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FRESH WATER FISHERIES
BIOLOGY AND TAXONOMY**

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T. HECHT

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PIETERSBURG

University of the North
Private Bag X5090
PIETERSBURG
0700
Republic of South Africa

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**THE VALUE OF OTOLITHS IN FRESH WATER FISHERIES
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INTRODUCTION

The primary aim of this paper is an attempt to stimulate interest in the use of otoliths in fresh water fish biology in South Africa, as these structures have hitherto been grossly neglected. The paper is divided into three parts. The introduction briefly reviews international otolith research. The second part deals more specifically with otoliths as an aid to taxonomy and finally the use of otoliths in fresh water fisheries biology is discussed.

According to Stinton (1975) otoliths were first observed by Aristoteles in the 3rd century B.C. but only began to attract wider attention during the 19th century. Cuvier (1828) was the first to recognize their specificity. Sheperd (1914) was the first fresh water fish biologist who described a few mormyrid otoliths. This was followed by Frost (1925bb and 1925c) who described some otoliths of fishes belonging to the Cypriniformes and the Siluriformes. Only in 1956 did the first major work regarding fresh water fish otoliths appear when Berinkey described the asterici otoliths of the Hungarian Cypriniformes. More attention was at this time, however, given to the otoliths of marine fishes (Frost 1925a, b & c, 1926, 1927, 1928, 1929 and 1930, Chaine et Duvergiere 1934, 1935, 1936 and 1942, Bauza-Rullan 1956, 1958, 1959, 1960 and 1961). Since then this trend has been continued on a limited scale by Kotthaus (1967-1977), Karrer (1971), Fitch and Barker (1972), Trewavas (1977) and Hecht (1978a and b). Much attention has also been given to fossil otoliths- again however, with special emphasis on marine fishes (Weiler, 1942, Stinton 1968, Nolf 1970, Gaemers 1971 and Schwarzhans 1976).

The common names of fish used in this paper are according to Jackson (1975). The author has recently started building up a reference collection of fresh water fish otoliths. The aim of this collection is twofold. Firstly for the purpose of more elaborate systematic studies on South African fresh water fish otoliths. Secondly the collection will be available to workers wishing to identify fish remains from otoliths found in the stomachs of piscivorous predators.

Otoliths and Taxonomy

Three "earstones" or otoliths are found in the capsula auditiva on either side of the neurocranium. According to their structure the three otoliths are termed the sagitta, the astericus and the lapillus (Koken 1884). Except in the fishes of the orders Cypriniformes and Siluriformes, the sagitta is the largest of the three. The astericus, which is star shaped in the cypriniform fishes, is the largest of the three otoliths; and in the siluriform fishes, which include the barbels, catfishes and squeakers, the lapillus is the largest. It is the sagittal otolith which is usually used for taxonomical purposes, as these show many more recurring features for comparative descriptions than either the lapillus or the astericus.

Although variations do occur the important sagittal features may be described as follows (see also Hecht 1978a and Fig. 1). The most important feature is the sulcus acusticus, a usually shallow furrow situated medially along the horizontal axis. The open end of the sulcus in the majority of cases indicates the anterior end of the otolith. The sulcus is ideally divided into an anterior wide ostium and a posterior usually narrower cauda. Other diagnostic features of the sulcus include the cristae superior and inferior, both of which are ridge-like borders on the dorsal and ventral side of the sulcus. Also present within the sulcus is the colliculum represented by a raised structure. In certain cases the colliculum occurs as a divided structure — termed the anterior and posterior collicula. Situated antero-ventrally is the rostrum, usually larger than the antero-dorsally situated antirostrum. In certain cases one or both of the rostra may be absent as in the case of the Mormyriiformes. The excisura ostii is a V-shaped intrusion between the rostrum and the antirostrum. Its presence or absence and size should be noted. The geometric shape is of value on considering the ontogeny of a species, genus, family or order. The sculpture of the outer margins, i.e. whether lobed, denticulate or serrate should also be noted. The dorsal and ventral areas are also important as regards their size, presence or absence. Similarly the presence or absence of dorsal grooves as well as the postero-ventral groove should be noted. Further valuable aspects include the nature of the medial and lateral faces of the otolith i.e. whether they are either convex medially and concave laterally, as is usually the case, or otherwise. The lateral side of the sagitta is usually devoid of any diagnostic features except in the marine families Sciaenidae and Chanidae and to a lesser extent in the Cypriniformes and Siluriformes. The otolith length/fish-length relationship as well as the otolith-length/otolith-depth/otolith-breadth relationship has to be considered when using otoliths for taxonomic purposes.

A number of figures have been included to illustrate the value of sagittae as a taxonomic aid. Figure 2 shows the sagittal otoliths of the marine barbel, *Tachysurus feliceps*, the marine barbel eel, *Plotosus limbatus* and the fresh water silver barbel *Eutropius depressirostris*: these represent three different families of the order Siluriformes. In gross morphological terms the figure clearly shows the similarity of otoliths of different families of the same order. The diagnostic features of the siluriform sagittae are the slender elongated rostrum and the presence of the ridge-like colliculum. Figure 3 shows the sagittae of *E. depressirostris*, *T. feliceps* and the sagitta of the large scaled yellow fish *Barbus marequensis*. This figure shows a close relationship between the Siluriformes and the Cypriniformes. As otoliths must only be regarded as a taxonomic aid, they do not allow for the combination of these two orders. Lindberg (1974), however, does not recognize the order Siluriformes and includes these fishes within the Cypriniformes.

Figure 4 shows the distinctness of the otoliths of the Mormyriiformes (note the absence of both the rostrum and the antirostrum as mentioned above). It may perhaps be briefly mentioned that according to their sagittal structure the Salmonidae, which include the various trout species,

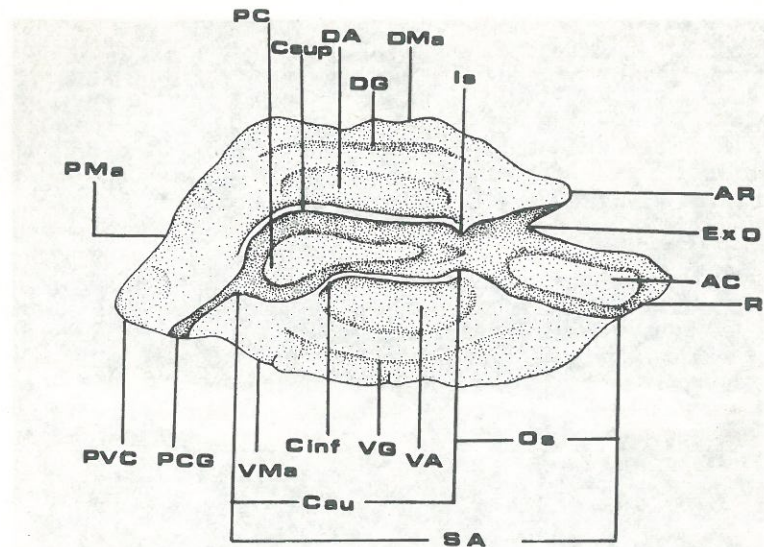


Fig. 1

Schematic sagitta illustrating the following features; SA - Sulcus acusticus, Cau - Cauda, Os - Ostium. VA - Ventral area, VG - Ventral groove, C.inf - Crista inferior, C.sup. - Crista superior, VMA - Ventral margin, PCG - Post caudal groove, PVC - Post ventral corner, PMA - Posterior margin, PC - Posterior colliculum, DA - Dorsal area, DG - Dorsal groove, DMA - Dorsal margin, Is - Isthmus, AR - Antirostrum, ExO - Excisura ostii, AC - Anterior colliculum, R - Rostrum.

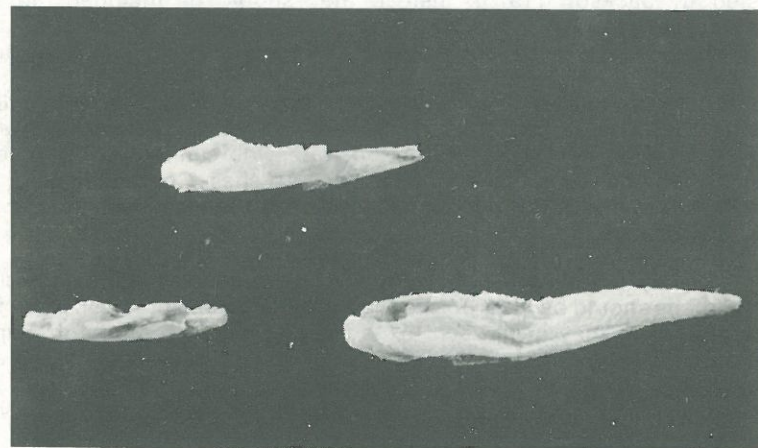


Fig. 2

Sagittae of *Eutropius depressirostris* (top, broken tip), *Plotosus limbatus* (bottom left, broken tip) and *Tachysurus feliceps* (bottom right).



Fig. 3

Sagittae of *Eutropius depressirostris* (top), *Barbus marequensis* (bottom left) and *Tachysurus feliceps* (bottom right).

do not fit into the general pattern of the Mormyriformes as suggested by Jackson (1975); instead they should be included into the Salmoniformes as stated by Greenwood, *et al.* (1966) (compare Figs. 4 and 5). Figure 6 shows representative sagittae of perciform families. Included are the sagittae of the mozambique tilapia, *Sarotherodon mossambicus*, the large mouthed black bass, *Micropterus salmoides*, the black tail or dassie, *Diplodus sargus* (marine) as well as the banded tilapia, *Tilapia sparmanni*. The figure clearly demonstrates the similarity of perciform otoliths, whether from marine or fresh water fishes. Characteristic of the perciform otoliths is the geometric shape and the clear definition of the sulcus acusticus.

Hopefully, by including the above figures, it has become sufficiently clear that otoliths should be incorporated to a greater extent into fresh water fish taxonomy than they have been up to the present time. Although marine ichthyologists are giving an ever increasing weight to otoliths (Collette and Chao 1975, Trewavas 1977) it must also be borne in mind that the systematic description of otoliths as an aid to taxonomy is still in its very early stages.

Otoliths and Fisheries Biology

The sagittal otoliths of eight of the ten fresh water teleostean orders

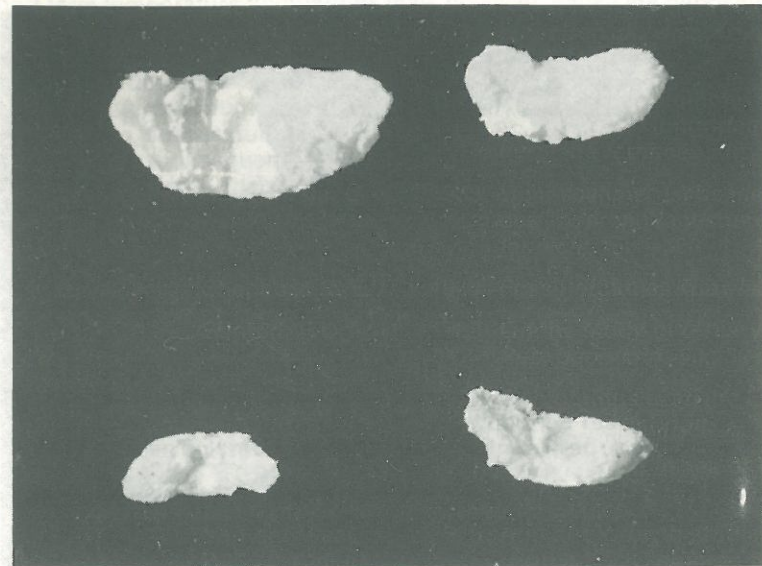


Fig. 4

Sagittae of *Gnathonemus macrolepidotus* (top) and *Petrocephalus catastoma* (bottom) (Mormyriformes).

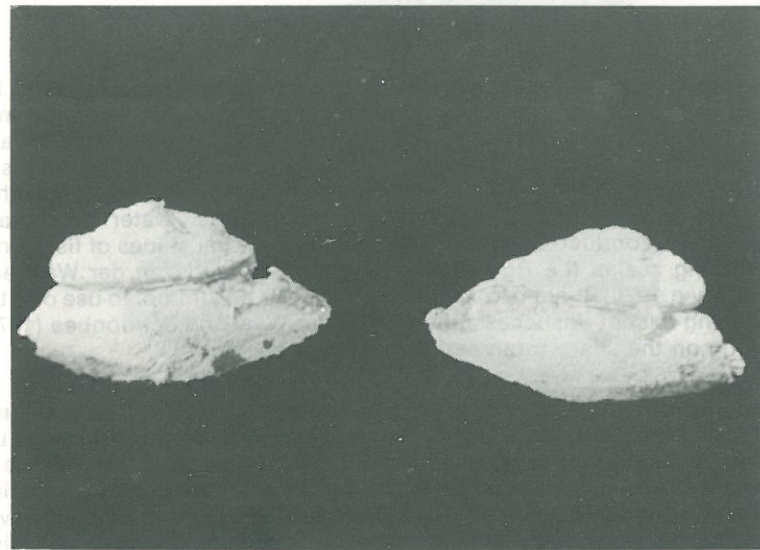


Fig. 5

Left and right sagittae of a rainbow trout, *Salmo gairdneri*.

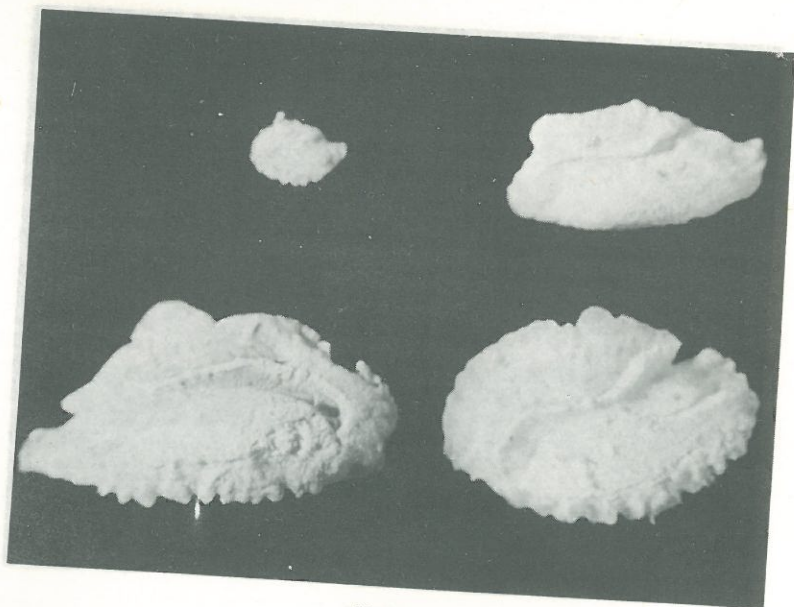


Fig. 6

Sagittae of *Tilapia sparmanni* (top left), *Sarotherodon mossambicus* (bottom right) (Cichlidae), *Diplodus sargus* (top right) (Sparidae) and *Micropterus salmoides* (bottom left) (Centrarchidae).

occurring in South Africa (Jackson 1975) could possibly be used for biological studies such as age and growth. However, in the Cypriniformes and the Siluriformes the astericus and the lapillus should be used for age and growth studies respectively. For feeding studies the sagittal otoliths of all orders are used as they are more characteristic than any one of the other two. Age and growth studies on South African fresh water fishes have mainly been conducted using scales and the pectoral spines of fishes not possessing scales (Le Roux 1961, Gaigher 1969 and Van der Waal and Schoonbee 1976). It appears that there has been no attempt to use otoliths for ageing except unsuccessfully by Van der Waal and Schoonbee (1975) working on the sharp tooth catfish, *Clarias gariepinus*.

A number of questions, however, arise when considering the scale and pectoral spine methods of ageing. Before continuing, however, it must hastily be added that experience has shown that the otolith technique of ageing also has its problems. It has been adequately documented that ring deposition on scales, spines and otoliths is caused by two major factors, viz. reproductive seasonality and seasonal temperature changes (Hickling 1933, Segerstråle 1933, Garrod 1959, June and Roithmayer 1960 and Moreau 1974). Frequency of ring deposition as caused by reproductive seasonality can easily be detected on scales, spines and otoliths. Severe

short term temperature fluctuations may, however, cause the deposition of 'false rings' or secondary rings on scales (Lee 1920). Such secondary rings could result in an overestimation of age. Hecht (1976) found this whilst working on demersal trawlfish species of the Eastern Cape coast and subsequently discontinued their use. Similarly Baird (1974) experienced difficulties in successfully ageing mackerel, *Scomber japonicus*, using scales and also subsequently discontinued their use. Moreover, it has been noticed that in large specimen (>31cm TL) of *Sarotherodon mossambicus* the rings are crowded towards the scale margin, which makes the reading difficult and more often than not results in an underestimation of age. Le Roux (1961) also mentions the problem of 'cutting over' which may also result in an underestimation of age.

It is well known that the pectoral spines of siluroid fishes like the silver barbel, *E. depressirostris* and the sharp tooth catfish, *C. gariepinus* possess a hollow lumen which increases progressively with fish length (see Fig. 7). The possibility, therefore, exists that rings may be resorbed during the process of lumen enlargement, probably resulting in an underestimation of age.

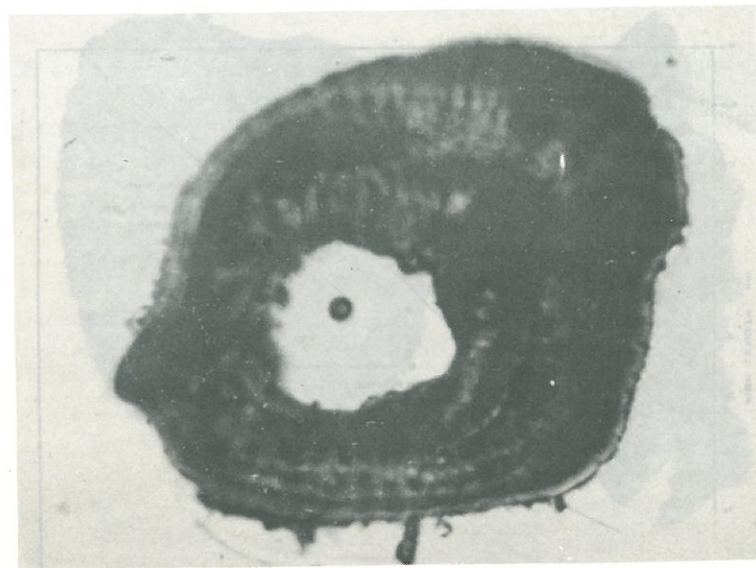


Fig. 7

Pectoral spine of *Clarias gariepinus* illustrating the lumen.

Similar to scales and spines when otoliths are used for age determination, the frequency of annual ring deposition has to be determined over a minimum period of twelve months by monthly edge examination of a representative sample. This has to be done before any growth calculations may be attempted. Moreover, it must be determined whether a correlation exists between otolith length and fish length (Baird 1970, Botha 1971, Geldenhuys 1973 and Hecht 1977).

Pectoral spines, otoliths and scales have been collected on a monthly basis since October 1977 of four indigenous fresh water fish species from various localities in Lebowa and Venda. The four species include *Sarotherodon mossambicus*, *Barbus marequensis*, *Clarias gariepinus* and *Eutropius depressirostris*. Initial investigations have shown that otoliths are easier to read than either scales or spines. Moreover, it has been found that for all four species concerned otoliths have a higher percentage readability than scales or spines. Initial calculations have also shown that there is a relatively good correlation between the number of rings on the otolith of the silver barbel and the length of the fish. Moreover, a good correlation between otolith length and total fish length was found for all species concerned (see Fig. 8). As regards the number of rings deposited annually, it has tentatively been found that one opaque and one hyalin ring are deposited on the otolith in the case of *S. mossambicus*, *C. gariepinus* and *Barbus marequensis*. In *E. depressirostris* two opaque and two hyalin rings are deposited on the otolith annually.

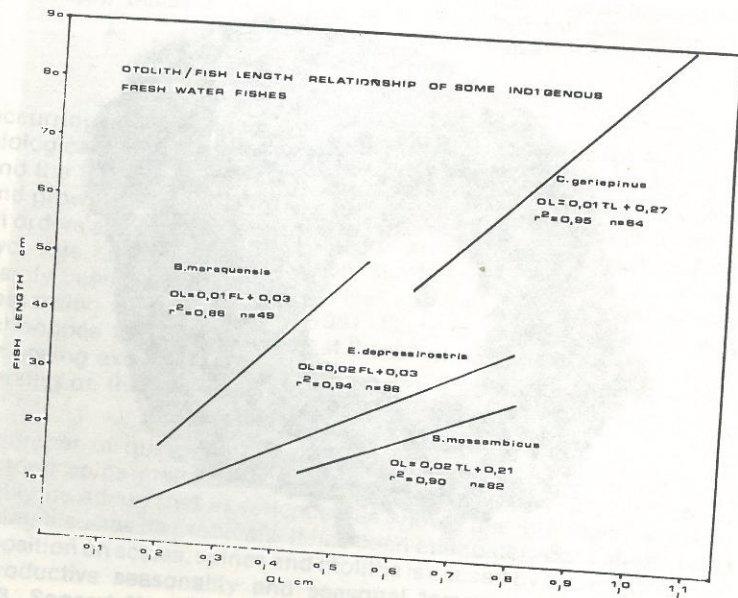


Fig. 8

Otolith length/fish length relationships of four freshwater fish species.

Some otoliths can be read whole e.g. those of *S. mossambicus* although better readings can be made from sections. Considering the size and the hard, brittle and usually opaque nature of otoliths due to their chemical composition (Degens et. al. 1969), it is not at all surprising that they have not been used as much as scales and spines. A new apparatus has, however, recently been developed by Rauck (1976) of the Bundesforschungsanstalt für Fischerei in Hamburg, W. Germany. This technique allows 0,1 mm highly polished sections to be made. The apparatus was similarly used to cut sections from pectoral spines.

A number of figures have been prepared to show the rings on otolith sections. These are compared with scales and sections of siluroid spines. Figures 9 and 10 show spine and otolith sections of the same respective fish. From these two figures it becomes evident that otoliths are read with greater ease than pectoral spines. Figure 11 shows a sagittal section of *S. mossambicus*, again illustrating ring formation. Figure 12 compares a scale and an otolith of the same mozambique tilapia and Figure 13 shows a section of a silver barbel otolith showing very legible rings.

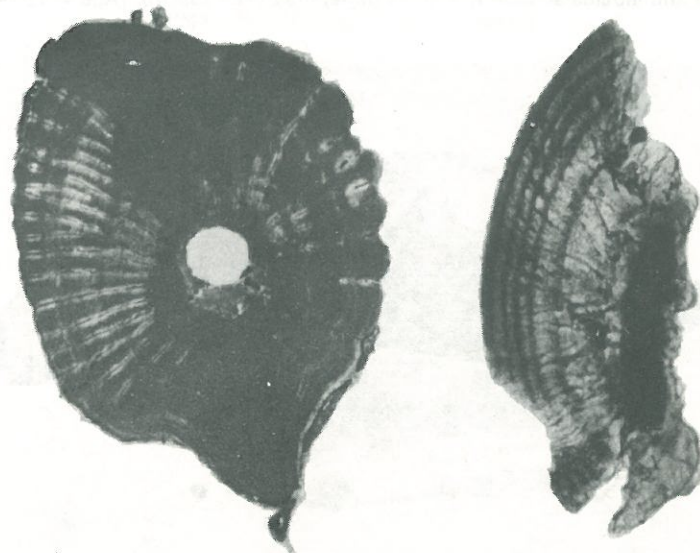


Fig. 9

Spine and lapillus section of *Clarias gariepinus* (TL=65cm). (Age = 5 years). One opaque and one hyalin ring deposited annually.

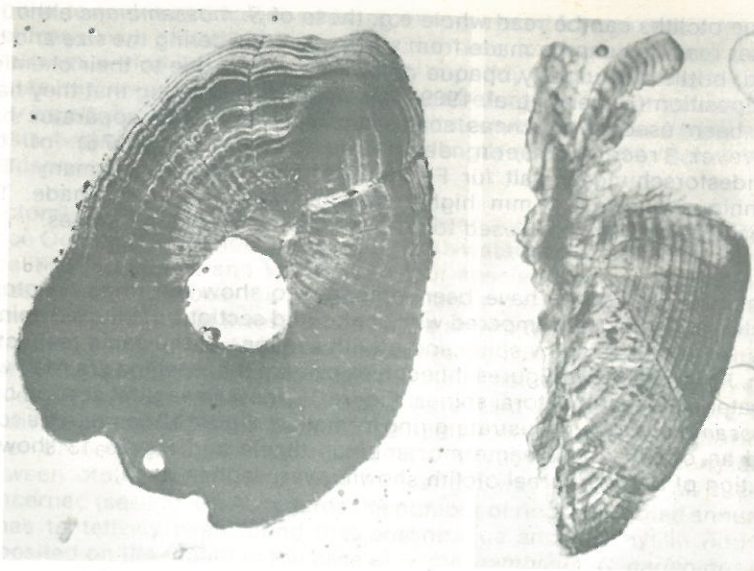


Fig. 10

Spine and lapillus section fo *Clarias gariepinus* (TL=109cm). (Age = 12 years).

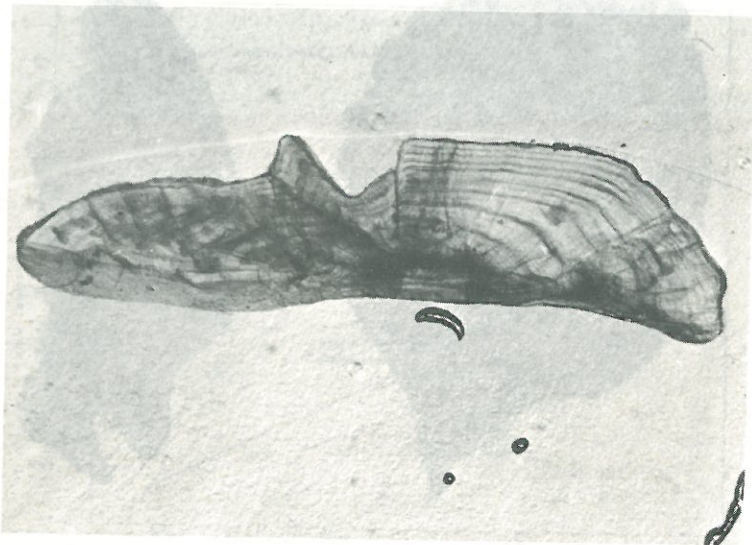


Fig. 11

Sagittal section of *Sarotherodon mossambicus* illustrating ring formation. (SL = 27,0cm) (Age = 8 years). One opaque and one hyalin ring deposited annually.

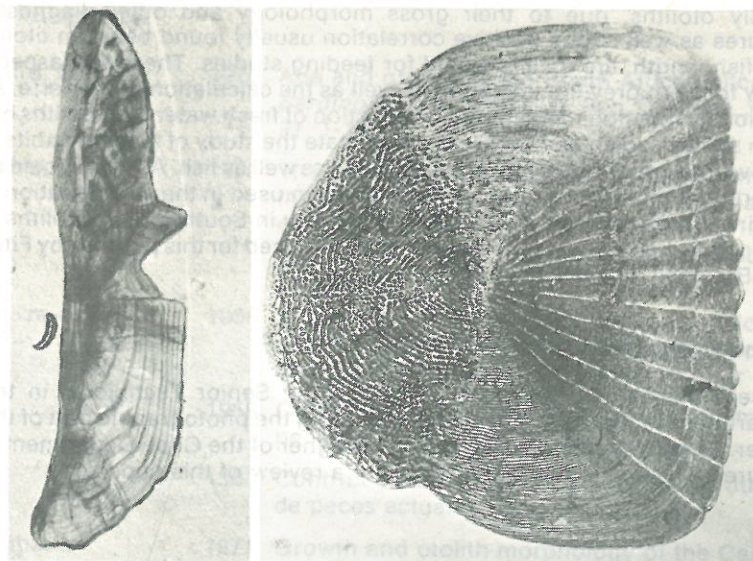


Fig. 12

Scale and sagittal section of *Sarotherodon mossambicus* illustrating distinct sagittal rings. (SL = 27,0cm) (Age = 8 years).

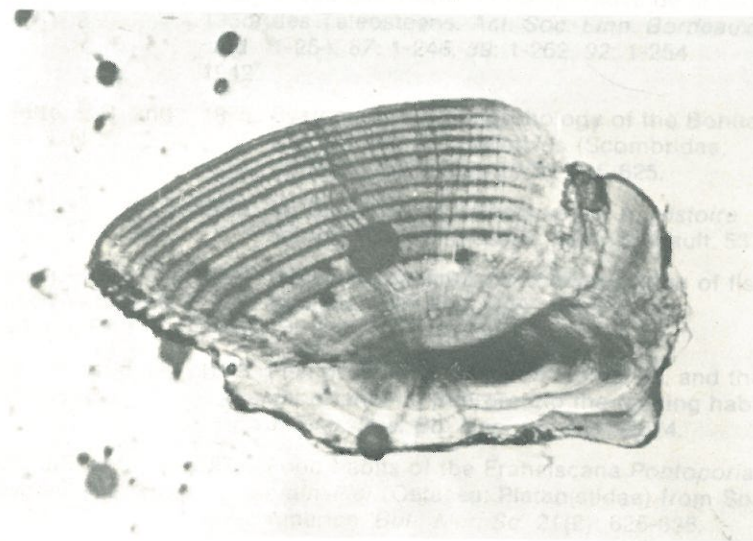


Fig. 13

Lapillus section of *Eutripius depressirostris* illustrating distinct ring formation. (TL = 33,2 cm) (Age = 5 years). Two opaque and two hyalin rings deposited annually.

Finally otoliths, due to their gross morphology and other diagnostic features as well as the positive correlation usually found between otolith and fish length, are ideally suited for feeding studies. These two aspects allow for both prey identification as well as the calculation of prey size. As previously mentioned a reference collection of fresh water fish otoliths has been started which should greatly facilitate the study of feeding habits of piscivorous predators such as otters, birds as well as fish. As far as could be ascertained otoliths have not previously been used in the interpretation of feeding habits in fresh water fisheries biology in South Africa. Otoliths of marine fish have, however, been successfully used for this purpose by Fitch and Brownell Jr. (1968 and 1971).

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ABSTRACT

The purpose of this paper is a twofold attempt to stimulate interest in the use of otoliths in freshwater fish biology in South Africa. Firstly the specific nature of otoliths and how they may, therefore, aid in taxonomy is discussed. Secondly it is shown that otoliths can be successfully used for ageing and subsequent growth studies. Their advantage over spines and scales in growth studies is also discussed.

ZUSAMMENFASSUNG

Diese Arbeit ist ein zweifacher Versuch die Intresse für Otolithen in beide der Fischereibiologie und in der Süßwasserfisch Systematik in Süd Afrika zu stimulieren. Zuerst wird der Wert von Otolithen in der Systematik besprochen und zweitens der Wert von diesen Strukturen in der Fischereibiologie insbesondere über Altersbestimmung und Wachstum.

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