RESEARCH ARTICLE

Feeding ecology of tiger fish, (*Hydrocynus vittatus)* in the Kalimbeza Channel on the Zambezi River, Namibia

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ABSTRACT

The feeding ecology of tiger fish, *Hydrocynus vittatus* (Characidae), in the Kalimbeza Channel on the Zambezi River, Namibia was investigated between February - December 2016. The fish sampling was conducted monthly using cotton multifilament nets with stretched mesh sizes: 12, 16, 22, 28, 35, 45, 57, 73, 93, 118 and 150 mm. A total of 498 specimens of the fish were collected and their stomachs dissected for contents analyses. The findings indicated that large size classes of *H. vittatus* (>176mm) were largely piscivorous, and showed a diet shift with changes in size. The small size classes of *H. vittatus* (<140mm) consumed mainly *Aquatic insects* (21.1%), *Synodontis* spp (17.8%), and *Micralestes acutidens* (12.1%). They later shifted to diet in which *Synodontis* spp (26.1%), *Brycinus lateralis* (15.2%) and *M. acutidens* (13.0%) dominated. Seasonal shift in diet were apparent due to changes in seasonal food abundances and distributions. During the wet season, *H. vittatus* fed mainly on aquatic insects and later showed a shift to diet dominated by fish prey items during the dry season. *Hydrocynus vittatus* showed no strict food regime and this gives it a better chance of survival. Ratios of prey length-predator length averaged approximately 0.27. The study showed that *H. vittatus* plays an ecological role with the ability of converting un-exploitable non-commercial species into exploitable protein. Hence their population must be of conservation priority to ensure a balanced fishery in the Zambezi River.

Keywords: *Hydrocynus vittatus,* piscivory, predation, Zambezi River

INTRODUCTION

The Tiger fish *Hydrocynus vittatus* (Castelnau, 1861) is a member of the family Alestiidae, a piscivorous and ferocious pelagic predator, widely distributed in the Zambezi River (Jackson, 1961; Skelton, 2001). Larger specimens up to 700 mm in size, weighing over 150 kg had been documented (Dalu *et al.,* 2012). This species are generalist piscivorous (Jackson, 1961; Winemiller and Kelso-Winemiller, 1993; Mhlanga, 2003; Dalu *et al*., 2012) and supports an important commercial and recreational fishery on the Zambezi, Okavango/Chobe Rivers and Lake Kariba (Winemiller and Kelso-Winemiller, 1993; Hay *et al.,* 2002). *Hydrocynus vittatus* is ranked the sixth most important species in the fishery of the Zambezi-Chobe Rivers, contributing over 26% to the total annual catch (Hay *et al.,* 2002). Stomach content studies on freshwater fishes had been conducted to provide wealthy of information on their dietary requirements in their natural habitats (Sandon and Tayib, 1953; Verbeke, 1959; Corbet, 1961, Chilvers and Gee, 1974; Lewis, 1974 and Whyte, 1975). Swallowing the prey whole appears to be a common habit for most freshwater predatory fishes in Africa (Jackson, 1961). This presents a window that the prey in the gut contents can be observable to species level and that both body length and weight can be determined. While several studies have been conducted on the feeding ecology of *H. vittatus* (Lewis, 1974; Kelley, 1968; Winemiller and Kelso-Winemiller, 1993; Mhlanga, 2003; Dalu *et al.,* 2012), no study has systematically analysed their feeding ecology in Kalimbeza Channel on the Zambezi River. Kalimbeza channel is a newly established fishery reserve on the Zambezi River, with minimum exposure to human disturbance. Studies on fish feeding can yield relevant information that can affect competition, mortality, fecundity and growth in fish communities (Michelsen *et al*., 1994). Garrison and Link, 2000 highlight the importance of assessing different size class of the same fish species as each size class is assumed to play different ecological roles. This implies that food requirement at an early life stage of the same species can differ from the adult stage. Isumbisho *et al.,* (2004) stress the need to ascertain the feeding requirements of fish across its demographic in order to provide a complete picture of resource use and partitioning. The aims of this study were to elucidate seasonal and ontogenetic diet shifts and the feeding habits of *H. vittatus* in the Kalimbeza Channel on the Zambezi River, highlighting the effects of fish size and season on feeding.

MATERIALS AND METHODS

Study area

The Zambezi region borders on Botswana in the south, Angola and Zambia in the north and Zimbabwe in the east Figure 1a). The area is home to two perennial rivers, namely the Kwando/Linyanti in the west and the Zambezi Chobe in the east. The Zambezi River is characterised by a diverse range of habitats including a deep, wide mainstream with many small vegetated islands and sandbanks, small side streams, backwaters, lagoons and floodplains (Hay *et al.,* 2002). The Zambezi floods seasonally, water level starts to rise in December with a drastic increase in February and March (Hay *et al.,* 2002).

Field sampling

Monthly sampling was conducted in the Kalimbeza Channel of the Zambezi River (Figure 1b) from February to December 2016. The sampling program was conducted using a fleet of cotton multifilament nets with stretched meshes of 12, 16, 22, 28, 35, 45, 57, 73, 93, 118 and 150 mm. Freshly caught specimens of *Hydrocynus vittatus* were collected and measured to the nearest millimetre fork length (SL), weighed to the nearest gram. Fish stomachs were dissected out and carefully split open using a pointed nose pair of scissors. Stomach contents were spread out on white treys in the field and visually assessed. Each item in the diet was identified to the lowest possible taxonomic level (using the guides by Skelton, 2001 on fish, Garber and Gabriel, 2002 on insects) counted and measured to the nearest millimetre total length (TL), and weighed to the nearest gram.

Diet analysis

The diet was first determined by the frequency of occurrence and percentage number method according to Hyslop (1980). Frequency of Occurrence accounts for the number of stomachs in which each prey item occurs and expressed as a percentage of the total number of stomachs examined

$$\text{Frequency of Occurrence:} \quad O_i = \frac{J_i}{P}$$

Where, Ji is number of fish containing prey i and P is the number of fish with food in their stomach.

Number method was employed according to Zengeya and Marshall, 2007. The number of individual prey per stomach was enumerated and translated into a percentage of the total number of prey items in the specimen. Hence this was calculated as follows:

Percent by number: $$N_i = \frac{N_i}{\sum_1^Q N_i}$$

Where, N*i* is the number of food category ***i***

The food items were then combined into broader taxonomic categories for quantitative comparisons. The percentage of empty stomachs was determined. In order to determine whether there was a change in food composition among the different size groups, the fish were separated into three length class sizes ; small (<140 mm); medium (141-175 mm) and large (>176 mm). Length class selection was based on the biology and life history of *H. vittatus* according to (Skelton, 2001). Data on prey items according to season and fish size were first checked for normality and homogeneity of variances (Levene's test). To improve on assumptions of normality and homogeneity of variances, data were log10 transformed. In case where transformation failed to normalize the data, non-parametric Kruskal-Wallis analysis test was carried out to test the differences in stomach contents between size classes while the Mann-Whitney U-test was employed to test for differences in food items between wet and dry season. A linear regression was employed to assess the relationship between the predator and prey length. Statistical analyses were performed using SPSS 24 statistical software (Zar, 2010).

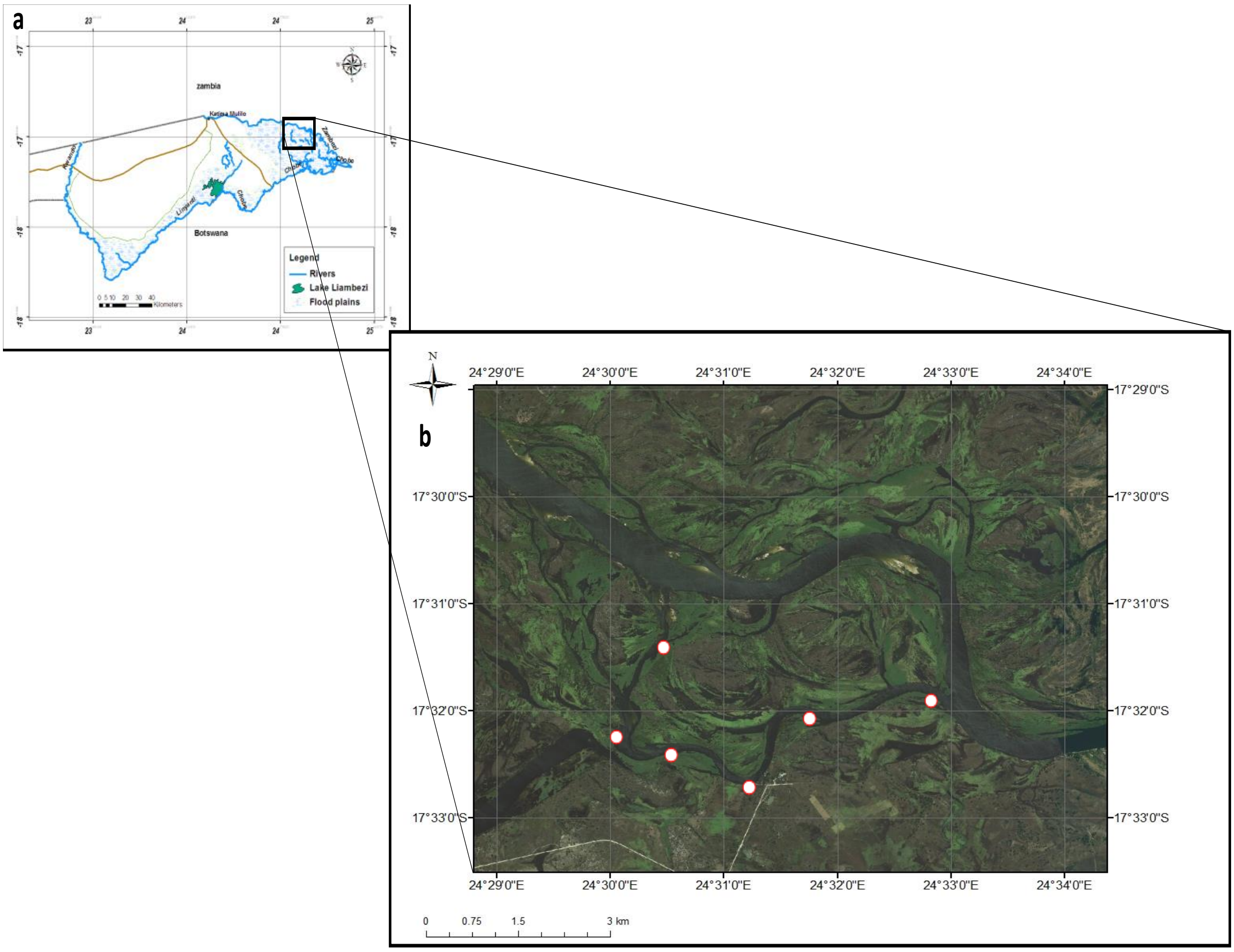

Figure 1. Map of the Zambezi Region (a), showing the Kalimbeza Channel on the Zambezi River (b), = gillnet sites catchment areas. Generated using ArcGIS 9.3.

RESULTS

Diet composition of Hydrocynus vittatus

A total of 498 specimens of *Hydrocynus vittatus* were sampled during the survey. Out of the 498, stomachs dissected, 176 (35.3%) had food. Twenty-five different prey items were identified and categorised into 18 broad groups (Table 1). Of the fish prey items, 21.1% could not be identified as they were in an advanced stage of digestion. The major prey groups were; Cichlids, Characids, Cyprinids, Mochokhids, Mormyrids, Micropanchax, Schilbids and Aquatic Insects. Figure 2 shows the cumulative numbers of unique prey species observed in the stomachs of *H. vittatus* over time. The results show a rapid detection of new prey species from day 1 up to day 28 and the graph stabilizes between day 29 and 40. One or two new prey species were detected between day 41 and 42 and eventually the graph stabilizes for the next 48 sampling days and no new species were detected thereafter. Hence the sample size was considered sufficient as no additional prey items could be detected during the latter days of the sampling period (Mlanga, 2003) (Figure 2). No single stomach content was observed on day 16 denoted by the gape in the graph. The number of empty stomachs observed between July and September were generally higher compare to those observed between January and June (Figure 3).

The results shows that *Synodontis* spp (15.2%) (17.8%) was the most important dietary component by percentage number and frequency of occurrence followed by *Micralestes acutidens* (10.3%) (12.1%), *Brycinus lateralis* (7.8%) (9.2%) and Aquatic insects (21.1%) (7.5%) (Table 1). Other prey occurred less frequently, for instance, *Petrocephalus catastoma, Enteromius fasciolatus, Enteromius unitaeniatus*, *Cyphomyrus cubangoensis*, *Petrocephalus catastoma, Rhabdalestes maunensis* and *Schilbe intermedius* contributed less than 5% to the total number of prey consumed (Table 1). Insects and fish were the two major groups in the diet. Fish material were the most important food item and accounted for 80% of the total prey identified. Aquatic insects of the order Trichoptera and Odonata were the important groups of insect found in the stomachs of *Hydrocynus vittatus*.

Table 1. Major prey categories and their importance in the diet of *Hydrocynus vittatus* in the Kalimbeza Channel on the Zambezi River (February - December 2016). N = Total number while FO = Frequency of occurrence.

Prey items	N	%N	FO	%FO
Synodontis spp.	31	15.2	31	17.8
Micropanchax johnstoni	2	1.0	2	1.1
Enteromius lateralis	16	7.8	16	9.2
Insects	43	21.1	13	7.5
Enteromius fasciolatus	2	1.0	2	1.1
Enteromius poechii	7	3.4	7	4.0
Enteromius radiatus	6	2.9	6	3.4
Enteromius unitaeniatus	2	1.0	2	1.1
Cichlids	7	3.4	7	4.0
Marcusenius altisambesi	11	5.4	11	6.3
Cyphomyrus cubangoensis	1	0.5	1	0.6
Micralestes acutidens	21	10.3	21	12.1
Pharyngochromis acuticeps	4	2.0	4	2.3
Pollimyrus castelnaui	1	0.5	1	0.6
Petrocephalus catastoma	5	2.5	5	2.9
Rhabdalestes maunensis	1	0.5	1	0.6
Schilbe intermedius	1	0.5	1	0.6
Unidentified fish	43	21.1	43	24.7
Total	**204**	100	**174**	100

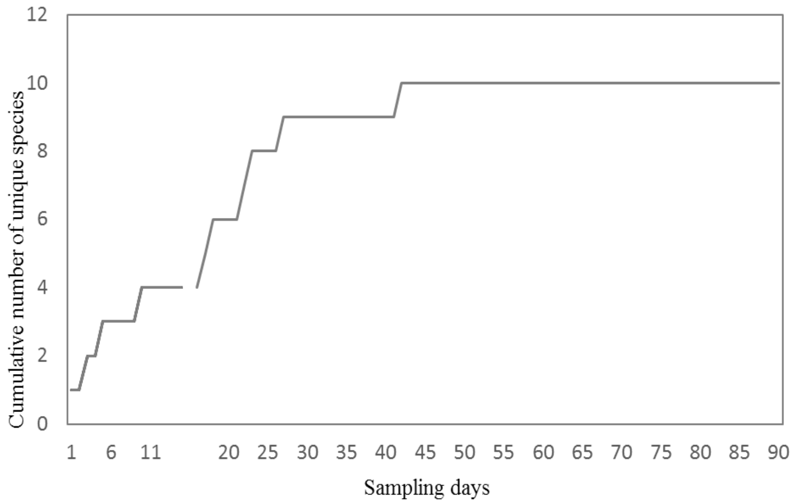

Figure 2. Cumulative number of unique prey items observed in the stomach of *Hydrocynus vittatus* in the Kalimbeza Channel on the Zambezi River (February - December 2016).

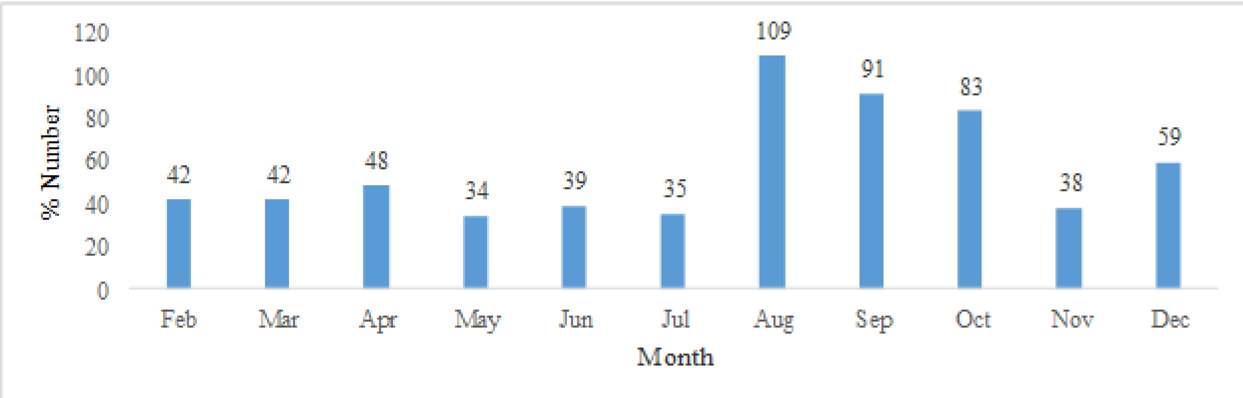

Figure 3. Incidence of empty stomachs in 498 specimens of *Hydrocynus vittatus* in the Kalimbeza Channel on the Zambezi River (February - December 2016).

Variation in relation to size class

Table 2 shows the variation in the food items according to the different size classes of *H. vittatus*. The length of specimens sampled ranged from 58mm to 603 mm. The body weight also varied from 6.6 g to 2910 g. Out of the 176 *H. vittatus* specimens with observable prey items in their stomachs, 69 samples were observed within the small size class, 59 in the medium size and 44 in the large size class respectively. The small *H. vittatus* (less than 144 mm SL) size class predominantly fed on *Synodontis* spp (14.1%), *M. acutidens* (9.9%) and Aquatic-insects (8.4%). *Enteromius unitaeniatus*, *E. fasciolatus*, *Micropanchax johnstoni*, *Marcusenius altisa-mbesi*, *Pollimyrus castelnaui*s were observed in small quantities (Table 2). Medium sized *H. vittatus* (141-175mm) had a total of 14 different prey items in the stomachs. This group preyed heavily on *Synodontis* spp (24.7%), *M. acutidens* (17.3%) and Aquatic insects (15.8%). Specie s such as *E. fasciolatus, Enteromius radiatus, Enteromiu s unitaeniatus* and *Pollimyrus castelnaui* were observed in small quantities (Table 2). Large adults size class (>176) showed a diet in which *Synodontis* spp (26.1%), *Brycinus lateralis* (15.2%) and *Micralestes acutidens* (13.0%) dominated the diet composition. No differences in diet were observed between small vs. medium size class, while significant differences were observed between small vs. large and medium vs. large size classes ($p<0.05$).

Table 2. Diet composition (in percentage) of *Hydrocynus vittatus* in the Kalimbeza Channel from the Zambezi River (February - December 2016) according to size class.

Prey items	Small <140mm (n=69)	Medium 141-175mm (n=59)	Large >176mm (n=44)
Micropanchax johnstoni	1.4	2.5	0.0
Brycinus lateralis	5.6	9.9	15.2
Insects	8.4	15.8	4.4
Enteromius fasciolatus	1.4	2.5	2.2
Enteromius poechii	2.8	4.9	4.3
Enteromius radiatus	1.4	2.5	8.7
Enteromius unitaeniatus	1.4	2.5	2.2
Cichlids	4.2	7.4	4.3
Marcusenius altisambesi	1.4	2.5	2.2
Cyphomyrus cubangoensis	0.0	0.0	0.0
Micralestes acutidens	9.9	17.3	13.0
Pharyngochromis acuticeps	2.8	4.9	4.3
Pollimyrus castelnaui	1.4	2.5	0.0
Petrocephalus catastoma	2.8	4.9	2.2
Rhabdalestes maunensis	0.0	0.0	0.0
Schilbe intermedius	0.0	0.0	2.2
Synodontis spp.	14.1	24.7	26.1
Unidentified fish	40.8	71.7	8.7

Table 3. Percentage Frequency of occurrence in numbers of prey components of *Hydrocynus vittatus* in the Kalimbeza Channel of the Zambezi River (February and December 2016) for the dry and wet seasons.

Species	Wet		Dry	
	FO	%FO	FO	%FO
Rhabdalestes maunensis	0	0.0	1	1.1
Barbus fasciolatus	0	0.0	2	2.2
Marcusenius altisambesi	1	0.9	10	10.9
Micropanchax johnstoni	2	1.8	0	0.0
Brycinus lateralis	7	6.3	9	9.8
Cyphomyrus cubangoensis	1	0.9	0	0.0
Insects	11	9.8	32	34.8
Barbus poechii	4	3.6	3	3.3
Barbus radiatus	4	3.6	2	2.2
Pharyngochromis acuticeps	2	1.8	2	2.2
Pollimyrus castelnaui	0	0.0	1	1.1
Barbus unitaeniatus	2	1.8	0	0.0
Cichlids	2	1.8	5	5.4
Micralestes acutidens	17	15.2	4	4.3
Petrocephalus catastoma	0	0.0	5	5.4
Schilbe intermedius	0	0.0	1	1.1
Synodontis spp.	16	14.3	15	16.3
Unidentified fish	43	38.4	0	0.0
Total	**112**	**100**	**92**	**100**

Variation between seasons

The observed diet components of *H. vittatus* in the wet and dry seasons are presented in Table 3. Fish were recorded in the stomachs more regularly among all sizes in both seasons. A total of 112 prey items were recorded in the wet season while 92 were recorded in the dry season (Table 3). During the wet season, *H. vittatus* consumed larger portions of *Micralestes acutidens* (15.2%), *Synodontis* spp (14.3%), *B. lateralis* (6.3%), and Aquatic insects (9.8%). The least important prey items in the wet season were *Marcusenius altisambesi* and *Cyphomyrus cubangoensis*. During the dry season, *H. vittatus* showed a shift to a diet which was dominated by Aquatic insects (34.8%, mainly flying termites), *Marcusenius altisambesi* (10.9%), *Brycinus lateralis* (9.8%) and *Synodontis* spp (16.3%). The least important prey items were *Pollimyrus castelnaui* and *Schilbe intermedius.*

Predator Prey length relationship

The prey length in relation to the predator length for *H. vittatus* is presented in Figure 4. Of the 126 *Hydrocynus vittatus* with measurable prey in their stomachs, the predator prey length relationship shows that small *H. vittatus* ingested prey (fish) from small size SL classes, whereas large *H. vittatus* ingested a wide range of prey sizes ranging from 50-170 mm SL (Figure 4), and showed a positive predator prey relationship. On average, *H. vittatus* consumed prey with a mean of 27.3% of its body length.

DISCUSSION

Diet composition of Hydrocynus vittatus

The stomach contents of many African inland water fishes has been studied with a view to ascertaining their dietary requirements in their natural habitats (Fagade and Olaniyan, 1973). Our results showed that *Hydrocynus vittatus* feeds extensively on non-cichlid fish species such as *Synodontis* spp. (17.8%), *Micralestes acutidens* (12.1%), *Brycinus lateralis* (9.2%) and Aquatic insects (7.5%). In a similar study, Mhlanga, (2003), reported that *H. vittatus* in Lake Kariba fed on Clupeidae (*Limnothrissa miodon*) (55%), cichlids (20%), other fishes (including Clariidae (catfish), Mochokidae (squeaker fish); (macroinvertebrates) (12%), and Alestiidae (*Brycinus* spp.) (< 5%). Winemiller and Kelso-Winemiller, (1994) also showed that *H. vittatus* fed variously on cichlids and *Synodontis* spp. (over 50%) in the Zambezi River floodplain suggesting that cichlids were the major food source. Hence *H. vittatus* habitually feed on diet components of animal origin (fin fish); the species is thus an exclusive piscivorous.

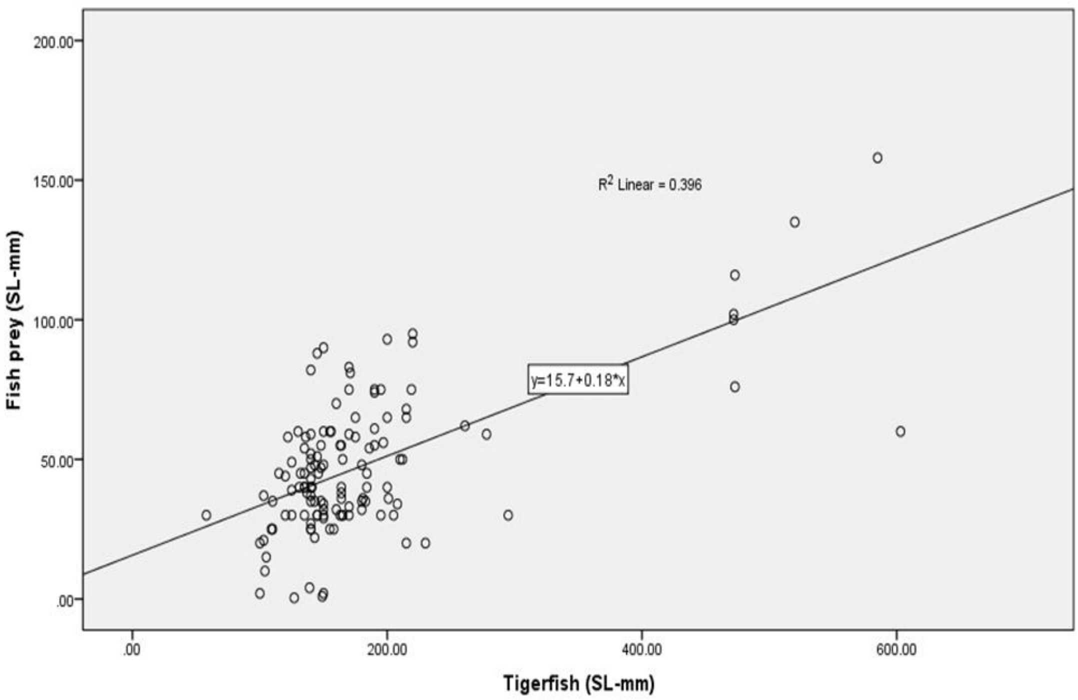

Figure 4. Predator prey length relationship for *H. vittatus* (Linear regression, P<0.05) at kalimbeza Channel, Zambezi River.

The results of the stomach analyses affirm the evidence of high incidence of empty stomachs as observed by Mhlanga, (2003), (Lake Kariba) and Dalu *et al.,* (2012) (Malilangwe reservoir). These findings are common in predatory fishes such as Tigerfish and the African pike. A high proportion of empty stomachs in piscivorous fish can be explained by post-capture digestion and change in daily temperature as postulated by He and Wurtsbaugh, 1993. The rate and change in temperature is directly proportional to the rate of digestion, with the emphasis that, the higher the temperature, the higher the rate of digestion (He and Wurtsbaugh, 1993). Thus, fish which entangle gill nets at night would digest the food in their stomachs faster under higher temperatures than cold gillnet nights (He and Wurtsbaugh, 1993).

Evidence of ontogenetic diet shift in Hydrocynus vittatus

There is evidence of ontogenetic diet shifts for the *H. vittatus* where both small and medium size classes feed on mixed proportions of both insects and fish relative to the large length class size which were typically piscivorous. These observations corroborated the report of Okon, (2002) on some aspects of the food and feeding habits of *H.vittatus* from a small Malilangwe reservoir, Zimbabwe. The diets shift from one particular food habits to another as found in this study might also be explained by the period the diet components are available in the resident water body or the process of ontogenesis in organism (mouth size gap) (Winemiller and Winemiller, 1994; Olojo et *al.,* 2003). Keast, (1985a) postulated possible factors which could account for producing size-related patterns of feeding among piscivorous fish. Firstly, small sized and juvenile fishes are inhibited by the small size of their mouth gape to exploit fairly small prey items such as aquatic invertebrates' and small prolific fish species such as barbs. Only after some time in growth will fish switch selecting small prey items to large prey items enhanced by an increase in size of the mouth gape. Secondly, the observed switching from invertebrate to fish prey may be allied to changing prey availability at a particular point in time as indicated by the seasonal prey availability Table 3. The occurrence of common prey categories in all sizes also points to a likelihood of intraspecific competition in *H. vittatus*. For instance, medium and large *H. vittatus* in this study are likely to compete for prey items such as *Synodontis* spp. Although there is evidence of overlap among prey items such as *Micralestes acutidens*, *Brycinus lateralis*, Aquatic-insects and cichlids; there are qualitative differences in the items recorded and the dominant food items in the diet of one particular size group match with those which are of only minor importance in another size group. However, the major prey items which formed the main fish prey for *H. vittatus* includes *Synodontis* spp. *Micralestes acutidens* and *Brycinus lateralis* which are available in large quantities throughout the Zambezi River (Peel, 2012).

Seasonal shift in the diet of Hydrocynus vittatus

Seasonally, all the diet components were encountered during wet and dry seasons throughout the study period. However distinctive numerical variations in prey selectivity between the wet and dry seasons were evident. A total of 112 prey items in wet season relative to 92 prey items in dry season were recorded. This imbalance may be explained by the abundance of prey items during the wet season and a decline in prey items selection by *H. vittatus* in the dry season (Winemiller and Winemiller, 1994). Similarly, the prominence of primary producers (e.g. algae, diatoms and zooplankton) during the wet season could be linked to nutrient-rich white flood waters that stimulated greater primary and secondary productivity (Winemiller and Winemiller, 1994). In turn, primary producers such as macrophytes might have provided new habitats and served an alternative food source (Winemiller and Winemiller, 1994). Variability in prey availability due to seasonal change has an indirect effect on the food composition of *H. vittatus,* implying that this species does not have a strict food regime and this gives it a better chance of survival. During the hot dry season characterised with low water levels and dissolved oxygen, *H. vittatus* switched prey from *Micralestes acutidens* to *Synodontis* spp (Winemiller and Winemiller, 1994). During this 'crunch period', target preys become limited due to hostile shrinking water bodies (Winemiller and Winemiller, 1994). During this period, the total number of potential preys such as *M. acutidens* and *B. lateralis* are reduced below sufficient levels to meet the daily energy demand of the predator population while hardy and tolerant species such as *Synodontis* spp persist in bulk. These outcomes justifies that, the observed seasonal differences in food composition of *H. vittatus* could be more derived from differences in relative prey availability in the resident habitats rather than prey selection by *H. vittatus.*

CONCLUSION

This study showed a high availability of prey items selected by *H. vittatus* in the Zambezi River. Small and medium size classes of *H.vittatus* fed on both insects and fish material, while larger size class strictly fed on fish. The overall patterns that arises from this study shows that *H. vittatus* is a generalist piscivorous at an early size class and strictly piscivorous at an adult stage. With respect to ontogenic in the diet of *H. vittatus*, generally all size groups consumed most prey categories, however insects were scarce in the large size group. The shift by *H. vittatus* from an insect-based diet to a fish dominated diet seem to occur earlier in life. Early shifts in diet may be a survival strategy because they decrease dependence on seasonal and short supply of prey food source such as insects. Hence, it can be deduced that insect availability in the Zambezi River is likely to regulate recruitment of juvenile *H. vittatus* fish into adult fish populations before they exceed the 100-mm size class. This study also revealed that, *H. vittatus* fed on fish less than 16 cm. Prey selected were less than 50% predator's length. The study revealed that *H. vittatus* has a less devastating effect upon the stocks of commercially important species, but rather serve as an ecologically important species with the ability of converting un-exploitable small sized species into exploitable protein. Hence their population must be maintained to ensure a balanced fishery in the Zambezi River.

Conflicts of interest: The authors stated that no conflicts of interest.

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