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Age and growth and maturity of southern Africa's largest cyprinid fish, the largemouth yellowfish *Labeobarbus kimberleyensis*

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The aim of this study was to use specimens of the largemouth yellowfish *Labeobarbus kimberleyensis,* southern Africa's largest cyprinid [IUCN red-listed as Near Threatened (NT)], obtained from gillnet by-catch to describe aspects of its biology in order to assist future conservation and management decisions. Ninety three *L. kimberleyensis* were collected between March 2007 and May 2008 from Lake Gariep, South Africa. *Labeobarbus kimberleyensis* was present in 38% of all gillnet catches, but in low numbers (2% of the catch) and it contributed 8% to the catch by mass. Age was estimated using astericus otoliths. Growth increment formation on these otoliths was validated as annual using edge analysis and the mark-recapture of chemically tagged captive fish. Resultant analysis showed that the species is slow growing and the oldest aged fish was a 17 year, 690 mm fork length (L_F) male. The smallest ripe female fish measured 394 mm L_F and was 7+ years old and the smallest mature male was 337 mm L_F and 5+ years old. Slow growth and late maturity make this species vulnerable to exploitation emphasizing the need for continued high conservation priority.

Key words: edge analysis; impoundment; life history; otolith; validation.

INTRODUCTION

Large fishes often suffer population declines as a result of human mediated impacts such as habitat degradation and fishing (Allan *et al.,* 2005; Olden *et al.,* 2006). The largemouth yellowfish *Labeobarbus kimberleyensis* (Gilchrist & Thompson 1913) is southern Africa's largest cyprinid. It is endemic to the Orange and Vaal River system and attains 825 mm fork length (L_F) and a mass of 22·2 kg (Skelton, 2001). Although widespread throughout its native range, it is nowhere abundant (Mulder, 1973; de Villiers & Ellender, 2007) and is regarded as a high conservation priority species (de Villiers & Ellender, 2007; Granek *et al.,* 2008) that has been assessed as 'Near Threatened' by the IUCN (IUCN, 2010).

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Although this species is categorized as 'Near Threatened' because of habitat degradation and pollution (IUCN, 2010), angling and illegal gillnetting may also be negatively affecting *L. kimberleyensis* populations (Granek *et al.,* 2008). Globally, severe population declines of other large cyprinid species have been attributed to both habitat degradation and exploitation (Jackson, 1989; Skelton *et al.,* 1991; Bhatt *et al.,* 2000; de Graaf *et al.,* 2004, 2006; Olden *et al.,* 2006). Such declines are most probably a result of low population recovery rates that are a consequence of the slow growth rates, long life span and late maturity common to this group of fishes (Skelton *et al.,* 1991; Winemiller, 2005; Olden *et al.,* 2006).

Understanding the life history of *L. kimberleyensis* is therefore important for developing effective conservation measures for this 'Near Threatened' fish. Unfortunately, little is known about its biology and life history (de Villiers & Ellender, 2007), and what is known, is based on the results of three biological studies (Mulder, 1973; Hamman, 1981; Tómasson *et al*., 1984). This information proved largely deficient because inadequate gear selection typically resulted in small sample sizes that constrained life-history assessments. More recently, life-history assessments requiring directed sampling are no longer possible because of the high conservation status of this species. As a result, such assessments can only be based on specimens obtained from non-directed sampling events *e.g.* when *L. kimberleyensis* are caught as by-catch during fisheries assessments.

During an assessment to determine the feasibility of developing a gillnet fishery in South Africa's largest impoundment, *L. kimberleyensis* constituted a small by-catch. These specimens provided a unique opportunity to undertake a biological assessment of this large cyprinid. The purpose of the present study was therefore to use these specimens to describe aspects of the biology of *L. kimberleyensis* to contribute knowledge upon which to base future conservation and management decisions.

MATERIALS AND METHODS

Labeobarbus kimberleyensis samples used in this study were unintentional by-catch during gillnet surveys undertaken as part of a National Research Foundation of South Africa funded 'Assessment of the fishery of Lake Gariep with particular reference to the development of a decision-making tool for obtaining optimal social and economic benefit from harvests' (National Research Foundation, 2009). These surveys were conducted between March 2007 and May 2008 (Ellender, 2008; Winker, 2010) in Lake Gariep (30° 38·703′ S; 25° 46·998′ E), a 360 km^2 large impoundment situated on the Orange River system in central South Africa (Fig. 1). The surveys were conducted bi-monthly using a fleet of five, 45 m long gillnets that were constructed of six ply, multifilament, green, nylon netting that was hung at a 50% height:width ratio. Each gillnet comprised five randomly positioned panels (9 m long × 3 m deep) with stretched mesh sizes of 47, 65, 77, 105 and 152 mm. Nets were set overnight (*c*. 1800–0600 hours), parallel to the shoreline at a depth of *c*. 3 m to ensure that all mesh sizes were set at a similar depth. The following morning, fish were removed from the gillnets. Most *L. kimberleyensis* were dead upon removal from the gillnets, those fish still alive were too damaged to return into the wild and were euthanized by a sharp blow to the head followed by destruction of the brain.

All fishes caught in gillnets were separated by species and mesh size and weighed. The relative abundance of fishes from the gillnets was expressed using the index of relative importance (I_{RI}) (Kolding, 1998) such that: $I_{RI} = (\%N + \%M)\%F$, where $\%N$ and $\%M$ are the percent number and mass of each species of total catch, and $\%F$ is the percent frequency of occurrence per gillnet per night (% of all net nights containing a given species).

FIG. 1. Lake Gariep gillnet sampling sites ⊙ (2007–2008) centred around the two launch sites, which are the only access points along the lakeshore. —— represents fishing areas.

To provide a measure of the vulnerability of *L. kimberleyensis* to different gillnet mesh sizes, catch-per-unit-effort (CPUE) was calculated as mean kg per mesh size per gillnet night (kg mesh^{-1} night^{-1}). As is often the case, the CPUE data were right-skewed and contained many zero catches (Maunder & Punt, 2004). In such situations, a bias corrected estimate for the mean CPUE (y) is given in form of Δ-lognormal distribution (Aitchison, 1955; Smith, 1990): $y_i = P_{\text{Ci}}\, \mathrm{e}^{(\ln y_{\text{posi}} + 0{\cdot}5\sigma^2)}$, where P_{Ci} is the probability of capturing *L. kimberleyensis* in mesh size i, $\ln y_{\text{posi}}$ is the mean of the ln-transformed positive catches and σ is the S.D. associated with $\ln y_{\text{posi}}$. The 95% C.I. for the expected mean CPUE per mesh size were estimated using a non-parametric bootstrap procedure (Efron, 1982) based on 1000 iterations. Effort units were standardized to net night^{-1} for gillnets.

For biological analysis, all *L. kimberleyensis* in the catch were measured to the nearest mm L_{F} and weighed to the nearest 0·1 g (M_{T}). Fish were then dissected, sexed and the gonads were visually assigned a stage of maturity according to the criteria outlined in Weyl *et al.* (2009). The gut was removed and the eviscerated mass (M_{E}) of the fish was recorded. The astericus otoliths were removed and stored for later examination.

Fish were considered mature if individuals had gonads in the developing, ripe, ripe and running or spent stages. The L_{F} at which 50% of males and females attain maturity (L_{F50}) was calculated by grouping mature and immature specimens into 50 mm L_{F} classes and fitting a two parameter logistic ogive model as $\psi = [1 + e^{-(L_{\text{F}} - L_{\text{F50}})\delta^{-1}}]^{-1}$, where ψ is proportion of mature fish per L_{F} class and δ describes the width of the logistic ogive. Maximum likelihood estimates of L_{F50} and δ were obtained by minimizing the negated binomial log-likelihood function and a likelihood ratio test (Cerrato, 1990) was applied to test for significant difference between sexes.

Otoliths were read whole, immersed in methyl-salicylate, and viewed using a dissecting microscope under transmitted light at various magnifications (×10–40) as outlined in Winker *et al.* (2010*a*, *b*). Growth zones were visible as alternating pairs of opaque and translucent zones. Growth zone interpretation was conducted according to the procedure outlined by Weyl *et al.* (2009). On each otolith, the pairs of opaque and translucent growth zones were counted twice at an interval of 14 days. If reading one and two were the same then the age estimation was accepted, if the readings differed, a third reading was done. After the third reading, those readings that were the same as either reading one or two were accepted. The median was taken for readings that differed by up to two otherwise they were rejected.

The accuracy of age estimation was validated by two methods: (1) edge analysis and (2) mark-recapture of chemically tagged captive fish as described for smallmouth yellowfish *Labeobarbus aeneus* (Burchell 1822) by Winker *et al*. (2010*a*). For edge analysis, the optical appearance of the outer margin of otoliths from fish samples collected on a bi-monthly basis was examined and its appearance (*i.e.* opaque or translucent) recorded. Subsequent analysis was based on the assumption that the relative frequency of opaque (or translucent) edges follows a periodic cycle when plotted against month of capture (Campana, 2001).

For the mark-recapture of chemically tagged captive fish, *L. kimberleyensis* were treated using identical methods to those employed for three other large cyprinids from this locality (Winker *et al*., 2010*a*, *b*). Due to the rarity and 'Near Threatened' status of *L. kimberleyensis,* only two wild-captured individuals from the Orange River, immediately below the dam wall were used for the study. These were injected with 60 mg kg^{-1} fish mass oxytetracycline hydrochloride solution (OTC; HiTet 120; Bayer; www.bayer.com) and placed in 40 m long × 20 m wide × 1 m deep earthen ponds in March 2007, kept under ambient conditions, and recaptured in May 2008. The ponds were located at the Lake Gariep State Fish Hatchery *c*. 3·2 km below the dam wall. Subsequent observation of the number of zones laid down between the fluorescent mark deposited on the otolith at the time of tagging and the margin of the otolith were then used to determine the periodicity of growth zone deposition.

The precision of age estimation was calculated using the average percent error method (Beamish & Fournier, 1981) and coefficient of variation (CV) method (Chang, 1982). Age and growth data were fitted with the von Bertalanffy growth model (VBGF): $L_t = L_\infty (1 - e^{-K(t-t0)})$, where t_0 is the theoretical age at zero length, L_∞ is the predicted asymptotic length (mm L_F) and K is the Brody growth co-efficient (Ricker, 1975). A likelihood ratio test was used to test for differences in growth rates between sexes at a significance level of $P \leq 0{\cdot}05$ (Cerrato, 1990).

Available von Bertalanffy growth parameters and minimum L_F at maturity for *L. kimberleyensis* were compiled from the literature. As populations with different growth parameters may have similar growth performances due to the interaction and dependence of K and L_∞, the growth performance index Φ' was calculated as $\Phi' = \log K + 2 \log L_\infty$ (cm L_F) to allow for comparisons among populations (Pauly & Munro, 1984).

RESULTS

Labeobarbus kimberleyensis was a frequent by-catch in experimental gillnets, occurring in 38% of the 144 gillnet sets, but only contributed a small percentage to the overall number and biomass of the total catch, which resulted in a low I_{RI} for this species (Table I). Individual fish were large (mean ± S.D. 1·6 ± 0·2 kg) and specimens were most efficiently caught by the two largest gillnet mesh sizes (105 and 152 mm) (Fig. 2). The CPUE by mass increased exponentially with mesh size ranging from 0·005 (95% C.I. = 0·005–0·006) kg mesh^{-1} night^{-1} in the 67 mm mesh to 0·7 (95% C.I. = 0·272–0·311) kg mesh^{-1} night^{-1}in the 152 mm mesh (Fig. 2).

Ninety-three *L. kimberleyensis* (100–692 mm L_F) were used for biological analysis, of these 45 were females; 42 were males, five were juveniles of indeterminate sex and one fish was not sexed. Sex ratio did not differ significantly from unity (d.f. = 1, $\chi^2 = 0{\cdot}05$, $P > 0{\cdot}05$). Linear regression t-tests of the ln-transformed L_F and M_T relationships showed no significant differences between males and females (intercepts: $P > 0{\cdot}05$, slopes: $P > 0{\cdot}05$). The data were therefore pooled and the combined L_F and M_T and M_E described as $M_T = 0{\cdot}000003\ L_F\ (\text{mm})^{3{\cdot}27}$ ($r^2 = 0{\cdot}98$) and $M_E = 0{\cdot}000003\ L_F\ (\text{mm})^{3{\cdot}217}(r^2 = 0{\cdot}98)$.

Only eight ripe female and 15 ripe male *L. kimberleyensis* were recorded during the study period. The smallest ripe female was 394 mm L_F and 6 years old and

TABLE I. Relative abundance of fishes from Lake Gariep gillnet catches by number (N), mass (M), frequency of occurrence (%F) and the index of relative importance (I_{RI})

Species	N	% N	M (kg)	% M	% F	% I_{RI}
Clarias gariepinus	43	1	128	7	24	1
Cyprinus carpio	102	3	82	5	34	2
Labeo capensis	2234	61	733	42	98	61
Labeo umbratus	37	1	21	1	17	0
Labeobarbus aeneus	1189	32	661	38	81	34
L. kimberleyensis	78	2	133	8	38	2
Total	3683	100	1757	100	292	100

the smallest recorded ripe running male was 337 mm L_F and 5 years old. Ripe running fish were only sampled between November and January (Table II). A likelihood ratio test showed that L_{F50} differed significantly between sexes ($\chi^2 = 11{\cdot}12$, d.f. = 2, $P < 0{\cdot}05$), with males maturing at a smaller size ($L_{F50} = 392$ mm, $\delta = 17{\cdot}9$) than females ($L_{F50} = 518$ mm, $\delta = 13{\cdot}6$). The corresponding ages-at-50%-maturity were estimated at 6·4 years for males and 9·0 years for females (Fig. 3).

Otoliths from all fish were used for age estimation. Edge analysis indicated a unimodal distribution of the frequency of opaque and translucent zones through the year (Fig. 4). Only one of the two chemically tagged fish was recaptured 426 days after tagging. This fish had deposited a single growth zone distal to the clearly

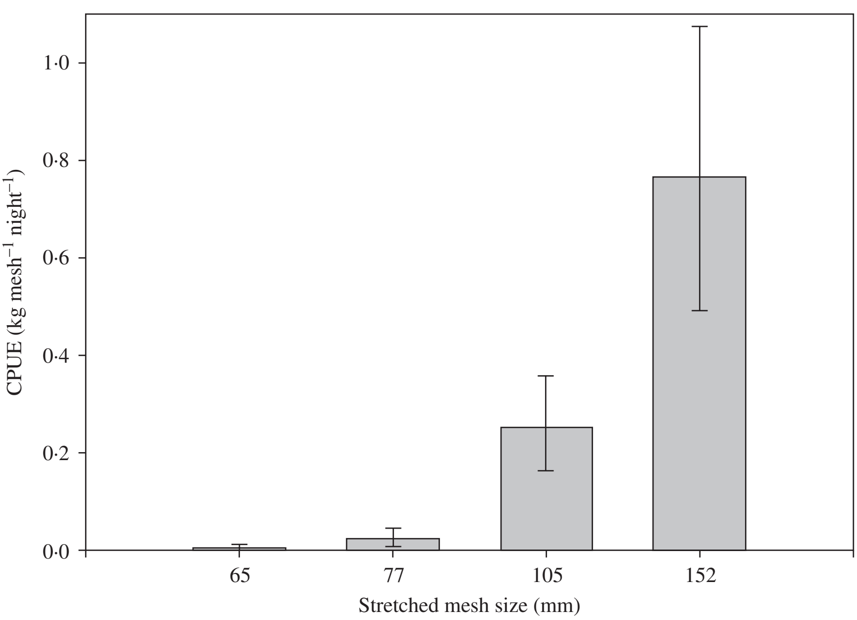

FIG. 2. Mean ± 95% C.I. gillnet catch per unit effort (CPUE) per mesh size for *Labeobarbus kimberleyensis* by mass (■) from Lake Gariep (2007–2008), illustrating the vulnerability of the species to larger mesh sizes.

TABLE II. Monthly numbers of male (M) and female (F) *Labeobarbus kimberleyensis* in each gonad developmental stage from Lake Gariep (2007/2008)

	Immature		Developing		Ripe		Ripe running		Spent	
Month	F	M	F	M	F	M	F	M	F	M
January	6	3	2	1	1	1	1	4		1
March	1	1								1
April			1	1						
May	3	1	4	1	1	1			1	3
June	6	8	2						1	1
August			1							
October	2	4	3	1	2	1				
November	3	2		2		1	1	3		
December	1				2					

visible fluorescent mark (Fig. 5). These results indicate that one opaque and one hyaline zone were deposited each year and growth zones were therefore validated as annuli.

Otoliths were available for 87 fish. Of these, only one was rejected as unreadable. The average percent error between readings was 3·7% and the C.V. was 5·1%. Growth differed significantly between sexes ($\chi^2 = 13{\cdot}31$, d.f. $= 3$, $P < 0{\cdot}05$). Ages ranged from 2 to 17 years for males and 4 to 14 years for females (Table III). The oldest *L. kimberleyensis* aged during this study was a 17 year old 690 mm L_F male (Fig. 6). The L_F at age was described by the von Bertalanffy growth equation as $L_t(\text{mm}) = 837(1 - e^{-0{\cdot}08(t=-1{\cdot}60)})$ for males and $L_t(\text{mm } L_F) = 978(1 - e^{-0{\cdot}07(t=-1{\cdot}20)})$ for females. The growth curve fits illustrated in Fig. 6 suggest that L_F-at-age was adequately described by the von Bertalanffy growth model.

A summary of data from this study and previous age and growth studies on *L. kimberleyensis* is presented together with minimum lengths- and ages-at-maturity in Table III. Growth performance showed little variation among *L. kimberleyensis* populations ($\Phi = 2{\cdot}60-2{\cdot}87$), indicating that growth performances were comparable with previous studies.

DISCUSSION

Understanding the life history of threatened fishes is important because species with delayed maturity and long life spans have longer generation times due to low potential rates of population increase and are therefore more vulnerable to population declines than early maturing, short lived fishes (Winemiller & Rose, 1992). The rarity or high conservation status of large fishes often precludes the collection of sample sizes necessary for the comprehensive analyses required to provide the validated age estimates that are essential for understanding these key biological aspects. In this study, the availability of specimens caught as by-catch provided a unique opportunity to undertake an age-based assessment of the life history of southern Africa's largest cyprinid.

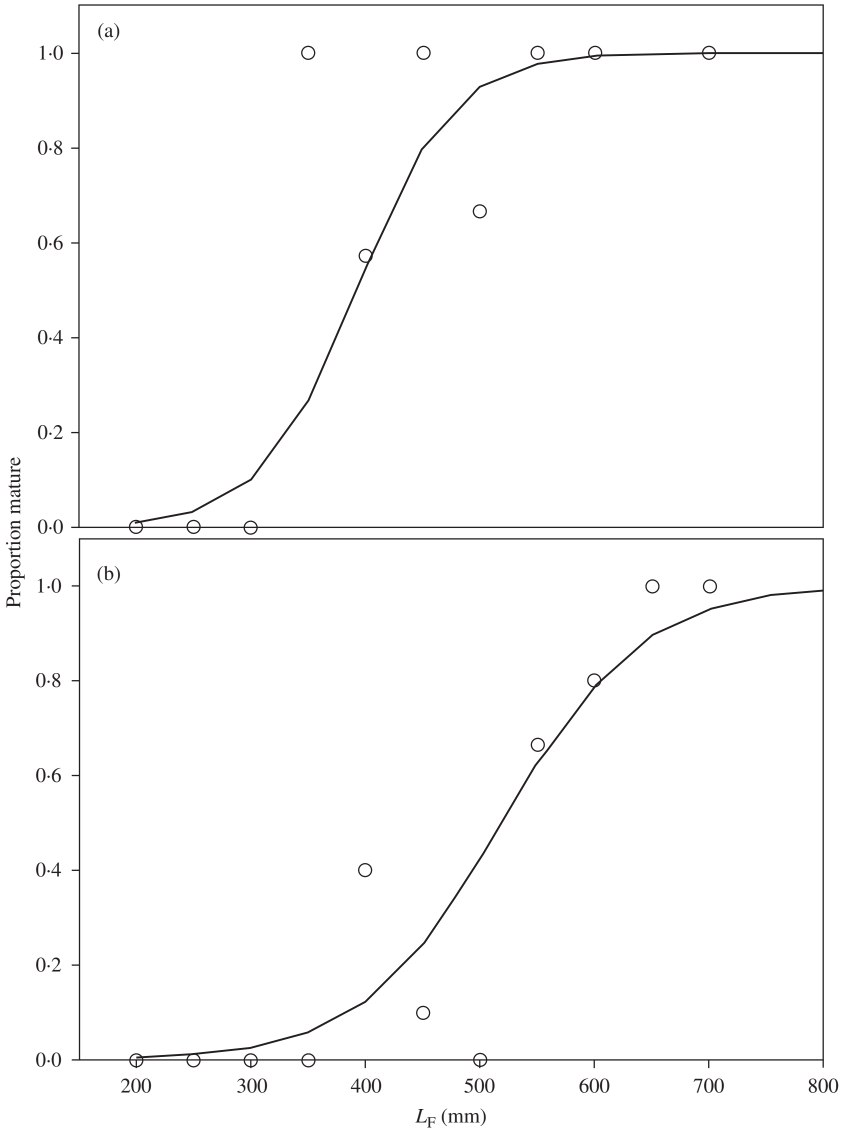

Fig. 3. Fork length (L_F) at 50% sexual maturity (L_{F50}) for *Labeobarbus kimberleyensis* (a) females ($n = 31$) and (b) males ($n = 32$) from Lake Gariep (2007–2008). Open circles denote observed length and the solid line predicted length.

Results from previous age validation studies conducted on three other large cyprinids from Lake Gariep showed that growth zone deposition rate was annual for the two native species *L. aeneus* and Orange River mudfish *Labeo capensis* (Smith 1841), but biannual for non-native *Cyprinus carpio* L. 1758 (Winker *et al.,* 2010*a*, *b*). These two studies demonstrated that deposition rates can vary not only among species but also among populations (Winker *et al.,* 2010*a*, *b*). Fortunately, sufficient *L. kimberleyensis* were available to allow for the validation of growth

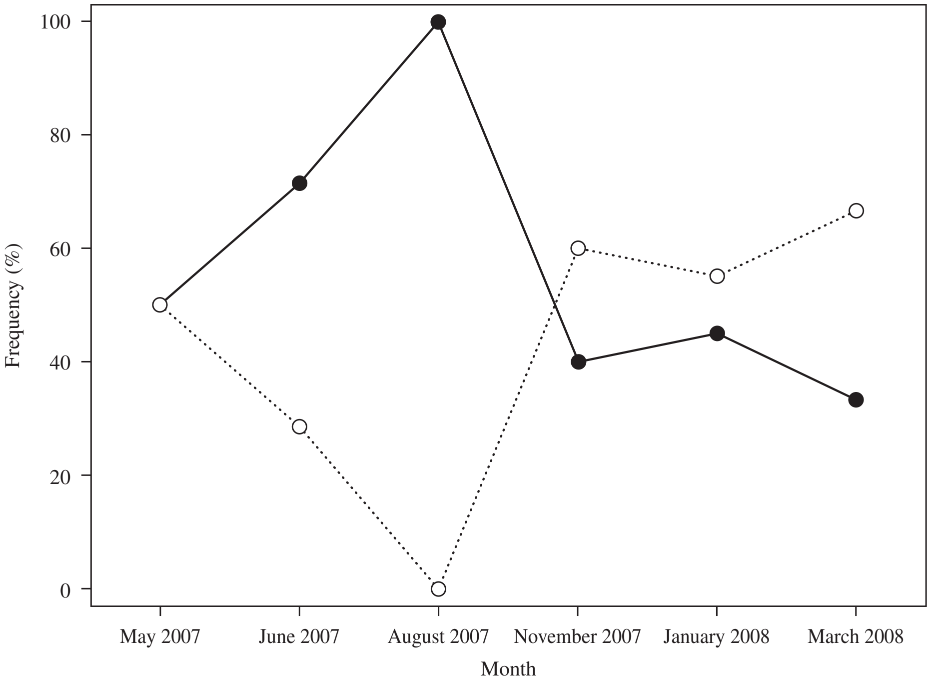

FIG. 4. The monthly percent occurrence of opaque (●) and translucent (○) zones on the otolith margin of *Labeobarbus kimberleyensis* sampled from Lake Gariep ($n = 87$) (2007–2008).

zone deposition rate using both edge analysis and the mark-recapture of a chemically tagged captive fish. The deposition of a single pair of growth zones on an annual basis agrees with that of its congener *L. aeneus* from Lake Gariep (Winker *et al.,* 2010*a*) and elsewhere (Weyl *et al.,* 2009).

The growth rate of *L. kimberleyensis* in Lake Gariep was similar to that from other, non-validated, scale-based estimates in both riverine (Mulder, 1973) and lacustrine (Hamman, 1981; Tómasson, 1983) environments in South Africa (Table III), despite only a few large (>500 mm L_F) *L. kimberleyensis* individuals having been aged in previous studies (Mulder, 1973; Hamman, 1981; Tómasson, 1983). The largest individual during this study was only 83% of the maximum reported L_F (825 mm L_F and 22·7 kg; Skelton, 2001). This makes it appear likely that the maximum age for this species exceeds that observed in the current study.

Similar longevity has been recorded for other large cyprinids. In the Ganga River, India, the Himalayan mahseer *Tor putitora* (Hamilton 1822) attained similar, although un-validated ages (17+ years) (Bhatt *et al.,* 2000). In Africa, the smaller *L. aeneus* has been aged to a maximum age of 12+ years (Richardson *et al.,* 2009) although recent research in the Vaal River suggests that this species may also attain ages of 19+ years (Gerber, 2010). Mulder (1973), Hamman (1981) and Tómasson (1983) all used scales to age *L. kimberleyensis*. They obtained maximum age estimates of 11 years (Hamman, 1981), 12 years (Mulder, 1973) and 14 years (Tómasson, 1983). These younger ages may, however, have been a result of a lack of fish >600 mm L_F in their samples. In addition, it must also be noted that scales have been shown

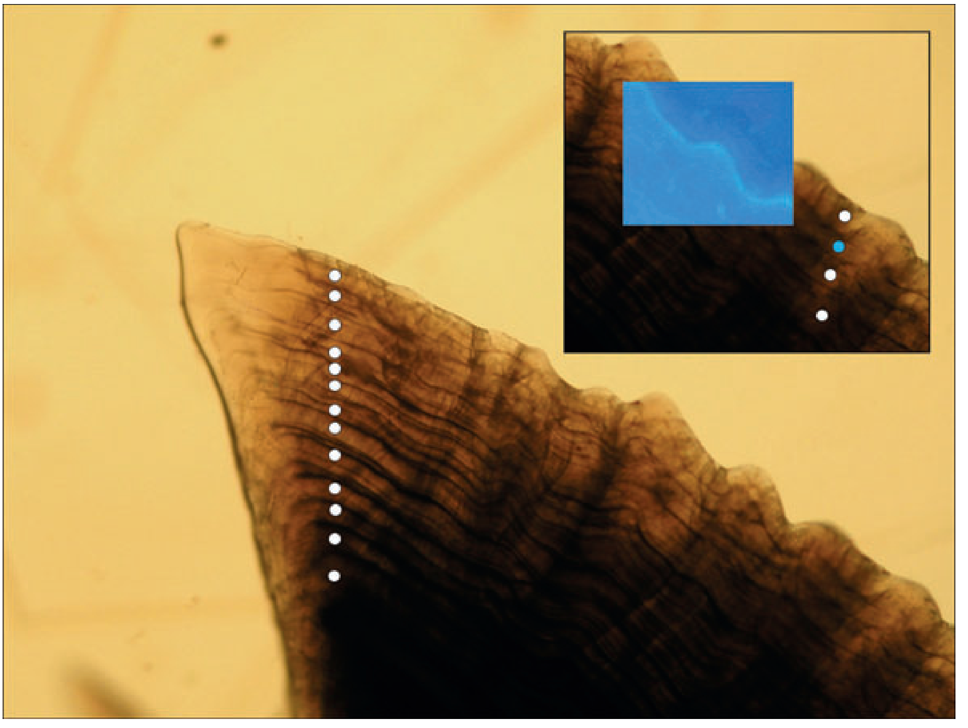

FIG. 5. Photomicrographs of a *Labeobarbus kimberleyensis* astericus otolith viewed under transmitted light. Inserts show magnified portions of the margin which is overlaid with portions of the same section viewed under fluorescent light (○, translucent zones; ●, position of the oxytetracycline mark).

to underestimate age for a variety of species (Boxrucker, 1986; Booth *et al.,* 1995; Vilizzi & Walker., 1999; Phelps *et al.,* 2007).

This study is the first to provide estimates of L_{F50} and corresponding ages-at-maturity for *L. kimberleyensis*. The species is considerably late maturing with males (L_{F50} = 392 mm; 6·4 years) maturing earlier than females (L_{F50} = 518 mm; 9 years). This corresponds to double the age-at-maturity reported for any established population of the closely related *L. aeneus* (Weyl *et al.,* 2009). The youngest mature males and females collected during this study (males = 5 years and females = 6 years) were estimated to be 2 and 1 year younger, respectively, when compared with estimates derived from the early impoundment population of Lake Gariep (Hamman, 1981), but similar to the estimate for males from the Vaal River (6·5 years) (Mulder, 1973).

The life history of *L. kimberleyensis*, like that of many other large African cyprinids (Skelton *et al.,* 1991), is characterized by slow growth rates, long life span and late maturity. Such characteristics make them vulnerable to population reducing events, and particularly to fishing. This was shown for another large cyprinid *T. putitora*, where, in an unexploited section of the Ganga River, India, old individuals (maximum age 17+) were still present, but in the exploited section of the river only younger fish (maximum age 10+) were recorded (Bhatt *et al.,* 2000).

TABLE III. Summary of von Bertalanffy growth function (VBGF) parameters (L_∞, k, t_o) and maximum (L_{Fmax}) and minimum fork length (L_{Fmin}) and age at maturity (A_{mat}) and age range data available for *Labeobarbus kimberleyensis*

Locality	Sex	Method	L_∞	K	t_0	Φ'	L_{Fmax}	L_{Fmin} (mm)	A_{mat} (years)	Age range (years)	Period
Lake Gariep[a]	Male	Otoliths	837	0·08	−1·60	2·75	692	337	4·8	2–17	2007–2008
	Female	Otoliths	978	0·07	−1·20	2·83	670	394	6·2	4–14	2007–2008
Lake Gariep[b]	Male	Scales	647	0·12	0·01	2·70	570	360	6·8	2–10	1972–1977
	Female	Scales	1108	0·06	−0·08	2·87	560	400	7·4	2–11	1972–1977
Lake Vanderkloof[c]	Male	Otoliths	553	0·13	0·03	2·60	460	—	—	1–14	1978–1979
	Female	Otoliths	639	0·11	0·10	2·65	567	—	—	1–15	1978–1979
	Male	Otoliths	556	0·16	0·20	2·69	460	—	—	1–14	1979–1980
	Female	Otoliths	630	0·14	0·20	2·74	567	—	—	1–15	1979–1980
	Male	Otoliths	512	0·22	0·39	2·76	460	—	—	1–14	1980–1981
	Female	Otoliths	574	0·18	0·38	2·77	567	—	—	1–15	1980–1981
Vaal River[d]	Male	Scales	667	0·12	0·27	2·73	463	350	6·5	1–10	1969–1971
	Female	—	—	—	—	—	622	460	—	1–12	1969–1971

Φ, growth performance index.
[a]This study.
[b]Hamman, 1981.
[c]Tómasson, 1983.
[d]Mulder, 1973.

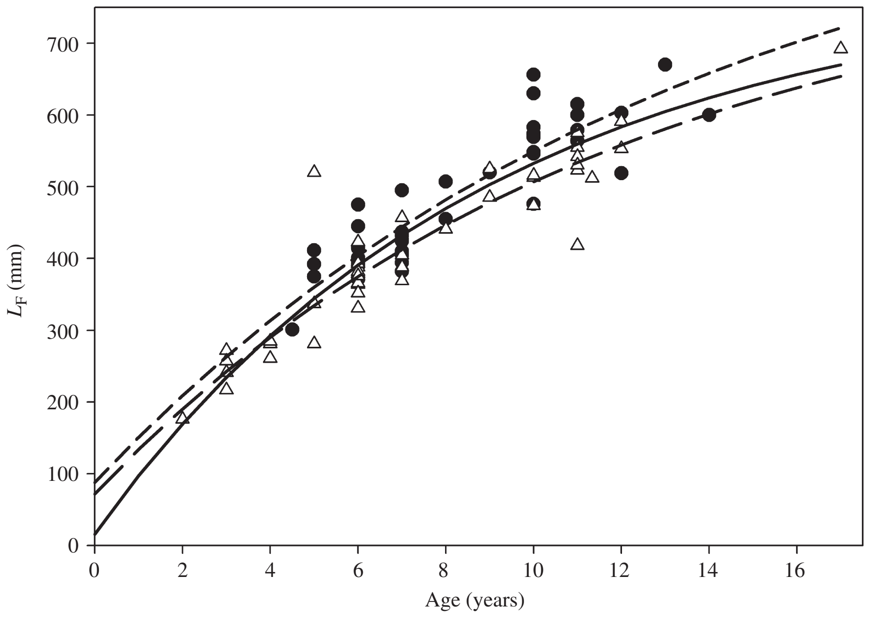

FIG. 6. *Labeobarbus kimberleyensis* sex specific, and combined von Bertalanffy growth curves illustrating observed (males = △, females = ●) and predicted (males = _ _ _, females = __ __, combined = ____) individual fork lengths (L_F) at age ($n = 87$) from Lake Gariep (2007–2008).

Although *L. kimberleyensis* is not exploited in Lake Gariep (Ellender *et al.,* 2010), it is a popular sportfish in the Vaal and lower Orange Rivers where a large recreational fishery targets this species (de Villiers & Ellender, 2007; Granek *et al.,* 2008). *Labeobarbus kimberleyensis* is a no take angling species (South African Nature Conservation Ordinance, No. 8 of 1969) and fisheries are primarily catch and release (Granek *et al.,* 2008).

South African inland fisheries are, however, increasingly being targeted for fisheries development (Andrew *et al.,* 2000; Weyl *et al.,* 2007; Richardson *et al*., 2009). While the low biomass of this fish in gillnet catches makes it an unlikely target species, results of the current study indicate that *L. kimberleyensis* will be a by-catch if a gillnet fishery is to be developed. Jennings *et al*. (1999) noted that long-lived fishes, with slow growth rates and late maturation, were vulnerable to overfishing even if not directly targeted. It is, therefore, important that the conservation importance of inland reservoirs such a Lake Gariep to *L. kimberleyensis* be considered when making fisheries development decisions.

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