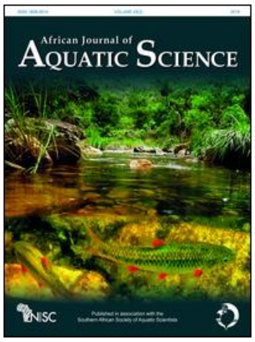

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Size at maturity, maturity stages and sex ratio of tigerfish *Hydrocynus vittatus* Castelnau, 1861 in Lake Kariba, Zimbabwe: assessing the influence of decades of fisheries exploitation

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Size at maturity, sex ratio and maturity stages are key population parameters in fisheries management of exploited stocks because they influence survival of fish populations. The decline in *Hydrocynus vittatus* catches during the tigerfish competition and along the shoreline of Lake Kariba, Zimbabwe prompted this study. This study investigated population parameters of *H. vittatus* in the Sanyati Basin, Lake Kariba. A gonadal reproductive stage determination index was used to determine sexual maturity and the logistic growth curve was used to estimate size at 50% sexual maturity (L_{50}). The study revealed that the L_{50} value had decreased from 30 cm to 22.1 cm for males and 35 cm to 27.8 cm for females since 1961. Males and females had an L_{50} of 22.1 cm and 27.8 cm, respectively. The male to female ratio was 1:0.8, which is typical of stressed populations. Increased fishing pressure in the Sanyati Basin, Lake Kariba is a potential threat to the *H. vittatus* population. More research and monitoring of the population parameters of tigerfish is required, in order to predict long term effects of overexploitation and to enable responsible authorities to protect the fish stock from collapsing.

Keywords: fish, gonadal reproductive stage determination index, management, sexual maturity

Introduction

The importance of biological knowledge in exploited fisheries has become evident in the past two decades in view of the collapse of some notable fisheries, such as the Pacific salmon and Atlantic cod (Lopes et al. 2014). Unbiased fish demographic details, such as length frequency distributions, length-weight relationships, sexual maturity size and gonadal maturity stages, are crucial for managing fisheries resources (Sarkar and Banerjee 2010; Dalu et al. 2013a). Size at maturity (L_{50}) defined as the length at which 50% of a population become sexually mature for the first time, is a key population parameter that is important in fisheries management of exploited stocks (Karna and Panda 2011). Age-at-maturity is also equally important, because it strongly influences population model estimates of sustainable harvest rates (Hannah et al. 2008; Dalu et al. 2013b) and, along with mean body size, is an important predictor of overexploitation risk (Day and Rowe 2002).

For a management regime to ensure that a sufficient number of juveniles reach sexual maturity usually requires information on the size at first maturity (Moutopolous 2013). Sexual maturity has been known to be associated with physiological and behavioural changes (Peixoto et al. 2018). Size at sexual maturity is strongly correlated with growth, maximum size and longevity of a particular fish species (Tsikliras 2010). It not only influences how individuals in a population start to reproduce, but also how much they can reproduce, because fecundity is often closely associated with body size (Hossain et al. 2009). Lappalainen et al. (2016) highlighted that increased fishing pressure generally tends to affect the size distribution of adult stock recruited to a fishery by reducing the proportion of large (or target size) individuals. This change in the size structure is generally regarded as unhealthy for fish communities, whereas the opposite situation, with a high frequency of large and sexually mature individuals, is often considered to indicate a healthy structure of fish stocks (Hutchings and Reynolds 2004). Size at maturity and sex ratio are also directly affected by overexploitation. According to Ojuok (2007), size at maturity decreases when fish are over-exploited over a period of time. Decrease in size at maturity is believed to be offset by an increase in adult mortality hence for fish to ensure survival, they must start reproduction at smaller sizes.

Several methods have been used to determine size at sexual maturity, but the most widely used method is to observe the seasonal development changes in fish gonads. A study on size at sexual maturity of tigerfish *Hydrocynus vittatus* Castelnau, 1861 from the Okavango Delta by Gerber et al. (2009) used microscopic and histological techniques in gonad staging of male and female tigerfish, in order to determine when sexual maturity

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is reached and concluded that it was the most suitable method of estimating size at sexual maturity.

Hydrocynus vittatus is a piscivore and popular recreational fish species that can grow up to 70 cm fork length and weigh up to 15 kg. *Hydrocynus vittatus* is also a fish of importance in Lake Kariba as local communities along lake shorelines depend on it for both income and food (Marufu et al. 2017). The decline in *H. vittatus* catches during the tigerfish competition and along the lake shoreline prompted this study to be conducted to assess whether there have been any changes in tigerfish populations since dam construction. Moreover, *H. vittatus* has been exploited for decades in Lake Kariba and the size at maturity has not been assessed to determine whether there have been any adverse changes as a result of increasing fishing pressure. Hence, the present study aimed to assess the size at sexual maturity, sex ratio and maturity stages of *H. vittatus* based on gonad development. The study also investigated whether there had been any changes to the size at first maturity first reported in 1961 given the decades of artisanal and recreational fishing in Lake Kariba.

Materials and methods

Study area

Lake Kariba is a artificial reservoir along the Zambezi River (Figure 1), shared between Zambia and Zimbabwe (16°28′ S and 18°6′ S, 26°40′ E and 29°3′ E). Lake Kariba is 276 km long with a mean width and depth of 19 km and 29.5 m, respectively. The lake has five hydrological basins namely; Mlibizi, Binga, Ume, Sengwa and Sanyati. The Sanyati Basin is next to Kariba town and it is where most limnological studies have been carried out and is the biggest basin. Surface water temperatures reach 32 °C in October to December and drop to 18 °C between June and August (Magadza 2010). The mean monthly atmospheric temperature around Lake Kariba is usually above 20 °C with distinct seasonal variation. Three seasons are distinct for Lake Kariba namely (1) cool-dry (April–August) (2) hot-dry (September–October) and (3) hot-wet (November–March) (Magadza 2010)

Sampling

Sampling was carried in the Sanyati Basin, Lake Kariba (Figure 1). In total, 892 *H. vittatus* were caught using gill and seine nets over a one-year period, between July 2017 and August 2018, except for June 2018 when no tigerfish catches were made. For seine netting, two hauls were performed every month at the shallow areas of the sampling site. Gillnets were set every fortnight at the sampling sites. Gillnets of mesh size 4–18 cm, with a length of 45 m and a width of 2.5 m, were set late in the afternoon at 16:30 and collected the next morning at 06:30. The fish were transported in cooler boxes with ice for processing to the laboratory at the University of Zimbabwe Lake Kariba Research Station. In the laboratory, the fish were weighed using a digital CAS SWII scale to the nearest gram. The total length (TL) and standard length (SL) were measured using a 1 m fish measuring board. Fish were also bought from the fishing camps and processed in the same way as those caught in nets.

Catch per unit effort (CPUE)

Catch data from experimental gillnetting were obtained from the Lake Kariba Fisheries Research Institute (LKFRI) to show changes in the abundance of tigerfish in the Sanyati Basin. The data cover the period from 1993 to 2017. The experimental gillnetting site has been maintained since 1960 to ensure uniformity of data and to allow assessment of temporal variation in fish species.

Gonad development

Female and male gonads were removed and stored in 10% formalin. The gonads (ovaries and testes) were

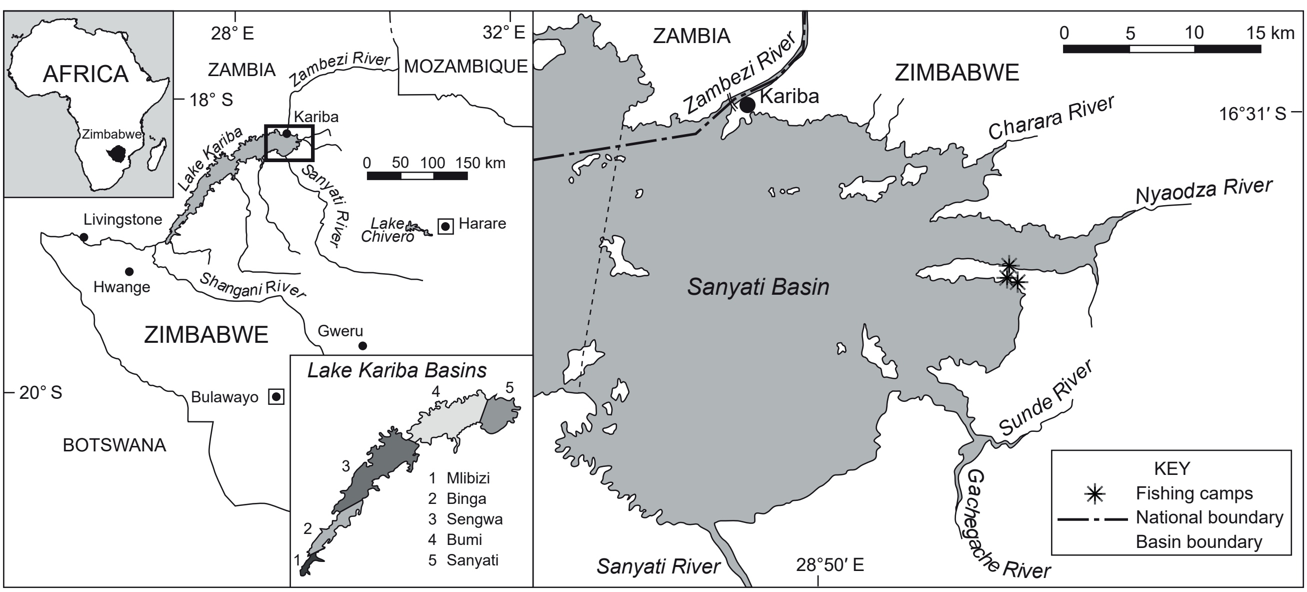

Figure 1: Location of the Sanyati Basin (Zimbabwe) where sampling was done

then prepared through fixation, embedding, sectioning and staining using standard techniques (Humason 1962). The samples were then examined under a Nikon Diaphot inverted microscope. The gonadal reproductive stage determination index proposed by Schmitt and Dethloff (2000) was used to determine sexual maturity. Using this index, male gonads were considered to be mature if they had a rating of Stage 1 or higher. The gonad stages for 1 or above in males were described as having spermatozoa in different quantities. The gonad stages for 0 were described as immature, because they contain no spermatozoa, but just spermatocytes and spermatids (Table 1). For female gonads, Stages 2 and above were described as mature and these contained peripheral yolk vesicles, late-vitellogenic follicles and post-ovulatory follicles. Ovaries with Stages 0 and 1 were considered immature, because they contain only pre-vitellogenic follicles and no mid-vitellogenic follicles.

Data analysis

To calculate the length at 50% maturity (L_{50}), the percentage of mature fish, were observed and assigned maturity stages. The percentage of mature fish was also calculated for each body length class at 50 mm intervals.

To test for differences between monthly and total sex ratios, an independent samples *t*-test was done using R software (Calenge 2006). The L_{50} was estimated using the logistic curve equation: $M(L) = 1 / (1 + \exp^{-aL+b})$, where *a* and *b* are constants calculated by maximising the likelihood of binomial distribution using an Excel add-in tool (Karna and Panda 2011). The logistic equation for female tigerfish was $M(L) = 1 / (1 + \exp^{-0.2471+ 7.371})$. For male tigerfish the logistic equation was $M(L) = 1 / (1 + \exp^{-0.1562 + 5.158})$.

Results

Sex ratios

In total, males and females comprised 55% and 45% of tigerfish caught, respectively. There was no significant difference between total proportion of males and females, because the total sex ratio of males to females was 1:0.8 ($t = 1.116$, $p = 0.277$). The lowest monthly male to female ratio of 1:0.26 was recorded in May 2018 and highest of 1:1.32 was recorded in November 2017. The male to female sex ratio was high during summer (November–February) and low during winter (May–July).

Maturity stages and size at maturity

Undeveloped male gonads (Stage 0) were observed throughout the whole year with a high proportion being recorded in August 2018 (Figure 2a). Gonads in the early–mid spermatogenic stage (i.e. Stages 1 and 2) were also recorded in most months, but were absent in May, June, July and August 2018. However, the proportion of fish

Table 1: The histological criteria used in gonad staging of *Hydrocynus vittatus* to determine when sexual maturity is reached. Adapted from Schmitt and Dethloff (2000)

Stage	Testis characteristics	Ovary characteristics
0	Undeveloped (immature) Little or no spermatogenic activity in germinal epithelium; immature states of spermatogenesis (largely spermatocytes); no spermatozoa observed.	Undeveloped Pre-vitellogenic oocytes observed exclusively; oocyte diameter <250 µm: cytoplasm stains basophilic with Haematoxylin and Eosin.
1	Early spermatogenic Mostly thin germinal epithelium with scattered spermatogenic activity; spermatocytes to spermatids predominate; few spermatozoa observed.	Early development >90% of oocytes pre-vitellogenic, remaining oocytes early to mid-vitellogenic; oocytes slightly larger (up to 300 µm); late perinucleolus through cortical alveolar stages.
2	Mid-spermatogenic Germinal epithelia of moderate thickness; moderate proliferation and maturation of spermatozoa and equal mix of spermatocytes, spermatids and spermatozoa present.	Mid-development Majority of observed follicles early and mid-vitellogenic; oocytes larger 300–600 µm diameter and containing peripheral yolk vesicles; globular and uniformly thick chorion (5–10 µm in black bass, 10–20 µm in common carp); cytoplasm basophilic, yolk globules eosinophilic.
3	Late spermatogenic Thick germinal epithelium; diffuse regions of proliferation and maturation of spermatozoa; all stages of development represented, spermatozoa predominate	Late development Majority of developing follicles late vitellogenic; oocyte diameter 600–1 000 µm, eosinophilic yolk globules distributed throughout the cytoplasm; chorion thickness 10–30 µm in black bass, 40–50 µm in common carp.
4	N/A	Late development/hydrated Majority of developing follicles late vitellogenic; follicles much larger (>1 000 µm).
5	N/A	Post-ovulatory Spent follicles, remnants of the theca externa and granulosa present.

with gonads at Stages 1 and 2 was slightly high (>60%) during the early hot-wet season (October–December 2017) and also in January 2018. Male gonads in the late spermatogenic stage (i.e. Stage 3) were recorded in the hot-wet season of 2017 and also between January and March 2018. The numbers were high in October and November 2017 and peaked in January 2018 when the proportion was 72%. Fish with undeveloped gonads (Stage 0) were found in almost all the months with the exception of January 2018 and June 2017 (Figure 2b). Female fish at Stage 0 were high in March and April 2018 and low in November 2017. Fish with gonads in early-mid development stages (Stages 1 and 2) were recorded almost throughout the year, with the exception of January and May–July 2018. The number of fish in Stages 1 and 2 peaked in October 2017 and declined in March 2018. Fish with gonads in the late development stage (Stage 3) were also observed in low numbers over the entire study period (Figure 2b). They were highest in the months of November and December 2017 and January 2018. Fish with gonads at Stage 4 were only recorded in the months of November and December 2017 and also January and February 2018.

Using the histological criteria of gonadal staging, the L_{50} for males was estimated ranging from 210 mm to 229 mm (Figure 3). Female *H. vittatus* reached sexual maturity at larger sizes (>270 mm) than males. There were some male *H. vittatus* that reached sexual maturity at sizes less than the L_{50} (Figure 3). In the 170–189 mm size class, 8% of the fish gonads already had spermatozoa in them in different quantities, whereas in the 199–209 mm size class 15% mature fish were also observed. After the L_{50} range, 38% of the male fish in the 230–249 mm size class, 22% in the 250–269 mm size class and 6% in the 270–289 mm size class were observed to be still immature. Conversely, L_{50} was reached between 270–289 mm in females (Figure 4). In this size class, 72% of the fish had mature gonads, whereas 28% still had immature gonads. Mature individuals before the L_{50} size class range were also observed in 210–229 mm size class (4%), 230–249 mm size class (10%) and the 250–269 mm size class (27%). After the L_{50} size class range, 3% immature fish were observed in the 330–349 mm size class. As shown in Table 3, the current study produced lower L_{50} values, compared with past studies. In general, the size at maturity value has decreased from 1961 to the present.

Discussion

The expected sex ratio of a healthy fish population is 1:1 and different factors, however, normally cause a deviation from this ratio (Lappalainen et al. 2016). In the current study, the overall sex ratio of 1:0.8 was lower than expected ratio, indicating a stressed system. According to Lappalainen et al. (2016), more males than females are produced when a population is stressed. The increase in the intensity of activities, such as artisanal and recreational fishing, might be causing a decrease in the number of *H. vittatus* females. Moreover, in a study on global climate change and production in Lake Kariba, the results showed that there has been considerable warming of waters of Lake Kariba in response to the warming of the air temperature (Ndebele 2006). According to Mahere et al. (2014), between 1986 and 2011, the mean temperature of the lake increased by 0.7 °C, a rate equivalent to an increase of 0.03 °C y^{-1}. This rise would have cascading effects on production in the lake as primary production would decrease, thereby also affecting *Limnothrissa miodon* (kapenta) production. Kapenta form an important part of the diet of tigerfish (Marufu et al. 2016),

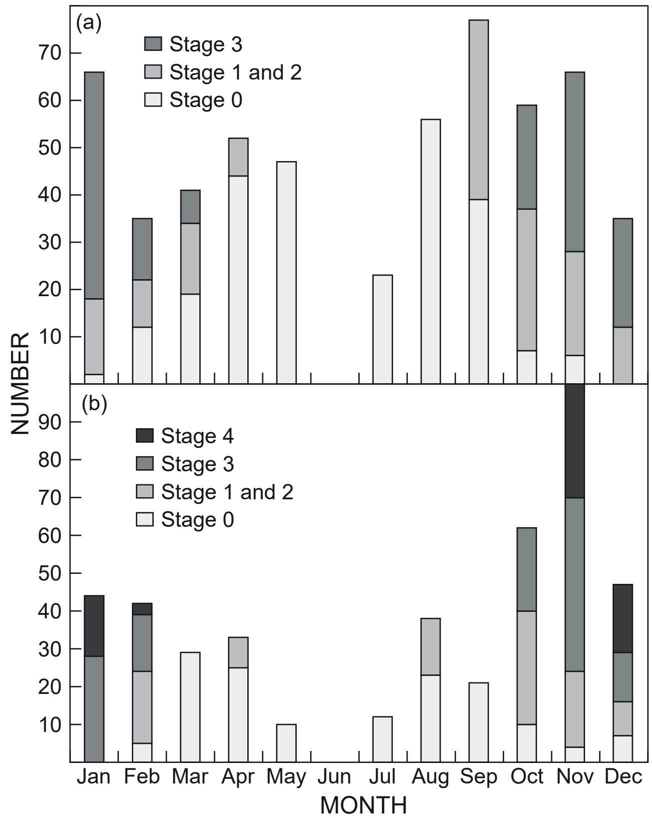

Figure 2: Maturity stages of (a) male and (b) females of *Hydrocynus vittatus*

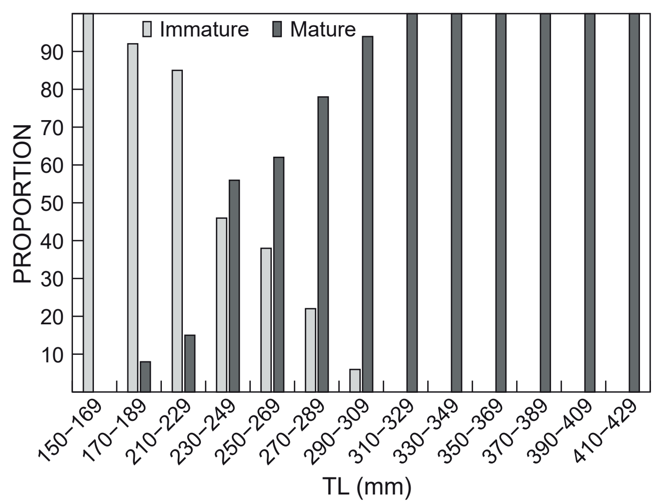

Figure 3: Percentage immature and mature male *Hydrocynus vittatus* for each length class

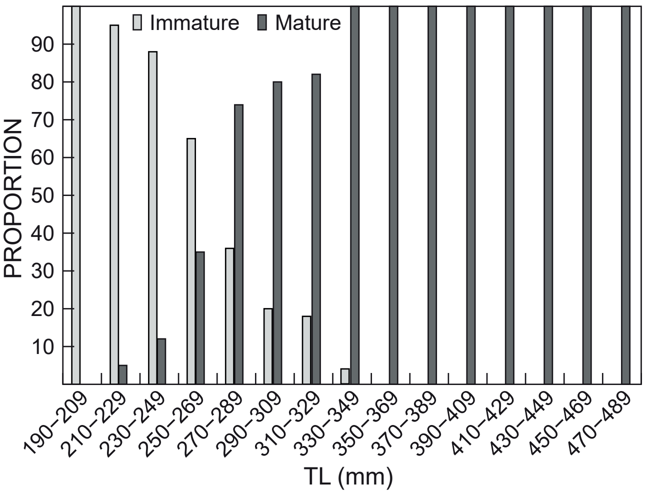

Figure 4: Percentage immature and mature female *Hydrocynus vittatus* for each length class

Table 2: The monthly and total sex ratio for male and female *Hydrocynus vittatus* sampled between August 2017 and July 2018 in Sanyati Basin, Lake Kariba. Bold typeface indicate significant differences ($p < 0.05$) in sex ratios

Month	Male	Female	Total	Ratio	*p*
August	54	25	79	1:0.46	0.002
September	53	24	77	1:0.45	0.001
October	49	44	93	1:0.9	0.138
November	53	70	123	1:1.32	0.147
December	42	52	94	1:1.24	0.511
January	63	74	137	1:1.17	0.621
February	35	31	66	1:0.89	0.552
March	41	29	70	1:0.71	0.035
April	42	28	70	1:0.67	0.029
May	38	10	48	1:0.26	0.000
July	23	12	35	1:0.52	0.017
Total	493	399	892	1:0.8	0.265

Table 3: The different size at maturity values for *Hydrocynus vittatus* recorded in previous studies in Lake Kariba, Zimbabwe

Year	Reference	Total length (mm)	
		Males	Females
1959	Jackson (1961b)	300	350
1966	Badenhuzein (1967)	310	350
1971	Kenmuir (1973)	300	360
2017	Current study	221	278

Table 4: The number of individuals in each size class for both males and females of *Hydrocynus vittatus*

Size class (mm)	Males	Females
150–169	9	0
170–189	24	0
190–209	26	10
210–229	37	24
230–249	35	22
250–269	46	29
270–289	52	59
290–309	41	49
310–329	50	47
330–349	46	25
350–369	40	32
370–389	36	43
390–409	34	22
410–429	17	14
430–449	0	6
450–469	0	5
470–489	0	12
Total	493	399

hence a decrease in kapenta, which is their primary food source, might also be stressing the fish and thereby resulting in the observed sex ratio.

Furthermore, our analysis showed on a larger scale that the sex ratio was male biased. It was assumed that the difference was largely, if not entirely, related to sexual dimorphism of tigerfish and effect of size-selective fishing by the fisher. Sexual dimorphism, a condition where two sexes of the same sex exhibit different characteristics beyond the differences in their sexual organs also occurs in tigerfish (Ojuok 1999). In tigerfish, females are substantially larger than the males. The reason is that because of their larger size, they are caught the most by anglers and artisanal gillnetting fishers. This is likely to affect the sex ratio of the population. Records show that more than 50% of the total catches caught during the Kariba Invitational Tigerfish Tournament are females (KITFT 2016). This demonstrates the existing fishing pressure on females and potential threat to the reproductive biology of this population.

The active to ripe and running gonads were evident from October to February and this observation suggests that *H. vittatus* breed in the hot-wet season. It is therefore important that the fish are protected during the breeding months (November-January). Fishing pressure, especially during the breeding season can be a big threat to the *H. vittatus* population, because not only individuals are removed from the system, but also the egg pool that is supposed to ensure recruitment (Gagiano 1997; Dalu et al. 2012). It is also important to note that sexually active fish do occur during non-breeding seasons, which emphasises on the presence and influx of prebreeding *H. vittatus* prior to the hot-wet season as was observed by Kenmuir (1973). Currently enforcement is lacking from the ZPMWA in terms of monitoring poaching activities during the breeding season of the tigerfish in the Sanyati, Nyaodza and Gache gache Rivers that all feed into the Sanyati Basin and are also breeding corridors for fish. During this period, tigerfish travel upstream for breeding. The fish poachers lay nets across the rivers where the fish are caught in large numbers. The large males and females migrating upstream for breeding are mainly caught in the nets. This is also believed to be having an impact on the tigerfish population, as a result of the continued mortalities of the breeding population (Kemuir 1973).

The study revealed that the L_{50} for both *H. vittatus* male and female in Lake Kariba had decreased from what had been last observed by Kenmuir (1973). The results also indicated that males mature earlier and at a smaller size than females, which explains the greater duration of life of the female that mature later. This observation is consistent with what was observed by other researchers in Kariba (Jackson 1961; Badenhuizen 1967; Kenmuir 1973; Langerman 1984) who noted that male *H. vittatus* matured earlier than the females and at smaller sizes.

According to the fisheries induced evolution theory, fishing can exert strong selective pressures on a stock, causing rapid evolution of key traits and behaviours. Size-selective fishing is typically expected to select for earlier maturation, slower or faster growth, and increased investment to reproduction (Dunlop et al. 2018). The results of the study are consistent with this theory. According to Karna and Panda (2011) a smaller L_{50} can be an indication of a stressed population, as a result of overharvesting of the females, which then forces them to reach sexual maturity earlier in their life stages. This is what has been observed in Lake Kariba where female *H. vittatus* are being poached at high quantities during their breeding season. Figure 5 shows that the CPUE of tigerfish has been fluctuating, but a constant decrease has been noted since 2011 and this could be attributed to increased fishing pressure from artisanal and recreational fisheries and climate change to a lesser extent (Takudzwa Changamire, Lake Kariba Fisheries Research Institute, pers. comm.). There is therefore a requirement for the responsible institutions to implement effective management tools, in order to protect the *H. vittatus* especially during their breeding season.

Conclusion

The current analysis revealed that *H. vittatus* population in the Sanyati Basin was stressed and it might be under potential threat from increased fishing pressure and changes in environmental conditions. Parameters such size at maturity, sex ratio and maturity stages of *H. vittatus* should be continually studied, because they an important indicators of the viability status of a fishery. The knowledge on length at maturity and spawning season determines when and at which length the fish should be protected. Proper management and conservation policies should be put in place to conserve the *H. vittatus* population in the Sanyati Basin of Lake Kariba.

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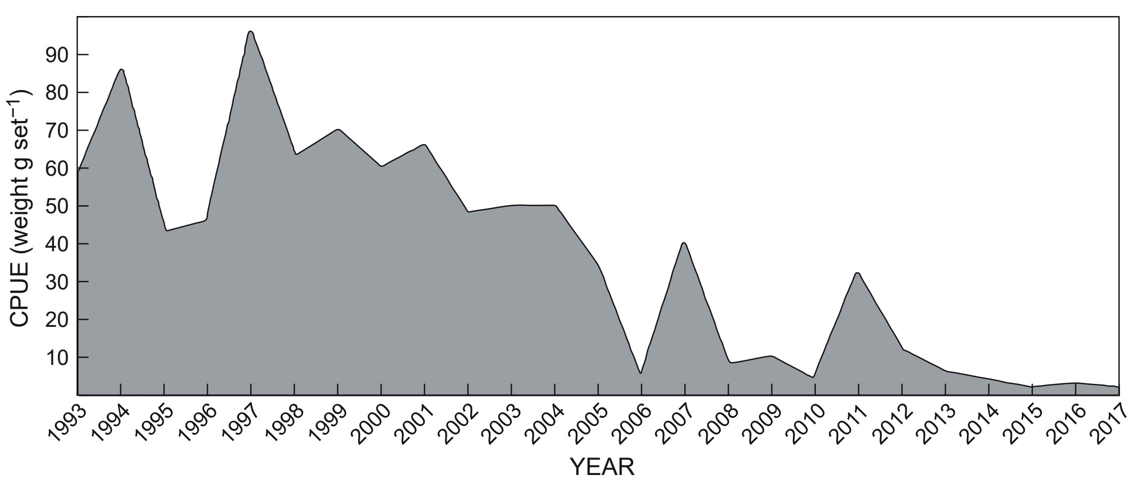

Figure 5: Catch per unit effort (CPUE) for *Hydrocynus vittatus* at Lakeside station in Lake Kariba, Zimbabwe from 1993 to 2017. Source: Lake Kariba Fisheries Research Institute (2018)

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