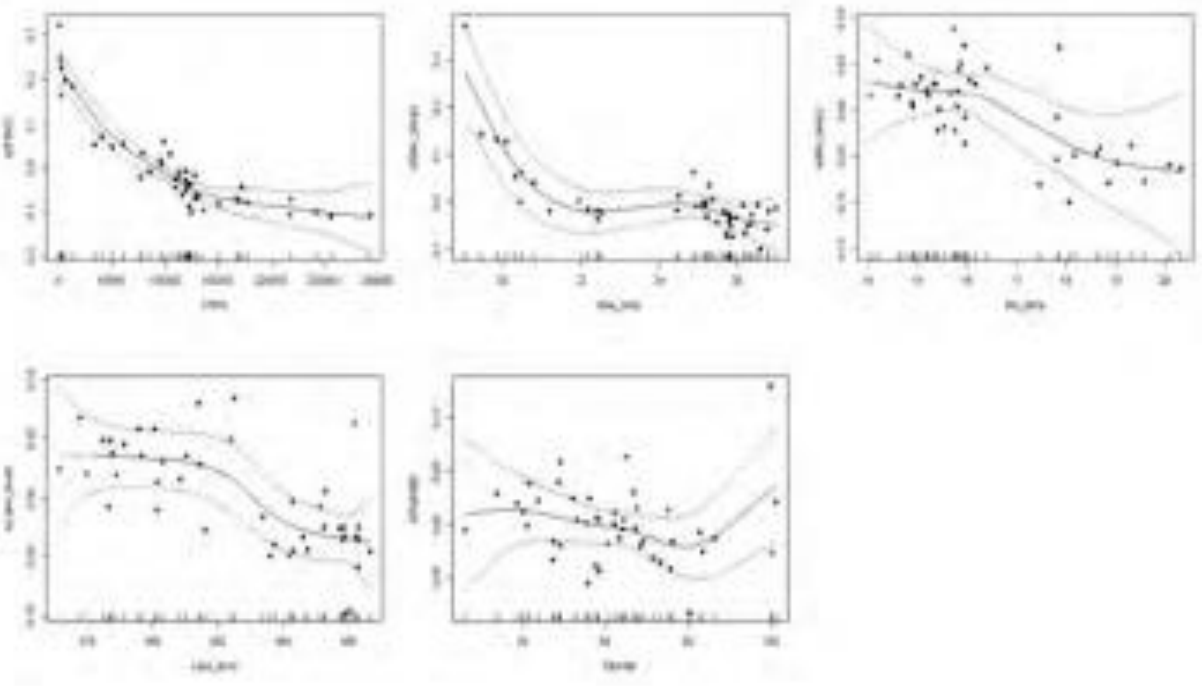

Figure 6: Graphical presentation of the relationship of kapenta CPUE with fishing effort, lake level, rainfall and temperature (minimum and maximum).

Impact of rainfall on kapenta yield

Our analysis shows that kapenta catches in Lake Kariba drastically decreased between 1974 and 2018, with fishers harvesting about 0.066 tonnes/night from 2015 to 2018, compared to 0.517 tonnes/night between 1974 and 1979. We show that there has been no significant change in rainfall trend from 1964 to 2018, and concurrently no significant relationship between rainfall and kapenta CPUE. Although we looked at rainfall data from one meteorological station, our results on rainfall trend are supported by findings by Muchuru *et al.* (2016) and Kampata, Parida and Moalafhi (2008). Muchuru *et al.* (2016) analysed rainfall data from 13 stations in Zimbabwe across the Lake Kariba catchment for the period 1970 to 2010, and found that there were no significant shifts in annual and seasonal rainfall. Similarly, Kampata *et al.* (2008) who analysed rainfall data from five stations in the headstream regions of the Zambezi River basin in Zambia, found no significant trend in rainfall.

Impact of water level fluctuations on kapenta yield

Water level fluctuations are an important factor in lakes as they affect many ecological processes, including productivity and biodiversity (Gafny, Gasith, Goren, 1992; Gafny & Gasith, 1999; Wantzen *et al.*, 2002). In lakes, fluctuations occur naturally through seasonal or long-term imbalance between water entering (by inflow, precipitation, runoff, and groundwater) and leaving (by evaporation and outflow). Additionally, for man-made lakes such as Lake Kariba that are used for hydroelectric power-generation, a substantial amount of water is lost through turbines used for power-generation. In lakes and reservoirs that are intimately associated with rivers, production is dominated by changes in the hydrological regime (Talling, 1986; Welcome *et al.*, 2006), and nutrient supplies from affluent rivers and the flooded marginal areas are critical in stimulating fish-production (Kolding and van Zwieten, 2012; Bayley, 1991).

The current study showed that following a period of high-water levels from 1964 to 1982, Lake Kariba experienced a 16-year period from 1983 to 1998, during which it was characterised by relatively low water levels. Since then, water levels as well as the magnitude of water level fluctuations have increased. Theoretically, the resultant increase in inundated area due to the increased water levels, and the greater fluctuations from 1999 to 2018, resulting in what Bayley (1991) called the 'flood pulse advantage', should have been associated with increase in CPUE for kapenta. Our analysis though, showed that this was not the case as increase in lake level was negative and significantly related to the CPUE.
Ndebele-Murisa *et al.* (2011) reported a significant negative relationship for water level with kapenta catches (not with CPUE), but a non-significant relation between water level and kapenta CPUE. An earlier study by Karenge and Kolding (1995) showed that kapenta CPUE was not correlated with absolute water levels but showed high correlation with different time-lagged indices of water level, whilst Chifamba (2000) reported positive correlation for Kapenta CPUE with water levels. The discrepancy between our study results and those by Karenge and Kolding (1995) and Chifamba (2000) are largely due to differences in the time periods covered by the studies. Our study explored a much longer period than the other studies, comprising the period before 1980 when water levels were high and magnitude of fluctuations relatively low, to the period 1983 to 1998 when water levels were low, and from 1999 to 2018 when levels were relatively high. As has been already noted, kapenta CPUE has generally undergone a decrease since the commencement of commercial fishing in 1974. As kapenta CPUE decreased when lake levels were high from 1974 to 1982 and continued to decline during the drought years (1983 – 1984, 1990, 1992 and 1995) when levels were low, it is therefore not surprising that water level was not significantly associated with kapenta CPUE. Although there was an increase in mean water level from 1999 to 2018, the kapenta CPUE continued to decrease. Therefore, our study found an overall negative and significant relationship between water level and kapenta CPUE.

Impact of temperature on kapenta yield

Our analysis showed that both maximum and minimum air temperatures changed significantly between 1964 and 2018, with maximum air temperature increasing by about 0.117 °C/year, which was an increase of about 6.4 °C, whilst minimum air temperature decreased by 0.051°C/year, a decrease on average of approximately 2.8°C. The growth of fish is strongly dependent on water temperature. In an environment with abundant food, fish growth rate generally tends to increase with increase in temperature, up to an optimal temperature, after which it rapidly decreases (Jobling, 1997). In natural environments, food is not always abundant such that growth decreases with increasing temperature due to increased energetic demands from higher metabolic rate at higher temperatures. Temperature also affects virtually all aspects of reproduction in fish including gametogenesis and gamete maturation, ovulation/spermiation, spawning and subsequent early development (Van Der Kraak and Pankhurst, 1997), thereby affecting recruitment success and yield.

Our analysis showed that maximum air temperature relationship to kapenta CPUE was significant, negative and non-linear, whilst the relationship with minimum air temperature was insignificant. Generally, as maximum temperature increased there was a quadratic decrease in kapenta CPUE. Chifamba (2000) also suggested that maximum air temperature defined by a quadratic function is the best predictor of kapenta CPUE when compared to rainfall, river inflow and the water level, whilst according Ndebele-Murisa *et al.* (2011) maximum temperature together with nutrients are the primary determinants of kapenta production.

Impact of fishing pressure on kapenta yield

Over the 45-year period from 1974 to 2018, fishing effort on kapenta on Lake Kariba increased at a rate of 2811.3 nights of fishing per year. The most recent studies that have been done to determine the trend in kapenta catches have tended to ignore or discount the effect of fishing effort/pressure, or if they did (e.g., Ndebele-Murisa *et al.*, 2011) they tended to only consider fishing effort from either Zambia or Zimbabwe, but not both. In this study the annual fishing effort considered the two countries. Generally, fishing effort was relatively low and steady from 1974 to 1978, but steadily rose thereafter, and the increase in effort was significantly and negatively associated with kapenta CPUE.

CONCLUSION

The results of this study suggest that maximum air temperature, lake level and fishing effort had significant impact on kapenta catches in Lake Kariba. Generally, increase in maximum air temperatures were associated with decrease in kapenta catch per unit effort. This is in agreement with assertion by Magadza (2010) and Ndebele-Murisa *et al.*, (2011a, b) that climate-change, in particular increase in temperature, has had a negative impact on kapenta catches in Lake Kariba. High water levels and greater water level fluctuations have not been associated with greater kapenta CPUE as would have been expected with the 'flood pulse advantage' (see Bayle, 1991). The continual decrease in kapenta CPUE since commercial fishing began, and even before climate warming was an issue of concern, suggests that fishing effort (pressure), which has grown tremendously has also had significant negative impact on kapenta yields in Lake Kariba. Unlike Marshall (2012) who asserts that the impact of fishing is the only factor that can explain the decline in kapenta CPUE, we conclude that increased fishing effort/pressure has been a major factor, but indeed warming of the climate has worsened the decline in kapenta catches.

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