Age and growth of the longfin eel, *Anguilla mossambica* Peters, 1852 (Pisces: Anguillidae) in Transkei rivers

A. McEwan and T. Hecht

Department of Ichthyology and Fisheries Science, Rhodes University, Grahamstown

Otoliths were successfully used for age determination and growth-rate calculation of the longfin eel, *Anguilla mossambica* Peters, 1852. The large opaque nucleus of the otoliths represents the leptocephalid stage and probably lasts from one and a half to two years. Thereafter, one opaque and one hyaline zone is deposited on the otoliths per year. *A. mossambica* in Transkei rivers have a slow growth rate and remain in fresh water for up to 18 years, during which they attain a maximum length of about 1 000 mm. The growth of the eels, ranging from 99–1004 mm total length, is isometric and is described by the equation L_t (mm) = 1390 $(1 - e^{-0,041\ (t+0,476)})$. The length/weight relationship is represented by W(g) = 7,143 × 10^{-4} $L(\text{cm})^{3,2998}$, and somatic growth can be expressed by the equation W_t (g) = 8418 $(1 - e^{-0,041\ (t+0,476)})^{3,2998}$

S. Afr. J. Zool. 1984, 19: 280–285

Otoliete kan suksesvol gebruik word om die ouderdom en groeikoers van die langvinpaling, *Anguilla mossambica* Peters, 1852 vas te stel. Die groot ondeurskynende nukleus word gedurende die larwale leptocephalusstadium neergelê, wat heel moontlik van een en 'n half tot twee jaar duur. Daarna word reëlmatig een ondeurskynende en een deurskynende ring per jaar neergelê. Die palings bly tot 18 jaar in varswater waar hulle lengtes van tot 1 000 mm bereik. Die groei van die palings tussen 99 en 1004 mm totale lengte is isometries en kan deur die formule L_t (mm) = 1390 $(1 - e^{-0,041\ (t+0,476)})$ beskryf word. Die lengte/gewigverhouding kan deur die vergelyking W(g) = 7,143 × 10^{-4} $L(\text{cm})^{3,2998}$ beskryf word en die groei in massa deur W_t (g) = 8418 $(1 - e^{-0,041\ (t+0,476)})^{3,2998}$.

S.Afr. Tydskr. Dierk. 1984, 19: 280–285

A. McEwan and T. Hecht*

Department of Ichthyology and Fisheries Science, Rhodes University, P.O. Box 94, Grahamstown, 6140 Republic of South Africa

*To whom correspondence should be addressed

Received 10 April 1984, accepted 25 June 1984

The freshwater eels of the genus *Anguilla* Shaw 1803, undergo a catadromous migration after attaining sexual maturity in fresh water. The freshwater stage can last from seven to 50 years, depending on species, sex and geographic location. The catadromous migration is preceded by a metamorphosis, from the yellow to silver-eel stage (Tesch 1977). In the longfin eel, *A. mossambica* Peters, 1852 the skin changes colour from an olive green dorsal surface and a yellow belly to a dark brown dorsal surface and white or silver belly. Also, the eyes enlarge by up to 50% in horizontal by vertical axis size. Simultaneously the animal becomes sexually mature and ceases to feed (Jubb 1961).

Spawning takes place at sea. No adult eels of any species have been recorded making the return migration and it is assumed that they die after spawning (Frost 1945; Tesch 1977; Moriarty 1978). Jubb (1961) postulated that *A. mossambica* spawns in an area to the east-north-east of Madagascar enclosed by latitude 10 °S to 20 °S and longitude 60 °E to 70 °E. The duration of the larval leptocephalid stage varies between species from six months to three years (Jubb 1961; Tesch 1977), during which they undergo a four-stage metamorphosis into the glass eel or elver stage (Tesch 1977). It is at this stage that the young eels enter into and migrate up rivers. *A. mossambica* is considered to be the most common eel entering Transkei rivers (Jubb 1961).

Generally, eels are considered to be relatively slow-growing and long-lived fishes (Tesch 1977; Moriarty 1978). The method for ageing eels has normally been confined to the interpretation of rings on otoliths (Frost 1945; Sinha & Jones 1967; Liew 1974; Balon 1975; Hu & Todd 1981). Scales have in the past also been used, but have generally been found unreliable as they are deposited only after the fish attain lengths of over 100 mm and/or after they have lived in fresh water for two to three years (Harrison 1953; Boetius & Boetius 1967; Tesch 1977). Also, scales are not found over the whole body and are not all formed at the same time. This means that the number of years that must be added to the number of annuli on the scales is unknown and age estimates become unreliable.

The interpretation of growth zones on leptocephalid otoliths is also difficult (Tesch 1977; Appelbaum & Hecht 1978). The age of eels is, therefore, calculated from the beginning of the glass-eel or elver stage.

No previous attempts have been made to age eels in southern Africa using otoliths, apart from Balon's (1975) study on eels in Lake Kariba. As the eels in Lake Kariba showed intermingled characters of both the mottled eel *A. nebulosa labiata* Peters 1852 and *A. mossambica*, Balon was not able to distinguish between them and was therefore forced to lump the data for the two species. Harrison (1953) attempted to age eels by using scales but realized himself that his results were unreliable. The aim of this study was to determine the feasibility of using otoliths for ageing and then, if the data were found to be reliable, to calculate the growth rate of *A. mossambica*.

Material and Methods

General

Otoliths were removed from a total of 350 eels ranging in length from 95 mm to 1 004 mm total length (TL). They were collected by staff of the Rand Afrikaans University Zoology Department in four Transkei rivers (Figure 1) at different times during 1980 and 1981 (Table 1).

The eels were weighed to the nearest gram and their total length measured to the nearest mm. The length-weight relationship was calculated by logarithmic regression and expressed by the standard equation $W = aL^b$ (Ricker 1975).

Otoliths were then removed, cleaned and stored dry and their lengths measured to the nearest 0,01 mm using a stereo microscope with an eyepiece graticule. Owing to the size range of the otoliths and the fact that the interpretation of growth zones on eel otoliths is generally difficult, it was not possible to use a single standard technique for ageing. Various methods were, therefore, tried and tested and only those found to be most suitable for a particular size group are described.

Growth zones on small otoliths (< 1 mm in length) were best observed if immersed whole in methyl salicylate and viewed from the lateral side under reflected light. Opaque zones were white whereas the hyaline zones appeared dark.

For otoliths larger than 1 mm, it was found best to either grind them on the medial side down to the level of the margin on 400–500 grade carborundum paper using dilute (1%) hydrochloric acid as a wetting agent (Frost 1945; Sinha & Jones 1967) or to cut a section (0,2 mm thick) through the nucleus. For this method the otoliths were embedded in clear epoxy resin rods, whereafter sections could be cut using an otolith sectioning machine as described by Rauck (1976).

For the purpose of this study, one otolith of a pair (i.e. those > 1 mm) was ground while the other was sectioned. In order to identify and count growth zones, both the ground otoliths (Figure 2) as well as the sections (Figure 3) were mounted on

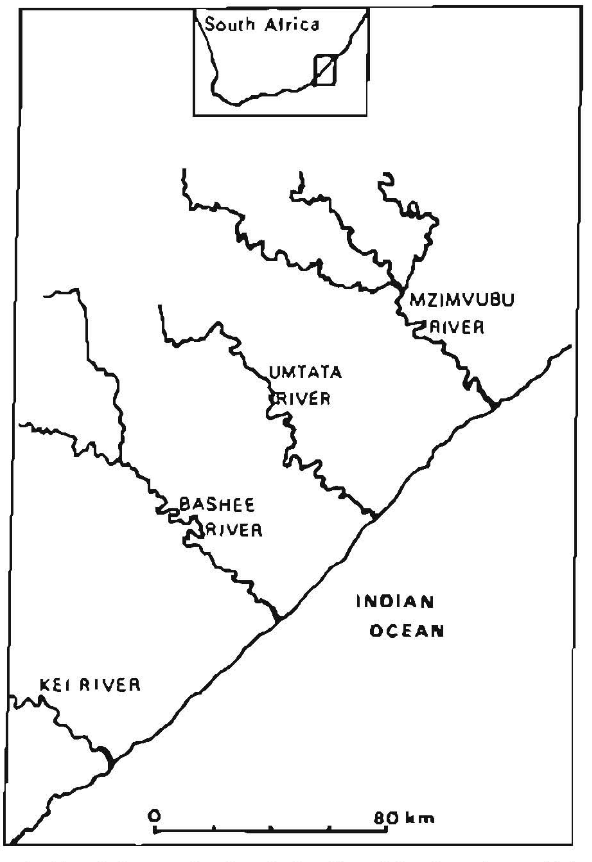

Figure 1 Transkei coast showing the locality of the rivers from which *A. mossambica* were collected

Table 1 The origin, date of collection and number of eels collected at each locality

River	Date	*n*
Bashee River	September 1980	62
Bashee River	July 1981	27
Mtata	November 1980	82
Mtata	July 1981	22
Mzimvubu	November 1980	22
Mzimvubu	January 1981	21
Mzimvubu	April 1981	36
Mzimvubu	July 1981	47
Kei	April 1981	10
Kei	July 1981	21

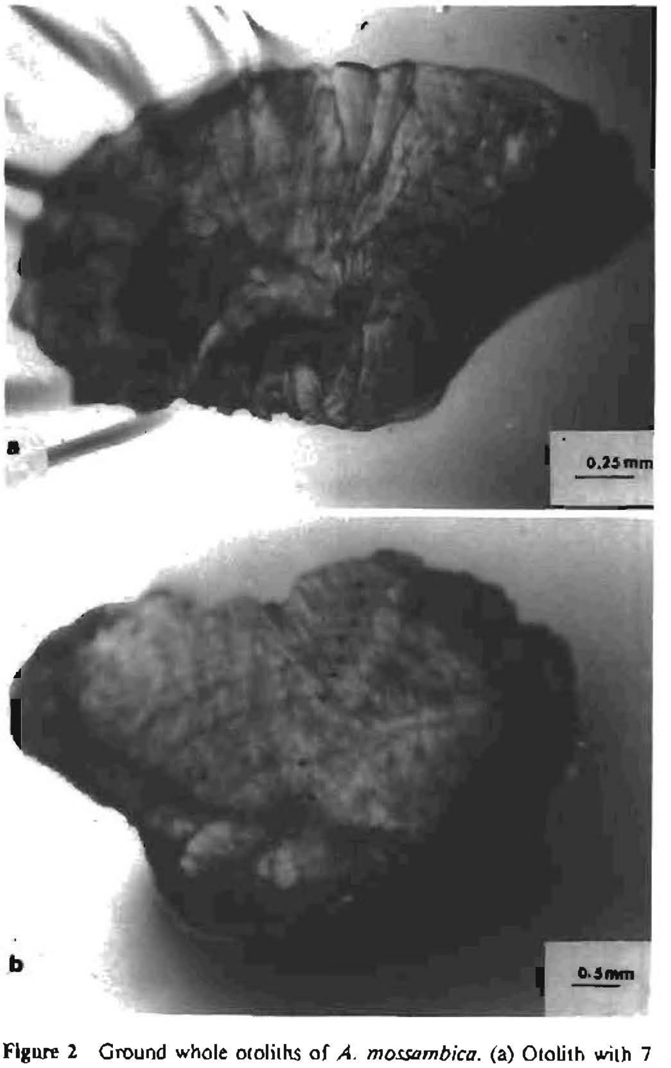

Figure 2 Ground whole otoliths of *A. mossambica*. (a) Otolith with 7 annuli. Otolith length = 2,75 mm and total fish length = 381 mm. (b) Otolith with 10 annuli. Otolith length = 4,01 mm and total fish length = 565 mm. f = false growth zone, n = nucleus, + = annulus.

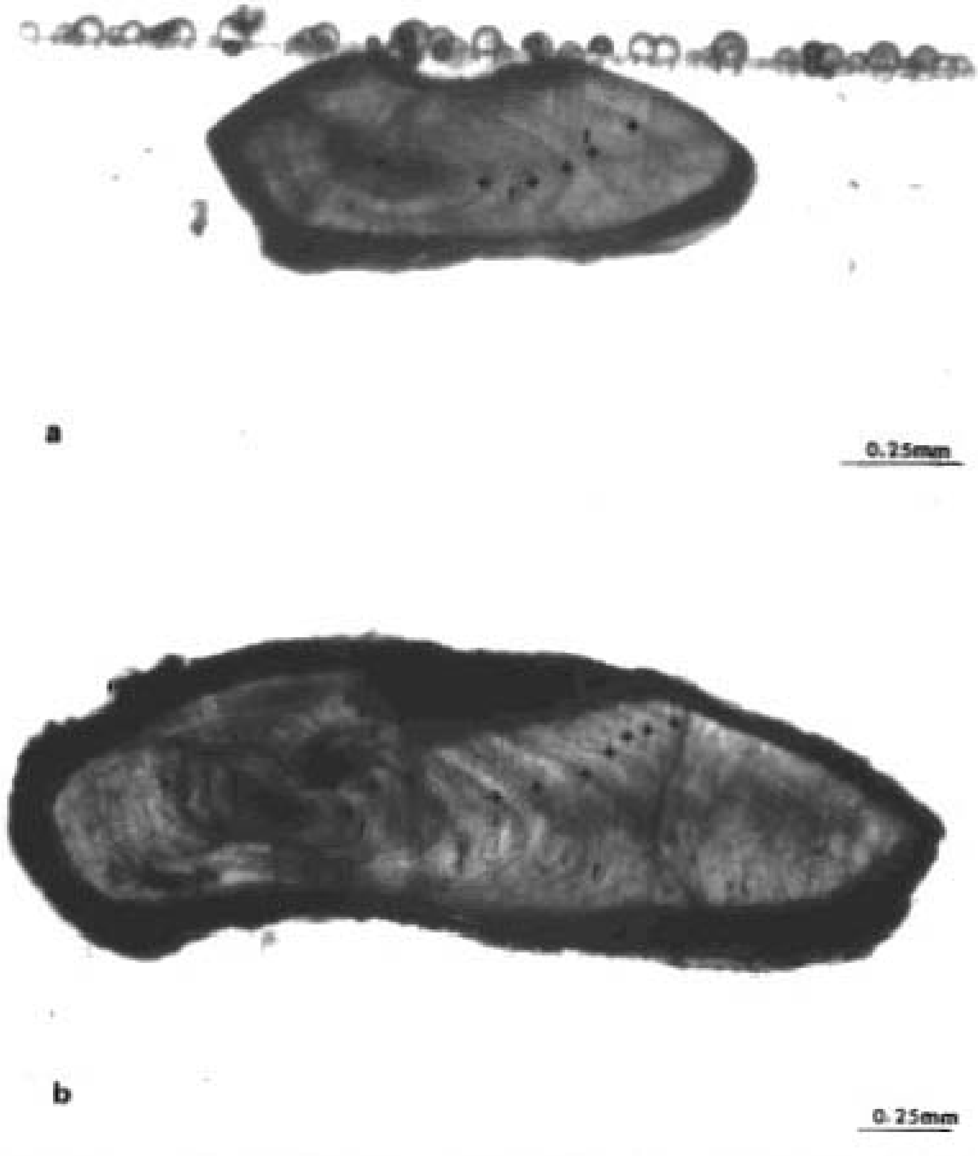

Figure 3 Sectioned otoliths of *A. mossambica*. (a) Otolith with 5 annuli. Otolith length = 2,01 mm and total fish length = 270 mm. (b) Otolith with 10 annuli. Otolith length = 3,71 mm and total fish length = 555 mm. f = false growth zone, n = nucleus, + = annulus.

glass slides and viewed through a stereo microscope under transmitted light. In this way it was possible to compare and check growth zone counting accuracy. Otoliths were read seven times and only those data sets where six or all seven readings corresponded were used for further analyses. Of the 350 pairs examined 63% could be used with certainty.

Great care must be exercised not to confuse false growth zones with true annuli on eel otoliths. False zones can be distinguished from annuli as they do not continue around the entire otolith. According to Liew (1974) and Tesch (1977) false zones on eel otoliths are stress related e.g. during periods of environmental instability or food shortage, resulting in growth cessation.

Burning the otoliths according to the methods developed for eel otoliths by Moriarty (1978), Jellyman (1979), Todd (1980) and Hu & Todd (1981) was attempted but the growth zones on longfin eel otoliths prepared in this way were not as clear as when using the techniques described above.

Periodicity of ring formation

To test whether the number of rings on an otolith is indicative of age, the outer margins of the otoliths from each sample were examined. The presence of either an opaque or hyaline outer margin was noted and expressed as a percentage of the total sample. In this way it was possible to establish the number of annuli deposited per year, on the assumption that the growth zones on the otoliths were all formed at the same time in the different rivers from which the eels were collected.

Growth calculations

To determine whether otoliths could be used to age this species, the relationship between otolith length and TL as well as between otolith length and the number of rings on an otolith was determined by exponential regression analysis. In order to test whether the data could be fitted to the von Bertalanffy growth model a linear regression of L_t on L_t+1 (Ford-Walford plot) was calculated (Ricker 1975). The slope of the plot was found to be < 1 and the data could, as a result, be fitted to the model. The mean observed length-at-age data were fitted to the model in the form of $L_t = L_\infty (1-e^{-k(t-t_0)})$ (Ricker 1975), by the method of least squares. Somatic growth was calculated by substituting the calculated length-at-age data into the length-weight equation. These data were then fitted to the von Bertalanffy equation in the form of $W_t = W_\infty (1-e^{-k(t-t_0)})^b$, where b is the exponential constant derived from the length-weight equation (Ricker 1975).

Results

Despite the paucity of regular monthly samples, the data illustrated in Figure 4 show that one opaque and one hyaline zone are deposited on the otolith per year. The hyaline zone is deposited during the summer months from November to February, while the opaque zone is deposited during the winter months from June to September. One opaque and one hyaline zone were, therefore, interpreted as representing one year's growth.

The relationship between otolith length (OL) and TL in mm was found to be TL = 122 $OL^{1,072}$ (r^2 = 0,90; n = 221) and that between OL and the number of rings was found to be OL = 0,7855 no. of $rings^{0,66}$ (r^2 = 0,91; n = 221). The goodness of fit (in both instances $p < 0,01$) between these parameters clearly indicated that otoliths could be used to age this species (Figures 5 and 6). Table 2 shows the length distribution of the various age classes and Figure 7 illustrates the size frequency distribution of those eels of which the otoliths could be read successfully. The length-weight relationship was found to be W(g) = 0,000714 L $(cm)^{3,2998}$ (r^2 = 0,98; n = 350) and is illustrated in Figure 8.

As most of the eels could not be sexed, the data for males and females were combined. It is difficult to sex eels < 200 mm TL, but from then onwards sexual differences become discern-

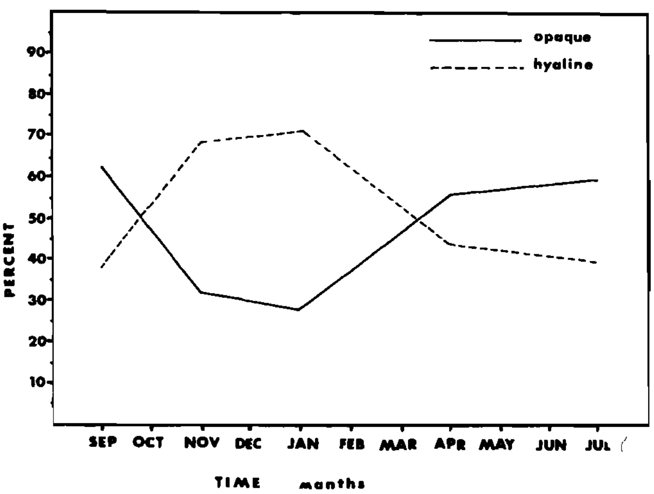

Figure 4 Temporal changes in the marginal increment of *A. mossambica* otoliths.

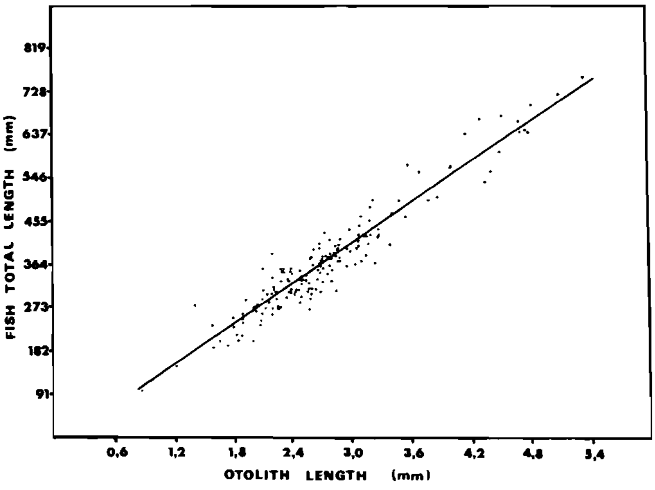

Figure 5 The relationship between total fish length and otolith length of *A. mossambica*.

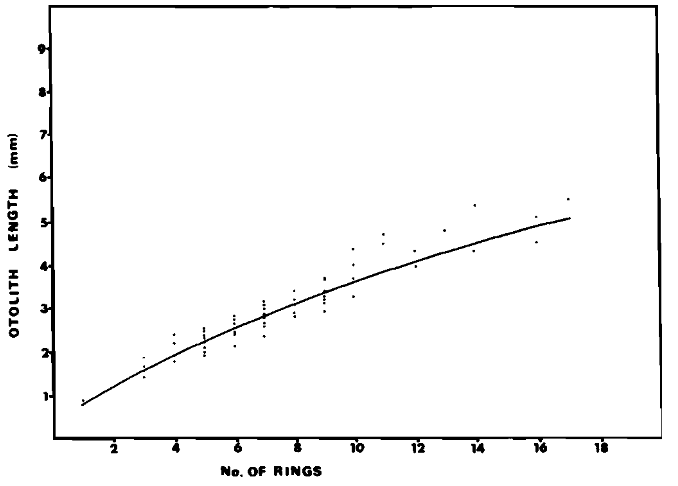

Figure 6 The relationship between otolith length and annuli number of *A. mossambica*.

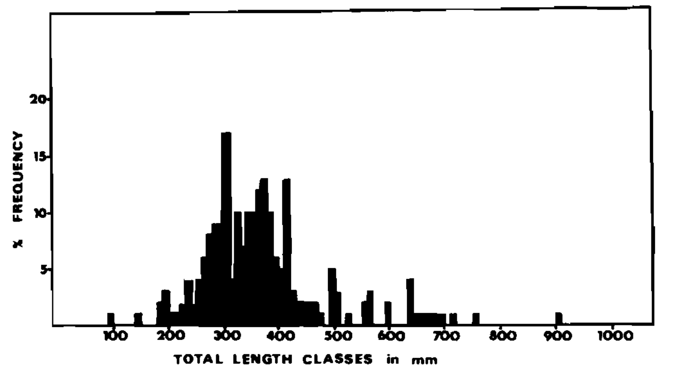

Figure 7 The size class percentage frequency distribution of *A. mossambica*.

Table 2 The total length (mm) at age (years) distribution of *A. mossambica* from Transkei rivers

Total length (mm) classes	Age (years) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
50																	
100	1																
150																	
200			5														
250			4	8	8												
300			2	6	15	6	3										
350				4	15	15	7										
400						11	13	10	8								
450							5	7	10	4							
500								3	7	4							
550										5							
600										5	3	4		2			
650											3	1	3				
700											3	4		2		1	
750																1	
800														2		1	
850																	
900																	
950																	1
1000																	

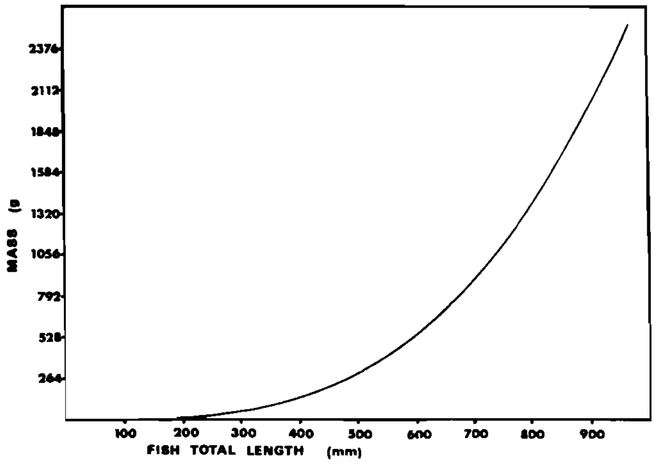

Figure 8 The length/weight relationship of *A. mossambica* from Transkei rivers.

Table 3 The mean observed length-at-age, the standard error (SE) of the mean, the number of specimens and the calculated length-at-age of *A. mossambica* from Transkei rivers

Age (years)	$\bar{x}$ observed length-at-age (mm)	SE	n	Calculated length-at-age (mm)
1	99		1	82
2				134
3	219	22,3	11	185
4	256	16,6	18	233
5	295	10,8	38	280
6	337	15,7	32	324
7	365	15,5	28	367
8	403	19,9	20	408
9	410	19,2	25	447
10	515	19,1	18	485
11	642	54,3	9	522
12	618	74,0	9	557
13	650	34,1	3	590
14	678	65,6	6	622
15				653
16	699	68,9	3	682
17	905		1	711
18				738

able (Pantulu & Singh 1962; Tesch 1977).

The von Bertalanffy equation describing the growth of *A. mossambica* in Transkei rivers, calculated from the mean observed length-at-age data shown in Table 3, was found to be $L_t = 1390\ (1-e^{-0{,}041\ (t+0{,}476)})$ mm (Figure 9). Using the length-weight relationship equation, illustrated in Figure 8, the somatic growth of *A. mossambica* in Transkei rivers can be described by the equation $W_t = 8418\ (1-e^{-0{,}041(t+0{,}476)})^{3{,}2998}$.

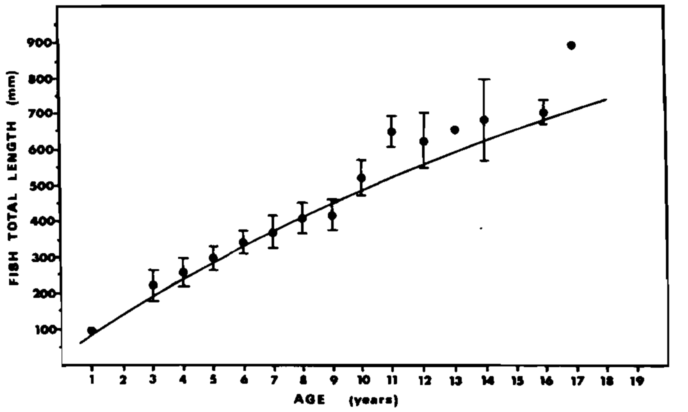

Figure 9 The growth in length of *A. mossambica* in Transkei rivers.

Discussion

Cognisance has to be taken of the fact that the eels were collected from different rivers, although in close geographic proximity. The calculated growth curve should therefore be regarded as representing the mean growth rate of *A. mossambica* in some of the major Transkei rivers.

The otoliths have a large central opaque nucleus. This portion is formed during the larval leptocephalid stage of the eel's life history. The European eel, *A. anguilla* is considered to have a larval period of two and a half years, the American eel, *A. rostrata* from six months to one and a half years and the New Zealand eel, *A. diffenbachi*, two years (Tesch 1977). The east African species, *A. nebulosa labiata* is thought to have a larval life of one and a half years (Pantulu & Singh 1962). Considering the distance from the hypothetical breeding grounds (Jubb 1961) it could possibly be inferred that the Transkei eels have a larval phase of two years, as their migration would take longer than that of the east African species. The length-at-age

Table 4 A comparison of growth rates in mm of various *Anguilla* populations

Species, locality and authority	Sex	Age (years) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A. anguilla, Windermere (UK) (Frost 1945)	Combined	90	154	195	227	264	322	384	408	432	486								
A. anguilla, N. Germany (Frost 1945)	Combined			220	260	350	470	490	600	600	690								
A. anguilla, Italy (Frost 1945)	M	109	155	210	260	315	365	410	460	520	590								
A. anguilla, France (Frost 1945)	M		232	254	275	340	356	455	470	480	505								
	F		232	254	275	340	356	376	395	420									
A. japonica, Japan (Tesch 1977)	M			279	316	403	452	529	561	658									
A. diffenbachi, New Zealand (Tesch 1977)	Combined	87	108	161	204	252	315	390	470	540	630	730	820						
A. rostrata, Lake Ontario Canada (Hurley 1972)	Combined				310		509	495	532	532	655	785	787	835	854	909	920	967	909
A. mossambica, Transkei (this study)	Combined	82	134	185	233	280	324	367	408	447	485	522	556	590	622	653	682	711	738

data presented in this paper, therefore represents the time from which the elvers enter the rivers until the beginning of the catadromous migration. Their true age is thus equal to the calculated age plus about two years.

From the data presented in this study, eels of a given length (especially those between 5 and 10 years old) may show an age variation of up to five years. Those older than 10 years (>500 mm total length) vary even more. This variation not only occurs in eels from natural populations but also in cultured eels, where after two years they may range from 95 to 610 mm TL (Appelbaum & Hecht 1978). Tesch (1977) also points out that the relatively large length-at-age variation is fairly common in eel populations the world over.

Anguilla species worldwide, including those from Transkei, are generally slow-growing fishes, reaching lengths greater than 650 mm only after at least 9 or 10 years (Table 4). In Europe most eels are younger than 12 years. Moriarty (1978) ascribes this to the heavy fishing pressure on the populations. In unfished waters a greater proportion of older eels is not uncommon and in Scotland, ages of up to 50 years have been recorded (Moriarty 1978).

In this study larger otoliths were more difficult to interpret than smaller ones. Figure 3 illustrates this by comparing a smaller otolith with five distinct rings to a larger otolith with 10 less distinct rings. However, by using a combination of methods for the larger otoliths, as described in this paper, the otoliths of *A. mossambica* can be used as reliable indicators of age.

Acknowledgements

To the CSIR for providing a postgraduate bursary to A. McEwan, A.T.J. Scholtz for building the otolith sectioning apparatus and to H.J. Schoonbee and A. Deacon of the Zoology Department of the Rand Afrikaans University for providing the material.

References

APPELBAUM, S. & HECHT, T. 1978. Otolith length-fish length relationship of leptocephali, elvers and sub-adult (reared) eels, *Anguilla anguilla*. *Env. Biol. Fish.* 3: 245–247.

BALON, E.K. 1975. The eels of Lake Kariba: distribution, taxonomic status, age, growth and density. *J. Fish. Biol.* 7: 797–815.

BOETIUS, I. & BOETIUS, J. 1967. Studies on the European eel, *Anguilla anguilla* (L). *Meddr. Danm. Fisk.-og Havunders* 4: 339–405.

FROST, W.E. 1945. The age and growth of eels (*Anguilla anguilla*) from the Windermere catchment area. *J. Anim. Ecol.* 14: 26–36, 106–124.

HARRISON, A.C. 1953. The age and scales of freshwater eels. *Piscator* 7: 9–12.

HU, L.C. & TODD, P.R. 1981. An improved technique for preparing eel otoliths for ageing. *N.Z. Jl. Mar. Freshw. Res.* 15: 445–446.

HURLEY, D.A. 1972. The American eel (*Anguilla rostrata*) in eastern Lake Ontario. *J. Fish. Res. Bd. Can.* 29: 535–543.

JELLYMAN, D.J. 1979. Scale development and age determination in New Zealand freshwater eels (*Anguilla* spp.). *N.Z. Jl. Mar. Freshw. Res.* 13: 23–30.

JUBB, R.A. 1961. The freshwater eels (*Anguilla* spp.) of Southern Africa: An introduction to their identification and biology. *Ann. Cape Prov. Mus.* 1: 15–48.

LIEW, P.K.C. 1974. Age determination of American eels based on the structure of their otoliths. In: Ageing of Fishes. (Ed.) Bagenal, T.B. Unwin, London. pp.124–136.

MORIARTY, C. 1978. Eels: a natural and unnatural history. David & Charles, London.

PANTULU, V.R. & SINGH, V.D. 1962. On the use of otoliths for the determination of age and growth of *Anguilla nebulosa labiata* McClelland. *Proc. Indian Acad. Sci. Sect. B.* 55: 263–275.

RAUCK, G. 1976. A technique of sawing thin slices out of otoliths. *Ber. dt. Wiss. Kommn. Meeresforsch.* 24: 339–341.

RICKER, W. 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Bd. Can.* 191: 1–382.

SINHA, V.R.P. & JONES, J.W. 1962. On the age and growth of the freshwater eels (*Anguilla anguilla*). *J. Zool., Lond.* 153: 99–117.

TESCH, F.W. 1977. The eel. Biology and management of anguillid eels. Chapman & Hall, London.

TODD, P.R. 1980. Size and age of migrating New Zealand freshwater eels (*Anguilla* sp.). *N.Z. Jl. Mar. Freshw. Res.* 14: 283–293.