ORIGINAL ARTICLE

Age and growth rate estimations as a basis for assessing the population dynamics of *Hydrocynus vittatus* Castelnau 1861 in the Sanyati Basin of Lake Kariba, Zimbabwe

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Abstract

In early fish life stages, information on their age structure can be used to clarify the effects of environmental changes on their growth and survival, thereby providing an improved understanding of factors affecting their recruitment success. There is currently inadequate understanding of the age structure of *Hydrocynus vittatus* in the Sanyati Basin of Lake Kariba in Zimbabwe. Accordingly, the present study investigated the age of tigerfish in the Sanyati Basin of Lake Kariba using whole otoliths and scales for comparison. The results indicated ages read on the basis of scales and otoliths of *H. vittatus* agreed to a larger extent for fish aged one to four years than for fish older than four years. There was a significant difference (χ^2 = 8.520, p = .024) in the ages obtained from analysis of scales and otoliths for fish older than four years. The average percentage error and coefficient of variation were found to be 6.03% and 8.1% for whole otoliths, respectively, for the present study. The APE and CV values for scales were 13.81% and 17.41%, respectively. Relatie age data for whole otoliths fit the von Bertalanffy growth model, while that for scales did not fit the von Bertalanffy model, resulting in many outliers and much scatter of the data. The whole otolith parameters for the von Bertalanffy growth curve were L-infinity = 682.5 mm, k = 0.530 and t_0 = 3.19. Based on the results of the present study, it can be concluded in this case that whole otoliths were the best method of ageing tigerfish from Lake Kariba. Accordingly, it is recommended that otoliths be used for ageing tigerfish in Lake Kariba and that scales be used for ageing tigerfish only up to four years in age.

KEYWORDS
growth rings, otoliths, precision, scales, tigerfish, von Bertalanffy

1 | INTRODUCTION

Hydrocynus vittatus (Castelnau 1861), also known as tigerfish, is one of the most important fish species being exploited in the freshwater bodies of Southern Africa (Marshall, 2011). According to Gerber et al. (2009), tigerfish in the Okavango Delta of Botswana are a sought-after sport fish and also an important component of a large commercial and recreational fishery in the region. It is also an

important angling fish species in Zimbabwe (Dalu et al., 2012, 2013a, 2013b). Despite the importance of this fish species, little information is available regarding various aspects of the ecology of the species, specifically in regard to its age structure (Soekoe et al., 2013).

Accurate knowledge of age and growth is fundamental to fishery science (Filmalter et al., 2009). Information on age structure in early life stages can be used to clarify the effects of environmental changes on growth and survival and can result in an improved

understanding of the factors affecting recruitment success (Soekoe et al., 2013). Knowledge of age and growth dynamics of adult fish can be used to determine the effects of fishing on the stocks and the efficacy of management policies in order to better understand life history events and maximize yields while also continuing to ensure the future of the resource (Winker et al., 2010).

Several studies have previously been conducted on fish ageing. The age and growth dynamics of fish can be determined by such methods as growing fish in confinement; raising fish from birth; examining the hard parts of fish that encode age information; and biochemical tests (Brouwer & Griffiths, 2004; Campana, 2001). The usefulness of these methods depends on the habitat and life history stage of the fish (Richardson et al., 2009). Scales and otoliths are the two most widely used hard parts for estimating age in fish, with growth rings in these parts having long been used to age fish. Scales were first used to age fish in 1888 (Carlander, 1987). Otoliths have been used to age fish since Reibisch first observed annular ring formation in *Pleuronectes platessa* in 1899 (Ricker, 1975). However, counting annuli is not always useful in estimating the age of juvenile fish that have not yet formed their first annulus, or for tropical or deep sea fish whose growth is more constant and annulus formation less certain (Campana, 2001).

Sectioned otoliths are considered the most appropriate structures for evaluating the age and growth dynamics of freshwater fishes. Gerber et al. (2009) and Soekoe et al. (2013) are the only studies using otoliths to estimate the age of *H. vittatus*. This is because otoliths show annual and daily patterns, therefore providing a permanent record of life history events. Moreover, experimental evidence indicates no resorption of otoliths under stress conditions (Taylor & Weyl, 2012). In contrast, fish scales have proven to be unreliable because deposition ceases at older ages, thereby often giving false age readings. A prime advantage of using scales is that their removal does not result in death of the fish, as well as the ease of scale extraction (Campana, 2001).

Chifamba and Videler (2014) previously reported that sectioned otoliths represented the best method for ageing *Oreochromis niloticus* and *Oreochromis mortimeri*, also recommending that future studies and monitoring programmes use sectioned otoliths. Taylor and Weyl (2012) reported that sectioned otoliths of *Micropterus salmoides* were more readable and provided more precise age readings than did scales. Further, another study concluded that sectioned otoliths of *Oreochromis andersonii* gave more reliable readings than scales (Bwanika et al., 2007).

Hydrocynus vittatus is an important fish in Lake Kariba since local communities along the lake shorelines depend on it for both income and food (Marufu et al., 2018). Accordingly, estimating fish age using otoliths (and scales for comparison) will facilitate accurate growth estimations of tigerfish in Lake Kariba. The age distribution of a stock is a good indicator of reproductive potential and reflects the survival chances of a given population. Accordingly, the primary objective of the present study was to estimate the age of tigerfish in the Sanyati basin of Lake Kariba using whole otoliths and scales for comparison. Whole otoliths instead of sectioned

otoliths were used in the present study because of lack of appropriate equipment to section otoliths. The present study also aimed at determining tigerfish length distributions and growth rates, with the study results anticipated to inform conservation efforts for *H. vittatus* in the Sanyati Basin, Lake Kariba. The results of the present study will also provide baseline data for future studies of *H. vittatus* ageing in Lake Kariba.

2 | METHODS AND MATERIALS

2.1 | Study area

Lake Kariba is a manmade lake (reservoir) located on the Zambezi River (Figure 1) shared between Zambia and Zimbabwe (26º40′E–29º3′E and latitudes 16º28′S and 18º6′S). The lake is 276-km long, with a mean width and depth of 19-km and 29.5-m, respectively. The major tributary rivers draining into Lake Kariba are the Gwayi, Sengwa and Sanyati rivers. The main inflow sources into the Zambezi River are the Kafue, Luangwa and Shire sub-basin tributaries. A minor (10%) of the mean annual rainfall within the basin contributes to the flow of the Zambezi River. 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 usually exceeds 20°C, with distinct seasonal variations. Three seasons are distinct for Lake Kariba, namely (i) cool to warm dry season from April to September; (ii) hot dry season from September until onset of the October rains; and (iii) hot–wet season from late-October to late-March (Magadza, 2010).

The lake is divided into five hydrological basins, namely the Sengwa, Binga, Ume, Mlibizi and Sanyati basins. The five basins are separated by narrower lake zones and/or a series of islands. The first and second basins are shallower and smaller in terms of surface area and volume, compared to the other three basins. The third and fourth sub-basins are deeper, containing 90% of the total reservoir capacity. The main land use in the lake catchment area is subsistence farming and pastoralism. The Sanyati Basin, in which most studies have been conducted, is the one most accessible to the University Lake Kariba Research Station (ULKRS). The basin is fed by the Sanyati, Gache Gache, Nyaodza and Charara rivers. The most influential river in the basin is the Sanyati River which exerts a significant influence on the Sanyati Basin in terms of productivity (Sanyanga et al., 1995). The Sanyati River brings highly mineralized water to the lake from farms, sewage and mining drainage effluents from Kwekwe through Sebakwe River.

2.2 | Sampling procedure

A total of 892 fish of different sizes were captured between June 2017 and June 2018. Gillnetting and seine netting were used to capture the fish at the Gache Gache, Nyaodza, Forthegill and Tsuwa fishing grounds (Figure 1). A total of 324 and 306 samples
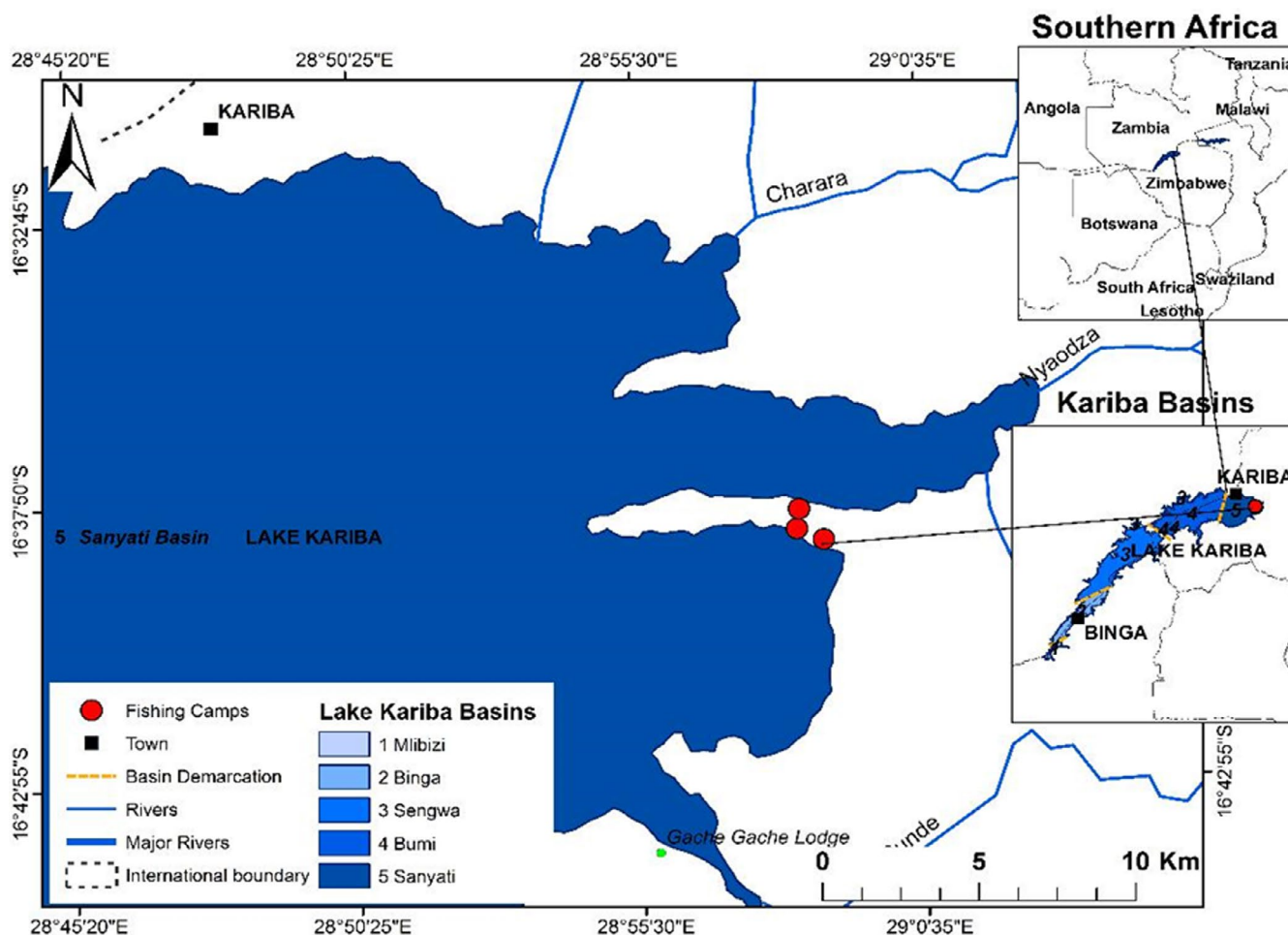
FIGURE 1 Sampling sites in Sanyati Basin of Lake Kariba, Zimbabwe

were collected using seine netting and gillnetting, respectively. Multifilament gillnets of varying mesh sizes (1.5–7 inches) were used for gillnetting. Bulk samples (262 samples) were also collected from anglers during the Kariba Invitational Tigerfish Tournament. The fish were transported fresh, with extraction of the otoliths and scales being conducted at the University of Zimbabwe Lake Kariba Research Station. Morphometric parameters of the fish were also recorded, including the sex.

2.3 | Fish ageing based on scales

Scales from 892 fish were sampled and analysed. Two scales were removed from either sides of the lateral line of the fish. The scales were placed in distilled water for 48 h to remove the slime. The scales were then dried and stored in small envelopes with the morphometric data, including total length, standard length and weight of the fish, being recorded. Annuli rings on the scales were counted using a Zeiss light microscope. The methods of Gerber et al. (2009) were used to age the scales. One growth ring (annulus) was assumed to represent one year. The rings were counted along the scale surface

from the nucleus towards the outer edge. A ring was considered as an annulus if the ring was continuous throughout the scale (Figure 2). Two replicate annuli readings were taken for each scale, producing a total of four readings taken for one fish by the same reader.

2.4 | Fish ageing based on otoliths

From a total of 892 caught fish, the otoliths from 602 fish were sampled and analysed. The other 290 otoliths were not read because of being damaged during the removal stage. The left and the right lapillus otoliths were removed and soaked in distilled water for 48 h. One growth ring was assumed to represent 1 year. A growth ring was counted if it was comprised of an alternating pair of opaque and hyaline zones that were continuous around the otolith. Rings that were not continuous, and which lay between two continuous rings, were considered false rings. Because otolith bands are formed over a period of time, the outer edge was not accepted as a growth zone. Two replicate annuli readings were taken for each otolith, resulting in a total of four replicate readings taken for each fish by the same reader.

FIGURE 2 Image of lateral line scale extracted from *Hydrocynus vittatus* specimen in Sanyati Basin of Lake Kariba (white dots represent growth zones)

2.5 | Accuracy and precision of otolith interpretation

Precision was determined by calculating the coefficient of variation (CV) and the average percentage error (APE) between readings of the otoliths and scales. The APE was calculated using the formula of Beamish and Fournier (1981), as follows:

$$\text{APE} = \frac{1}{R} \sum_{I=1}^{R} \frac{(X_{ij} - X_j)}{X_J} \times 100 \tag{1}$$

where X_{ij} = ith age determination of the jth fish; X_j = average age calculated for the jth fish; and R = number of times each fish is aged. The average APE was then computed across all j fish. The coefficient of variation was calculated as the ratio of standard deviation over the mean (Campana, 2001). The average CV was also computed across all j fish. The formula by Campana (2001) was used to calculate the coefficient of variation.

2.6 | Data analysis

The von Bertalanffy growth models were used to calculate the length-at-age data. The difference in ages obtained using the two different methods was assessed using Bowker's test (Hoenig et al., 1995). For this latter method, a chi-square (χ^2) test is used to determine whether the number of fish assigned age k using method 1 and m using method 2 differs from the number of fish

assigned age m using method 1 and k using method 2 (Chifamba & Videler, 2014). The analysis of growth parameters and length at age of *H. vittatus* were estimated using the FiSAT II (FAO–ICLARM Stock Assessment Tools) version 1.2.2 software (Gayanilo et al., 2005). The *H. vittatus* growth rate was determined using FiSAT II. A paired *t*-test was used to calculate differences in sex ratios between the different sampling months for assessment of the population characteristics.

3 | RESULTS

3.1 | Comparison of age estimates based on analysis of scales and otoliths

The numbers of fish assigned particular ages using scales and otoliths are summarized in Table 1. Ages based on scales versus otoliths of *H. vittatus* agreed to a larger extent for fish aged from one to four years than for fish older than 4 years. There was a significant difference ($p < .05$) in the ages obtained from scales and otoliths analysis for fish older than 4 years. This also is highlighted in Figure 3, which illustrates that there are many outliers and much scatter in the data for fish older than four years in age. Most of the age estimates obtained from otoliths were in some cases similar, whereas in other cases, the growth zones differed by at most two growth zones. However, this was not the case for scales, with most of the age estimates obtained from scales differing by up to five growth zones. Comparing the relative age estimates obtained from scales and from whole otoliths, it was found the scales overestimated the age of fish with more than eight growth zones. In regard to the precision of the data, the age data obtained from analysis of the whole otoliths were significantly more precise than for the data from analysis of scales.

The APE and CV were found to be 6.0% and 8.1% for whole otoliths, respectively, for the present study. The APE and CV for scales were 13.8% and 17.4%, respectively.

The age data for the whole otoliths exhibited a better fit to the von Bertalanffy growth curve. The age data from otoliths exhibited relatively few outliers and less scatter (Figure 4). The parameters for the von Bertalanffy growth curve were (L-infinity = 682.5; k = 0.53; t_0 = 3.19). These parameters are almost similar to those observed by Mhlanga (2001), although the latter author used a different method of ageing tigerfish in Lake Kariba.

4 | DISCUSSION

The objective of the present study was to estimate the ages of tigerfish in the Sanyati Basin, Lake Kariba, based on analysis of their scales and otoliths, as well as comparing the two methods in terms of accuracy. The Bowker's test indicated a statistically significant difference in ages obtained from scales and otoliths for fish older than four years. According to Chifamba and Videler (2014), this is a common problem in ageing fish since estimates of age based on different

TABLE 1 *Hydrocynus vittatus* assigned to different ages in Sanyati Basin of Lake Kariba, based on scales and otoliths (numbers where ages agree shown in bold type)

	Otolith age													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Scale age														
0	**48**													
1		**29**	9											
2			**63**											
3			12	**37**			0							
4				9	**26**	6	18							
5				5	0	**8**	6		10					
6				13	15	22	**24**		9					
7					8		0	**3**	0					
8							6	19	**6**	17		15		
9							14	11	7	**0**	14	0		
10								17	8	9	**23**	12		
11												**6**		
12													**11**	6
13													7	**14**

body structures often give different results for older fish. This problem has resulted in difficulties for researchers to determine accurate ages as the fish grow, thereby introducing ageing error (Campana, 2001). In this study, the otoliths gave lower age estimate than scales from age five in the present study, suggesting greater difficulty in reading ages from otoliths for older fish because of an increased number of growth zones.

The number of unreadable otoliths was indicative of problems in using whole otoliths. Otolith readability can be improved by sectioning or grinding prior to reading, thereby enabling the ageing of older fish compared to whole otoliths (Campana, 2001; Gerber et al., 2009). Taylor and Weyl (2012) found that sectioned otoliths of *M. salmoides* were more readable and gave more precise age readings than whole otoliths. Sectioned otoliths of *Oreochromis andersoni* gave more reliable readings than did scales (Booth et al., 1996). Thus, future *H. vittatus* studies in Lake Kariba should use sectioned otoliths to reduce bias in the age estimates.

The asymptotic length and growth constant observed in the present study were different from those obtained by previous Lake Kariba researchers. These differences can be attributed to the different localities in which the previous studies were conducted. Another factor that could have contributed to these differences is that the value of the asymptotic length is dependent on the largest size of fish caught, meaning that the asymptotic length will be smaller when the larger fish are not caught (Mhlanga, 2001).

According to Campana (2001), the ideal APE and CV values are 5.5% and 7.6%, respectively. The APE and CV were found to be 6.0% and 8.1% for whole otoliths, respectively, in the present study, while the APE and CV for scales were 13.8% and 17.4%, respectively. As indicated by these figures, the APE and CV values for whole otoliths were closest to the values determined by Campana (2001). Based

on the APE and CV values obtained in the present study, it can be concluded that whole otoliths were the most precise of the ageing methods used herein to estimate the age of tigerfish in Lake Kariba, whereas scales were less precise.

Dwyer et al. (2003) found the age data obtained through the use of otoliths of *Argyrozona argyrozona* fitted the three-parameter von Bertalanffy growth model better than those from the use of whole scales. This was also found to be true for tigerfish in the present study, wherein whole otolith relative age data best fitted the von Bertalanffy growth model. However, the scales relative age data did not fit the von Bertalanffy growth model, resulting in many outliers and much data scatter. Further, Booth et al. (1996) also found that, compared to scales, otoliths were more accurate for age estimation and fitted the von Bertalanffy model better for *O. andersonii* since scales tended to over emphasize the fish growth. Booth et al. (1996) and Kimura et al. (2006) agreed that the most suitable hard tissues for age determination are otoliths, particularly for tropical and subtropical freshwater fish species.

Ding et al. (2011) reported that whole and sectioned otoliths produced consistent ages until fish were of age six, and that there was a trend towards greater differences between the two methods with increasing age. In comparing the characteristics of whole and sectioned otoliths, they concluded the primary reason that whole otoliths led to underestimated ages for older individuals were that the surface of the central area of the whole otoliths is calcareous, so some annuli near the focus will be obscured and miscounted. They also concluded that whole otoliths require much less time for analysis than sectioned ones and may be used for rapidly growing fish.

In their comparison of use of scales and whole otoliths to estimate the age of whitefish *Coregnous lavaretus*, Skurdal et al. (1985) concluded the estimates of age obtained by reading scales were
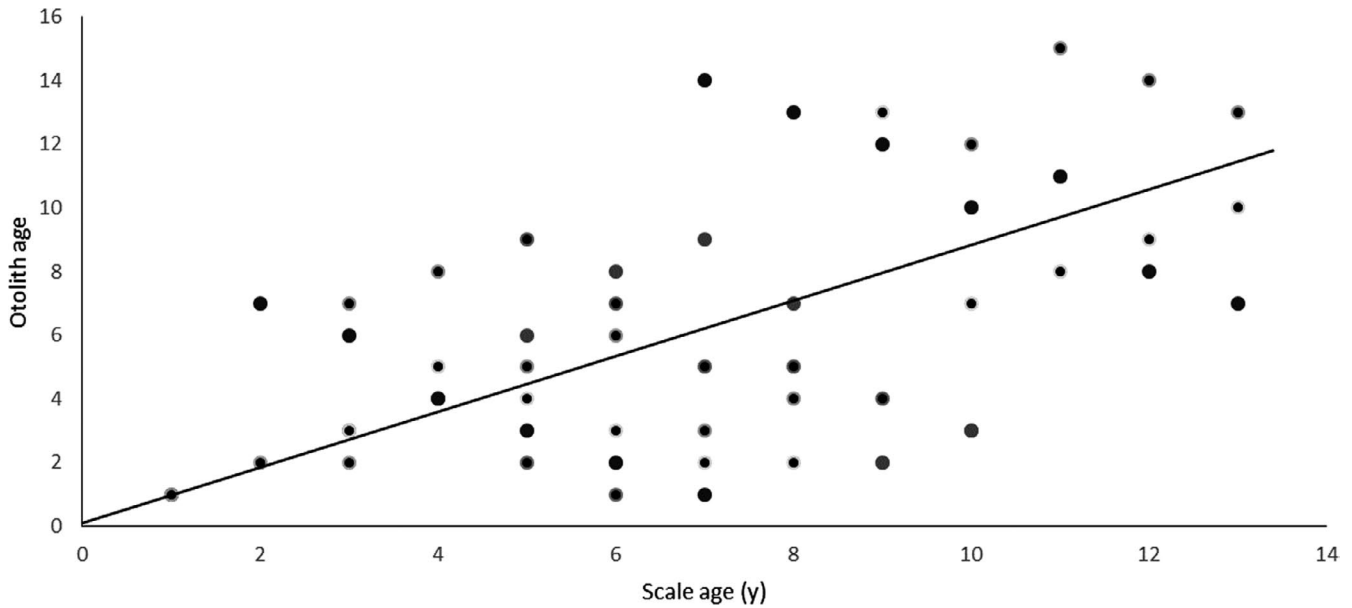
FIGURE 3 Scatter plot of *Hydrocynus vittatus* ages for whole otolith age vs. scale ages (solid line indicate 1:1 relationship)
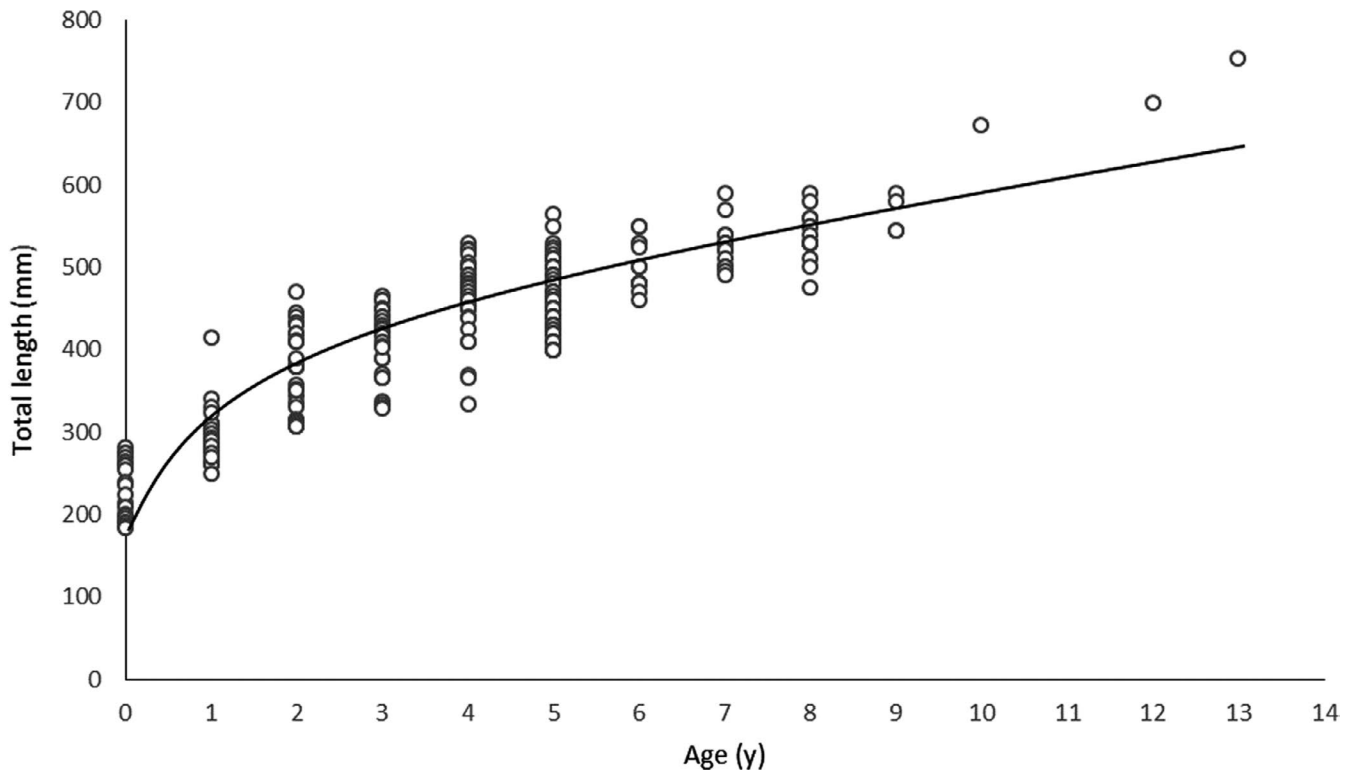

FIGURE 4 Size at relative age data for whole otoliths of *Hydrocynus vittatus* in Sanyati Basin of Lake Kariba, Zimbabwe (dotted line indicates von Bertalanffy growth models fitted to study data)

lower than those obtained by reading whole otoliths. Because whole otoliths gave more accurate age readings than scales, they recommended they be used for ageing *C. lavaretus*. They also argued that reading whole otoliths gave results almost identical to those obtained by reading burnt and cracked otoliths, although the estimates obtained with the latter method were slightly higher than those obtained by the former method, with this difference increasing with

increase age of the fish. Other age determination studies have indicated whole otoliths are suitable for ageing fish up to a certain point. Otolith-derived age estimates were found to be more precise in ageing in a study on whitefish in North America, while scale-derived age estimates showed a significant positive bias for fish younger than age six and a significant negative bias for fish older than six years of age (Booth & Merron, 1996). Booth and Merron (1996) and Kimura

et al. (2006) agreed the most suitable hard tissues for age determination are otoliths, particularly for tropical and sub-tropical freshwater fish species.

According to Balon (1974), who studied the early evolution of Lake Kariba, tigerfish is one of the most important fish species in Lake Kariba because of its high occurrence in gillnet catches, as well as its attractiveness to anglers. This was also confirmed in the present study. Balon (1974) observed that tigerfish reach 14–18 cm in length in the first year and 25 cm in the second year. He further observed that specimens of up to seven years of age covered the main age range of the fish species in Lake Kariba, and that the 0-IV age group represented as much as 72% of the total fish sampled. His observations are different from those in the present study wherein tigerfish reached 9–16 cm in the first year and 18–22 cm standard length. It was also observed in the present study that specimens of up to five years in age covered the main age range of tigerfish in the Sanyati Basin of Lake Kariba.

A large variety of length groups was observed in the present study, indicating five different year classes. The present study also observed that male tigerfish dominate the 100–400-mm size class, while the females dominated the 400–700-mm size class. This finding is consistent with those reported by other researchers who noted female tigerfish grew larger than male tigerfish. The different age groups observed in the present study indicate that, although the fish are stressed, recruitment is still occurring in the population. The largest specimens sampled were females (4–7 kg), and they were

assigned relative ages ranging from 7 to 13 years using whole otoliths. The two largest specimens caught in the present study were females weighing 6.89 and 6.07 kg. They were aged at 13 and 12 years, respectively (Figure 5). In recent studies in Zimbabwe, the largest specimens sampled by Winemiller and Kelso-Winemiller (1994) were two females weighing 7.1 kg (710-mm SL) and 5 kg (650-mm SL). These fish were aged at 11 and 9 years, respectively. It should be noted, however, that these two studies used scales for ageing the fish. Compared to tigerfish otolith age data from other water bodies, it can be noted that the ages obtained in the present study are in range with those observed in the past. The largest tigerfish specimens sampled by Gerber et al. (2009) in the Okavango Delta were between 5 and 8 kg and were assigned relative ages of 9–16 years using sectioned otoliths. The observed differences can be attributed to several factors, including the type of gear used in sampling and the productivity of the different systems. The rapid growth rate and huge size of tigerfish in the Okavango could be facilitated by the large quantity of food available on the floodplain (Gerber et al., 2009).

Based on the results of the present study, it can be concluded that whole otoliths in this case were the better method of ageing tigerfish from Lake Kariba. It is recommended, therefore, that scales not be used when ageing fish older than four years, and that they be stored for short periods for processing and reading them for age. Nevertheless, more work on the use of sectioned otoliths for ageing Lake Kariba tigerfish is warranted, as also
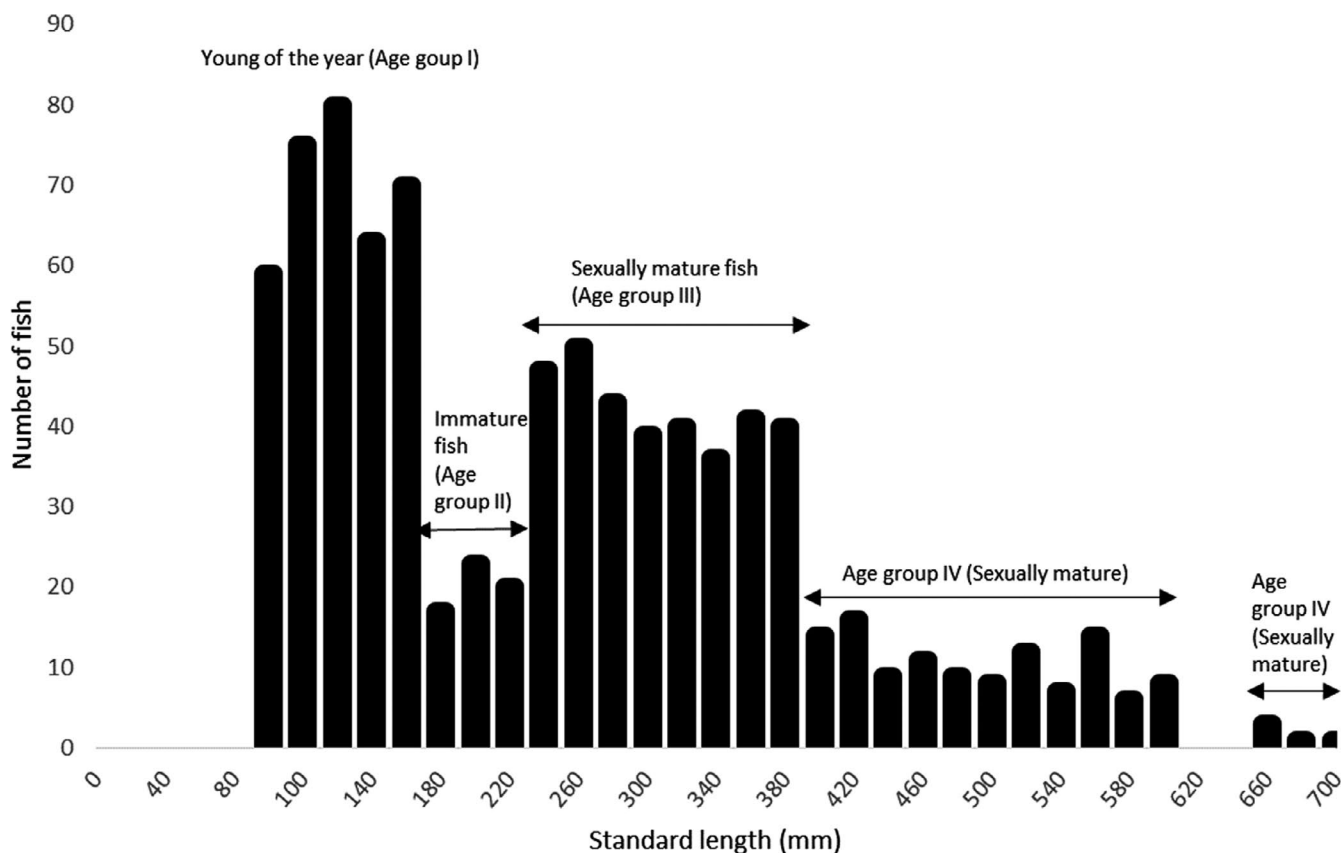

FIGURE 5 Length frequency analysis of *Hydrocynus vittatus* in Sanyati Basin of Lake Kariba, Zimbabwe

recommended by other researchers that have worked on tigerfish ageing in other waterbodies. Future research should also focus on validating the formation of the first otolith growth ring by collecting and analysing otoliths from juveniles at short intervals. Future studies should also validate the number of growth rings formed per year in otoliths.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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