

THE VALUE OF CERTAIN MORPHOLOGICAL FEATURES  
IN THE AGE DETERMINATION OF THE SMALL MOUTH  
YELLOW FISH BARBUS HOLUBI (STEINDACHNER 1894)

BY

C. C. STRAUB

(University of the North, Sovenga)

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CONTENTS

1.	INTRODUCTION .....	1
1.2	HISTORIC REVIEW .....	4
1.3	THE FISH SCALE .....	8
1.4	THE PROBLEM .....	11

SECTION I

2.	THE SUITABILITY FOR AGE DETERMINATION OF SCALES FROM DIFFERENT AREAS OF THE BODY .....	12
2.1	MATERIALS AND METHODS .....	12
2.2	THE FISH USED FOR THIS INVESTIGATION .....	13
2.3	REMOVAL OF THE SCALES, FURTHER TREATMENT AND MEASUREMENTS .....	15
2.4	BACK CALCULATIONS OF THE LENGTHS OF THE FISH ..	16
2.5	ANALYSES OF THE BACK CALCULATIONS .....	17
3.	RESULTS .....	19
3.1	BACK CALCULATIONS .....	19
3.2	VARIATION AMONGST SCALES FROM THE FISH OF GILFILLAN DAM AND AMONGST THOSE FROM THE FISH OF NEL'S PAN .....	23
3.3	ANALYSES OF VARIANCE OF THE SCALES FROM THE FISH OF GILFILLAN DAM AND NEL'S PAN .....	26
3.4	SCALE SHAPE .....	42
3.5	READABILITY OF THE SCALES .....	45

3.6	THE MOST SUITABLE SCALE NUMBERS FOR AGE DETERMINATION ACCORDING TO BACK CALCULATIONS OF FISH LENGTHS, SCALE SHAPE AND READABILITY .....	47
3.7	CORRELATIONS .....	48
3.8	THE NUMBER OF SCALES THAT SHOULD BE SAMPLED PER FISH .....	51
4.	CONCLUSIONS .....	53

SECTION II

5.	THE BODY-SCALE RELATIONSHIP OF <u>BARBUS HOLUBI</u> ..	55
6.	MATERIAL AND METHODS .....	59
7.	RESULTS .....	66
8.	CONCLUSIONS .....	70

SECTION III

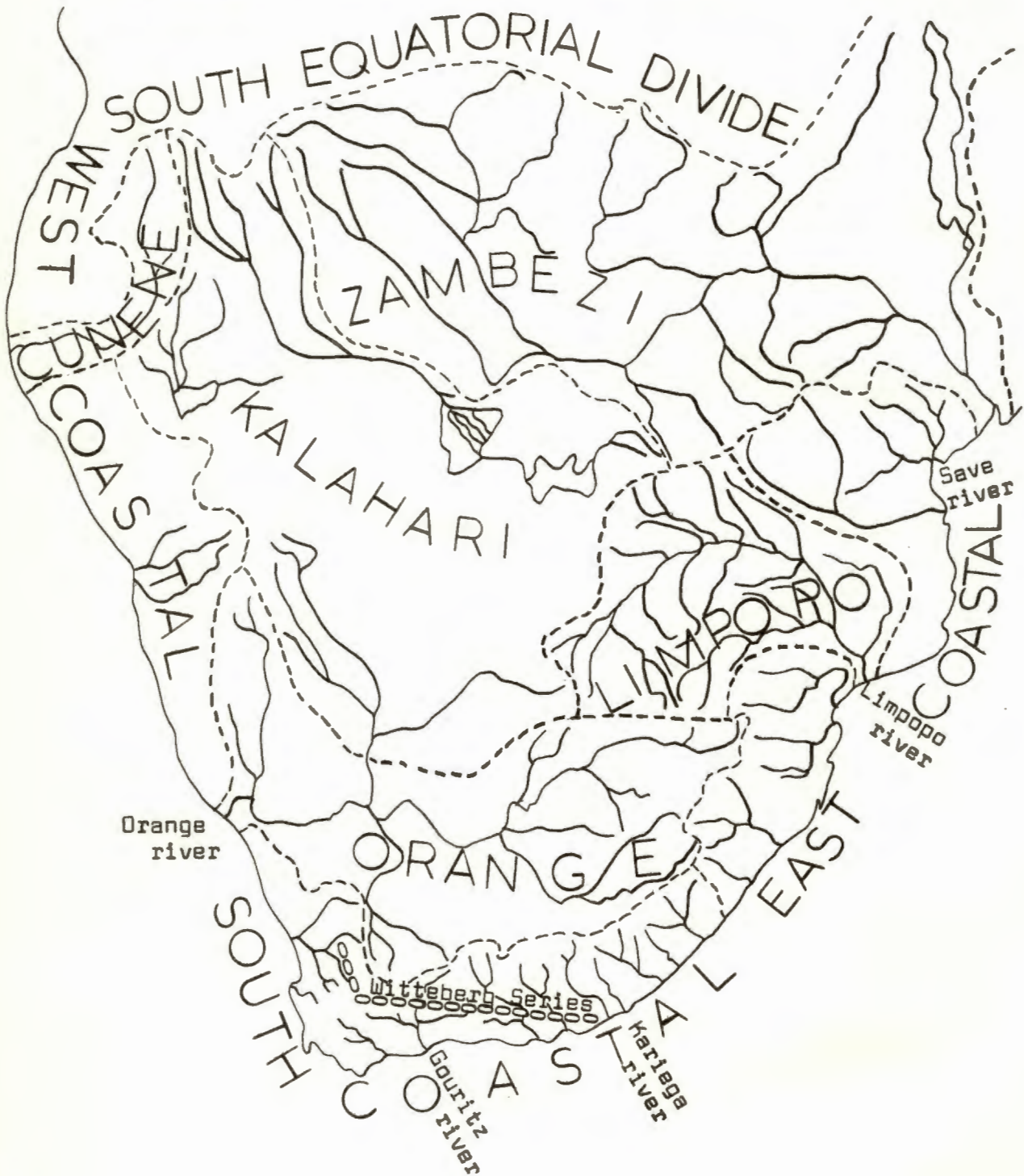
9.	A COMPARISON OF THE SCALE METHOD WITH THE LENGTH-FREQUENCY METHOD OF AGE DETERMINATION .....	71
9.1	INTRODUCTION .....	71
9.2	TIME OF ANNULUS FORMATION .....	73
9.3	LENGTH FREQUENCY MODES .....	74
10.	MATERIAL AND METHODS .....	74
11.	RESULTS .....	80
12.	CONCLUSION .....	83
13.	GENERAL DISCUSSION OF RESULTS .....	84
14.	SUMMARY OF RESULTS .....	88
15.	ACKNOWLEDGEMENTS .....	89
16.	LITERATURE CITED .....	90
17.	APPENDIX OF TABLES .....	94

## 1. INTRODUCTION

The oldest fossil records of fish in South Africa come from the Witteberg Series in the Cape Province (Fig. 1). These fish lived in the Palaeozoic Era about 250 million years ago and had ganoid scales. They could have been fresh water or marine forms. These fish gradually died out and were later replaced in the Mesozoic Era, about 150-175 million years ago, by endemic genera. Fossils of these can be found in the Beaufort beds of the Karroo System and they were probably fresh water forms. These fish were all destroyed by volcanic activity and drought. No fossils were deposited during the Tertiary Era nor during the past 60 million years in South Africa. Only during the past one million years have our present day fish moved down from North Africa and Asia, into Southern Africa. The genus Barbus (Cuvier and Cloquet, 1816) moved right down to the southern tip of the continent where most species today belong to the family Cyprinidae. This includes the mud fish and yellow fish as well as many minnows (Jubb 1967).

The Vaal river yellow fish, Barbus holubi (Steindachner, 1894), is one of the larger indigenous species from the Orange river and its tributaries in Southern Africa. The Orange river complex is the largest west-flowing river system in the Republic of South Africa and drains some of the highest rainfall areas of the Transvaal province. It also drains the Witwatersrand which harbours the highest concentration of anglers in the Transvaal. Winter temperatures in this area are too low for the survival of the numerous good

Fig. 1 The drainage basins of Southern Africa (After J.H. Wellington, 1955) showing the river systems into which the Vaal River yellow fish, Barbus holubi (Steindachner, 1894) has been introduced, and also the position of the Witteberg Series.



angling fishes found in the east-flowing rivers of the Transvaal, such as the Limpopo and Olifants. Consequently, B. holubi may be regarded as the most important indigenous fresh water angling fish in the Transvaal province. The barble, Clarias gariepinus (Burchell, 1822) is a much larger fish from both east and west flowing rivers and might also be far better for the table, but unfortunately it is sluggish and not favoured by anglers.

B. holubi is also an excellent fish for the stocking of impoundments in cold areas. Fingerlings appear to survive well after being moved from one area to another and since B. holubi breeds in flowing water only, it is possible to regulate a population of this species in an impoundment accurately, it being known that no natural population increase is taking place.

The importance of B. holubi as a freshwater angling fish is increasing. Fingerlings are bred at the Lydenburg, Transvaal Provincial Fisheries Institute from where they are sent to various rivers and impoundments not previously containing this species. The Limpopo river system is one example and they have also been introduced into the Kariega and Gouritz rivers in the Cape Province. In Rhodesia they have been introduced into Lake Kyle which is on a tributary of the Save river in Mozambique (Fig. 1).

The accurate control of angling pressure on any fish species depends on the ability to determine the age of samples caught. As a rule, the presence in an impoundment of only a few large fish which are not very old, indicates

that the angling pressure has been too high, causing too rapid a depopulation. By the same argument large numbers of small but old fish indicates overstocking or too little angling pressure. It is for this reason that this investigation has been carried out. Thus far very little work has been done on the age determination of the South African fresh water fishes. Le Roux (1961) used the scales of Tilapia mossambica (Peters, 1852) to determine its age. However, age determination from scales is a very old method.

## 1.2 HISTORIC REVIEW

Van Oosten (1929) reviewed the history of this technique and the following has become evident:

Scales were examined under the microscope by Fabricius d' Aquapendente (1618, 1621, 1625), Borellus (1656) and Hooke (1667). In a letter dated July 25, 1684, van Leeuwenhoek states that he found the same number of circular lines on different scales from the same fish. He concluded that one of these lines was added each year and that the fish concerned was therefore seven years old. Turrell (1911) believed that these circular lines referred to, were growth zones on the scales. In another letter dated May 22, 1716, van Leeuwenhoek described how he had determined the age of a carp which was  $42\frac{1}{4}$  inches long. Scales from this fish had 40 rings from which he concluded that it was 40 years old. In the same letter he also postulated that scale growth was due to the formation each year of a new larger scale underneath the old one. The two then gradually fused but the margin of the old one remained as an annual ring, and the process was repeated each year.

Réaumur (1718) stated that in his opinion the circular rings mentioned merely showed different degrees of growth in scales as the analogous markings do in the growth of mollusc shells. Early workers did not only study scales. Pastor Hederström (1759) noted that the vertebra from a boiled fish had certain rings on it, each representing a year in time.

Kuntzmann (1829) examined scales from young and old carp and found the same number of concentric lines on all. He concluded that these lines did not, therefore, indicate age. Blanchard (1866) came to the same conclusion from his examination of fish, the species of which is not stated. Agassiz (1834) believed that the number of rings increased with the growth of a fish and were caused by the "reflexed edges of the lamellae". Mandl (1839) claimed that their formation was linked with the "peripheral growth of the superior layer of the scale" while Williamson (1851) asserted that they were the "result of a peculiar arrangement of the superficial tissue of the scale".

After examination of young salmon Vogt (1842) found that scales only appeared after the third month and that as the fish became older the concentric rings on them became more numerous. Steenstrup (1861) was the first to state that the scales of osseous fishes persist for the duration of life and grow larger as the fish grows larger.

Baudelot (1873) compared the scales from one fish and also from numerous fishes of the same species. He examined twelve species in this way and found that the number of

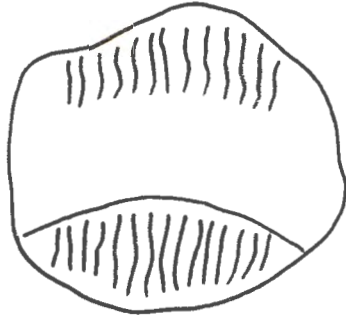
concentric ridges remained fairly constant on scales taken from the same body region of the fish and that their numbers could be correlated with age and size. He also noted that the distances between consecutive ridges varied, so that zones were visible on the scales. These results were correlated with those of van Leeuwenhoek's by Hintze (1888) who studied the age and life history of the carp.

Fritsch (1893) compared the circuli on salmon scales from fish of known age but varying lengths, the range being from 34 millimeters to 90 centimeters long. He found that the number of circuli represented the age of these fish and that the distance between them indicated the growth rate during that year.

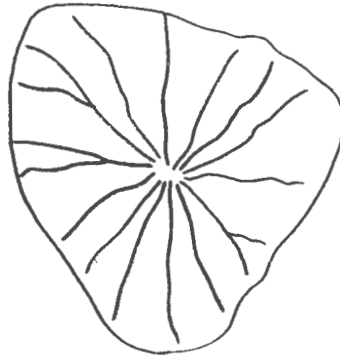
Petersen (1895) called the zones on eel scales "growth streaks" and believed that they may correspond in number with the age of the fish in years. Smitt (1895) observed that herring scales also have "growth rings" on them which van Oosten believed to be annuli.

In 1898 Hoffbauer published his findings on this subject which were based on conclusive evidence in favour of age determination by scales. He studied the scales of carp bred and reared in ponds for commercial purposes. All subsequent research in this field until at least 1929 was based on Hoffbauer's methods.

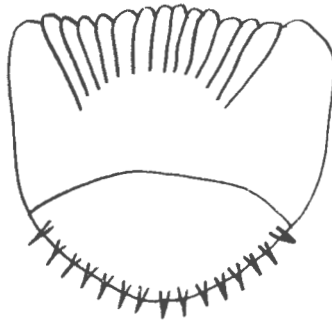
Fig. 2 Scale types, the first of which being found on B. holubi.



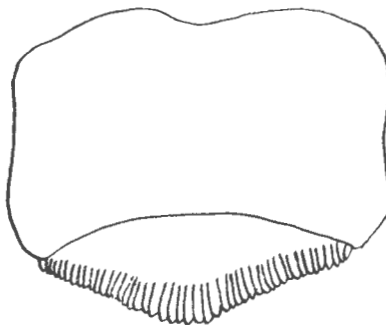
CYCLOID SCALE, longitudinally striated.



CYCLOID SCALE, radially striated.



CTENOID SCALE.



CILIATED SCALE.

### 1.3 THE FISH SCALE

Fresh water fishes in South Africa have three kinds of overlapping scales. They are cycloid, ctenoid or ciliated (Fig. 2). The striations or sulci of the former may be longitudinally arranged or radially arranged. Most large members of the genus Barbus, including B. holubi, have the former type. The eel and Clarias have no scales.

The part of a scale which is exposed on a fish, i.e. the posterior region, is called the lunula. On B. holubi this region of the scale shows no circular striations or circuli. All indications of age are found on that region of the scale covered by the others.

Neave (1940) made a histological study of the scales of the gold fish Carassius auratus L. and of the guppy Lebistes reticulatus (Peters), which are typical of the cycloid and teleost types. He made a microscopic section through the posterior region of a large goldfish scale, which was then stained with Alum haematoxylin and Eosin. This area of the goldfish scale has unusual pads or caps over the ridges and a sketch of the section shows one of these in relation to the other regions of the scale (Fig. 3). Figure 4 is a photograph of the transverse section of a yellow fish scale enlarged 580 times by a scanning electron microscope. This clearly shows the fibre plate shown in Fig. 3 to be made up of many lamellae.

Basically the teleost scale is covered by two cell layers on the external surface. The inner scale surface is lined by a cell layer which is continuous with the inner

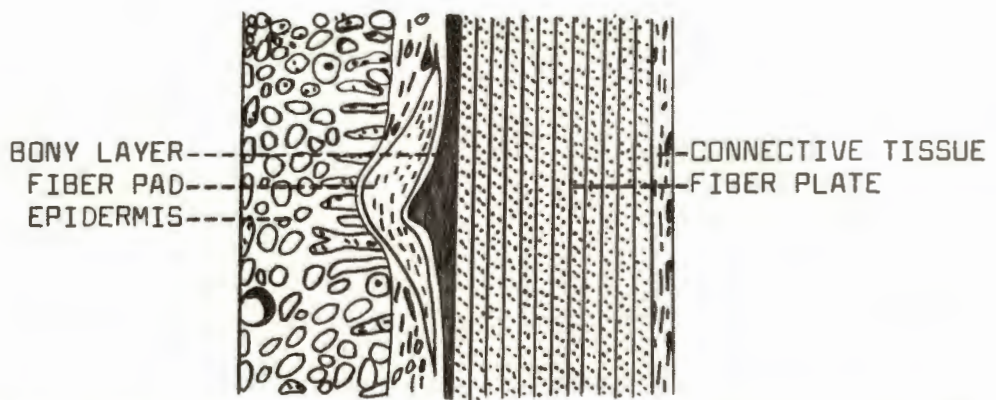


Fig.3 Sketch of transverse section through the posterior region of a large goldfish scale Carassius auratus L. showing the various tissue layers. (After Neave 1940)



Fig.4 Scanning electron microscope photograph X 580 of a transverse section through a yellow fish scale (B. holubi) showing the fibrous lamellae. (Film reference: A/20 10-11-1969)

cell layer on the outer scale surface. These cells are osteoblasts and osteocytes and form the outer calcified or bony portion of the scale. Below this is the fibrilla plate made up of many fibrous lamellae.

The outer calcified layer of the scale bears the ridges or circuli and annuli arranged in a concentric manner radiating out from the focus. These circuli are interrupted at intervals by the sulci or radial striations. Most of the circuli are restricted to the anterior region of the scale. Neave believes that the circuli are formed between cell rows from bone-forming materials in the inter-cellular fluid. The fibrillary plates below the bony layer are originally collagenous made of scleroprotein which later becomes impregnated with a substance Neave calls ichthyolepidin. The whole scale is mesodermal in its tissue relationships.

The striations or sulci on the scale are lines of flexibility which are caused by the absence of the bony layer and the absence of ichthyolepidin in the laminated layer along the striations.

Lost scales are regenerated either from one growth point or from a number of growth islands. Those of the former type are said to be monocentric and the latter polycentric. Regenerated scales are without circuli in the centre and Neave believes this to be due to a dearth of scale-forming material at the site of damage. The size of the central area does not correspond to the size of the original scale.

Time marks can be placed on goldfish scales by injecting them with lead acetate at a concentration of 0,5% Pb-acetate in 0,1 ml. of water per 10 grams fish weight (Hiyama and Ichikawa 1952). Another substance which can be used is a 5 to 7 percent solution of lead disodium versenate injected at a concentration of 50 milligrams per kilogram fish weight. This method was developed by Fry, Cucin, Kennedy and Papson (1960) and was tested on the white fish Coregonus clupeaformis (Mitchill) and the trout Salvelinus namaycush (Walbaum). Both these methods cause a dark band to be deposited in the scales of treated fish with each injection. In this way the age and rate of growth of a treated fish can be determined at a later stage. However, De Bont (1966) had no success with this method on members of the family Cichlidae, but injected aureomycin did mark the scales of Tilapia melanopleura (Dumeril 1859).

#### 1.4 THE PROBLEM

This investigation involved three separate projects. Section one was an examination of suitably prepared scales from fish of known age to see if they recorded the age in some way. The best body area from which to remove scales for this purpose was also determined.

Section two involved the comparison of the scale radii with fish lengths to find out what this relationship is and what formula best represents this relationship. Here fish of unknown age were used.

The third section involved the age determination of fish of unknown age from their scales and a comparison of the results with their age as determined by the length-frequency method.

## SECTION I

### 2. THE SUITABILITY FOR AGE DETERMINATION OF SCALES FROM DIFFERENT AREAS OF THE BODY

#### 2.1 MATERIALS AND METHODS

Phillips (1948) made an intensive study of 13 scales from each of a number of Pacific pilchards or sardines to see if some were not more suitable than others for determining age. However, it had already been shown by Walford L.D. and Mosher K.H. (1943) that age can be determined from the scales of the sardine, whereas in the case of B. holubi this had not yet been proved. An examination of the scales from specimens of B. holubi caught in Barberspan, Western Transvaal (Göldner, 1967), revealed numerous marks. It was in many cases difficult to decide whether these marks represented annuli or not. In order to solve this problem, the present intensive study of 520 scales from 20 specimens of known age was undertaken. The idea was to test the feasibility of age determination by the scale method on B. holubi, to define the most suitable scale sampling areas on the fish and to refine the technique involved, if necessary. The knowledge thus gained has been applied to B. holubi scales originating from Barberspan fish on which Göldner (1967) obtained age groupings on the basis of length frequency.

## 2.2 THE FISH USED FOR THIS INVESTIGATION

In November of 1962, fingerling yellow fish, bred at the Provincial Fisheries Institute at Lydenburg in the Eastern Transvaal, were placed in two impoundments. The one was a new dam built by Mr. C. Gilfillan on his farm which is situated thirteen miles from Oogies near Witbank,  $26^{\circ} 4'S$ ,  $29^{\circ} 3'E$ . Before stocking this dam, it was well netted to check that there were no other fish in it. This dam was built in a valley just below a number of pigsties and a dairy. It could, therefore, be considered to be a fertile dam. This was also borne out by the colour of the water and the size of the frogs, Xenopus laevis (Daudin), caught during netting operations. The size of this dam is about 4,3 hectares.

The second impoundment which was stocked is a natural pan, known as Nel's Pan, situated sixteen miles from Ermelo,  $26^{\circ} 32'S$ ,  $29^{\circ} 59'E$ . This pan is about 32,5 hectares in size and was, therefore, difficult to net thoroughly before stocking. However, all that was caught were eight blue gill, Lepomis machochinus (Rafinesque). Numerous water birds live on this pan.

In July 1966 both impoundments were netted again. Thirty-one B. holubi were recovered from the Gilfillan dam and twenty-nine from Nel's Pan. From each of these two groups, ten fish were chosen at random for this study. From each of these fish, twenty-six scales were removed from different places on one side of the body, as indicated by Fig. 5. Although the average length of all the males

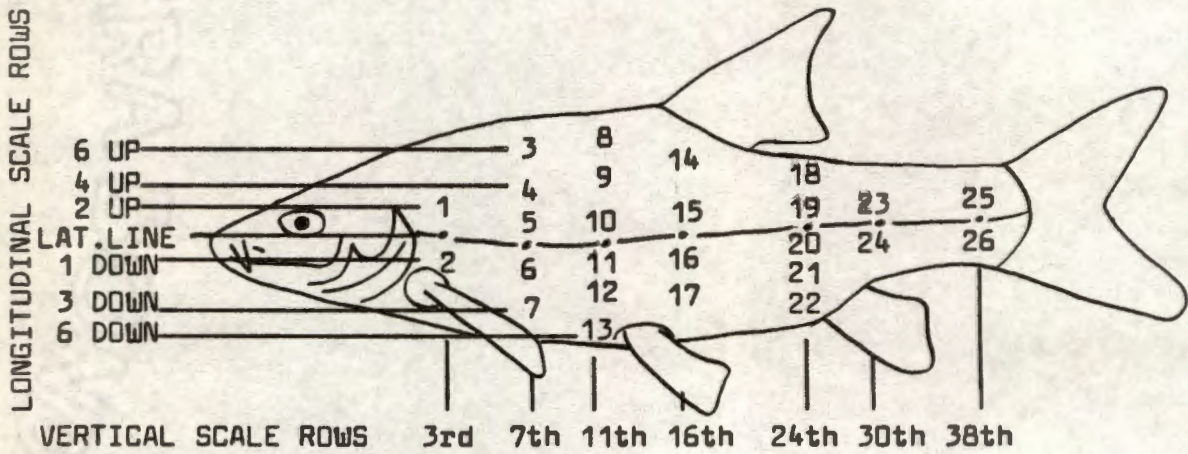


Fig.5 Areas from which scales were removed. The scales are numbered 1 to 26 on the fish.

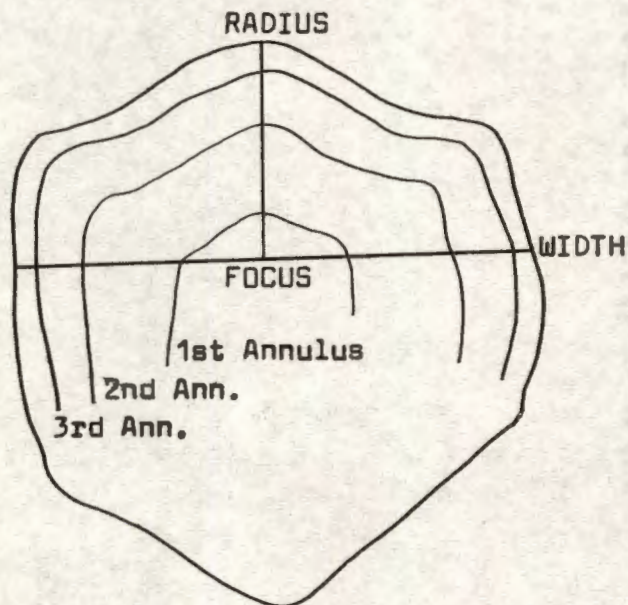


Fig.6 Sketch of scale showing where the various measurements were taken.

caught from both impoundments was slightly less than that of the females, the difference was not statistically significant. Consequently, the sex of the twenty fish chosen for this study was not taken into account.

### 2.3 REMOVAL OF THE SCALES, FURTHER TREATMENT AND MEASUREMENTS

Six longitudinal rows of scales were chosen, i.e. running from anterior to posterior, and seven vertical rows of scales were chosen, i.e. running from dorsal to ventral (Fig. 5). Where these rows crossed one another, twenty-six scales were removed and mounted dry between two microscope slides. The longitudinal rows were taken parallel to the lateral line but two rows, four rows, and six rows above it, as well as one row, three rows, and six rows below it. The vertical rows of scales were chosen three, seven, eleven, sixteen, twenty-four, thirty and thirty-eight scales back from the head along the lateral line. Scale 1, for example, was taken from a point three scales back along the lateral line and two scales above it. The others were removed from points as indicated in Fig. 5. Before mounting, the scales were first washed in water with a pinch of alumn dissolved in it and then washed in water containing a detergent. They were then rinsed in clean water.

These scales were then projected through a microfilm reader which gave a magnification of nineteen times. Measurements were taken of each scale as follows :- The distance from the focus to the scale edge or margin and from the focus to each concentric mark or circulus on the

scale was recorded as well as the width of each scale through the focus, as in Fig. 6. The focus is the centre of the sculptured or striated area on the anterior half of the scale. Disturbances in these striae leave marks or circuli which are referred to as annuli in cases where they occur at yearly intervals. In some fish, including the Indian fresh water carp, Catla catla (Ham), from the Jamuna river, the annuli are formed at spawning and as a result they are only formed after the fish are sexually mature. They appear as light bands caused by grooves between the striae (Natarajan and Thingran, 1963).

#### 2.4 BACK CALCULATIONS OF THE LENGTHS OF THE FISH

The fish length at the time of the formation of each annulus was then calculated by using the formula

$$f = \frac{sF}{S}$$

where:

f = the fork length of fish when annulus was formed

F = the fork length of the fish when caught

s = the length of the projected scale from focus to annulus

S = the length of the projected scale from focus to margin

(Phillips 1948)

The fork length of a fish is the length from the tip of its nose to the bottom of the V in the centre of the tail.

At this stage it was presumed that the ratio of scale growth to body growth is constant for B. holubi. The brown trout Salmo trutta L. does not always give constant scale length to body length. This ratio depends on the locality from where the fish come, (Kipling 1962)

## 2.5 ANALYSES OF THE BACK CALCULATIONS

The data for the fish from both impoundments was given the following treatment: The average length of each fish according to each annulus was calculated. The percentage difference from the mean length of each fish was then calculated for each scale. The absolute values for each scale number were then totalled and averaged. Scale numbers with the smallest percentage variation from the means should then be the best for back calculations. This procedure affords an easily understandable and rough idea of the extent of variation amongst scales, but does not necessarily reflect significant differences between the scales.

The back calculated lengths of fish for all three annuli from both Gilfillan dam and Nel's Pan were then subjected to a two-way orthogonal analysis of variance and to the F-test, to determine if there were significant differences between all the scales from each fish or the same scale number from all the fish. The back calculations according to the scales from the fish of both impoundments were then subjected to a two-way orthogonal analysis of variance after the differences between the average calculated fish lengths had been eliminated. One conceivable way of doing this is to randomise the scales according to scale numbers amongst the ten fish. However, it was decided to carry out transformations to achieve the same purpose. The average length of each fish according to each annulus was obtained and used to transform the value for each scale to a central value for each annulus. Thus the differences between the

mean values for each fish were eliminated while the variation between scale numbers and fish was retained.

The results of the analyses of variance were used to set up confidence limits for differences between the means for scale numbers in order to detect significant differences between these means and the central value. Scale numbers with means not significantly different from the central value would then be most suitable for back calculations.

The suitability of the scales for back calculations was also determined by their shape. A desirable scale would be a well formed one with large distances between annuli. The annuli were measured from the focus along the radius as indicated in Fig. 6. Therefore, the distance from the focus to the scale margin along this plane must be as great as possible compared to the width of the scale. To identify the best scales from this point of view, the mean ratios of scale width to distance from the focus to scale margin (scale radius) were calculated for each scale number. Scale numbers giving the lowest mean ratios should then be the best for back calculations. The magnitude of the differences in shape between scales was also illustrated by subjecting them to a two-way orthogonal analysis of variance and the F-test. The scales from each impoundment were first treated separately and then together.

The last criterion used to judge the scales for their suitability to age determination was their readability. Each of the 520 scales was classified according to its

readability under the following headings:- good, fair, poor, extra lines and dark bands. Scale numbers with the highest frequency of 'good' readability should then be the most suitable for age determination.

Correlations between the actual lengths of the fish when caught and lengths according to the back calculations were computed to see whether there were any close relationships between these values.

Finally, the number of scales per fish that should be measured to obtain acceptable confidence intervals for the back calculated values, was computed.

### 3. RESULTS

#### 3.1 BACK CALCULATIONS

The basic measurements made on the 520 scales are given in tables A1 and A2 in the appendix for the fish from Nel's Pan and Gilfillan dam respectively. (All tables with numbers prefixed by A, B or C are to be found in the appendix.) Since all further calculations based on this basic data involved ratios, these measurements of the magnified images of the scales were not transformed back to the real distances on the scales. In some cases the scales had been regenerated in the area nearest to the focus so that the first annulus could not be seen.

The back calculated lengths of the fish according to each scale and appropriate annulus are given in tables A3 to A5 and A6 to A8 for the fish from Nel's Pan and Gilfillan dam respectively. By comparing the calculated fish lengths for

each annulus as given in Tables A3 to A8, it was possible to see which results were obviously incorrect. These scales were re-examined and in this way the various annuli were identified correctly. This method turned out to be very useful.

About 32% of the scales showed no fourth annulus and so the above tables only deal with the first three annuli. As already stated, these fish were all  $3\frac{1}{2}$  years old when caught in the month of July. Indications are, therefore, that the annuli are formed in July and August or, basically in winter. There is evidence that the annuli and other circuli in the European pilchard, Sardina pilchardus (Walbaum), are caused when the growth of the fish stops for some reason or other. This could be due to spawning or wintering and rings are formed partly by absorption and partly by fracture of the scale edge. (Blackburn 1951).

Tables A3 to A8 also give the average of calculated lengths for each fish. For some reason the calculated lengths of the fish from Nel's Pan when the first annulus was formed, as given in Table A3, are too low. It can only be assumed that for some reason this annulus was formed before winter. In Table A6 the calculated lengths for the first annulus for fish from the Gilfillan dam are more like what one would expect. The average calculated fish length when the first annulus was formed in Nel's Pan is 47,7 mm which is more like the size of the fish when they were introduced into the pan. This annulus may have been caused by the shock of being moved. The difference in climate between the

impoundment where these fish were bred and Nel's Pan is far greater than the difference between this impoundment and the Gilfillan dam. The average calculated length at the first annulus for the fish from the Gilfillan dam is 77,4 mm. This is lower than what Göldner (1967) found in his investigation of Barberspan.

The average of the calculated lengths (tables A4 and A7) for the 2nd annulus is 227,9 mm for fish from the Gilfillan dam and 193,6 mm for those from Nel's Pan, giving a difference of 34,3 mm. This again shows a faster growth rate for the fish from the Gilfillan dam, in spite of the fact that it is so much smaller than Nel's Pan. The averages calculated from the 3rd annulus (tables A5 and A8) are 325,0 mm for the fish from the Gilfillan dam and 289,4 mm for Nel's Pan. The difference is 35,6 mm. The average length of the fish when caught from the Gilfillan dam is 381,2 mm and for those from Nel's Pan 361,0 mm. The difference is 20,2 mm and is less than the previous differences.

It is interesting to note that, of the 520 scales examined, 164 showed no fourth annulus. Of these, 134 came from fish from Nel's Pan and only 30 from the Gilfillan dam. The new season's growth after winter seems to start later and probably ends earlier, because snow in the Ermelo district is not uncommon, which indicates that the climate is somewhat colder there than it is in the Witbank district. The fish in Nel's Pan showed a faster rate of growth in the last year than those in the Gilfillan dam. This may have been caused by a change in diet due to age or a better season in the Nel's Pan area.

The absolute percentage variation from the mean calculated fish lengths averaged for each scale.

Fig.7 GILFILLAN DAM

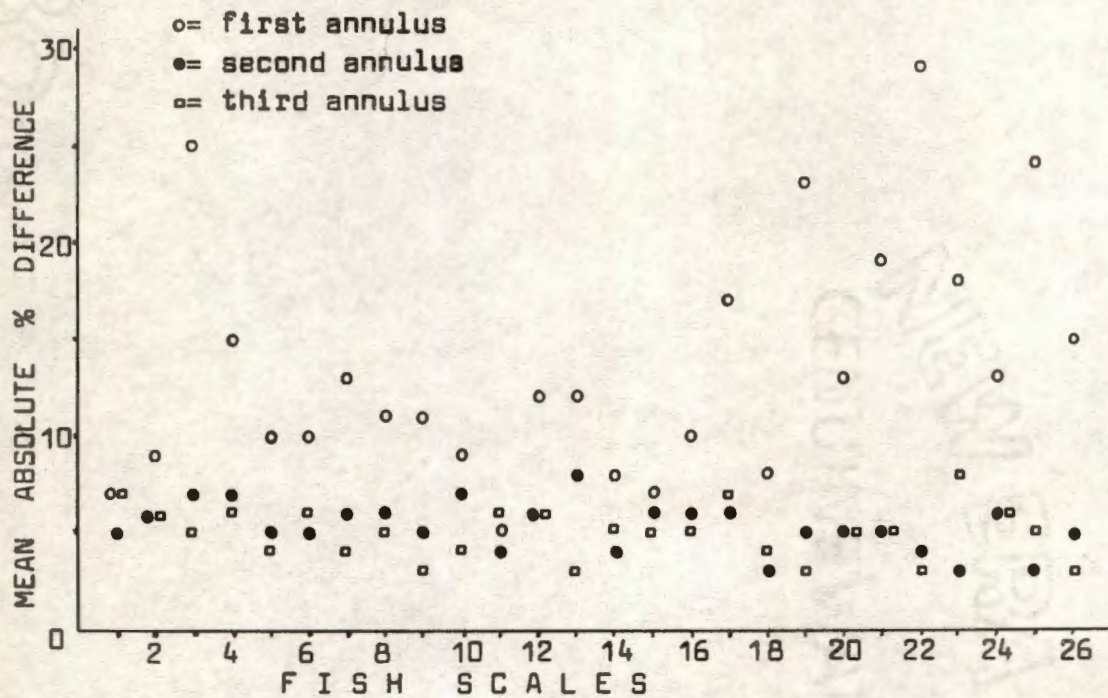
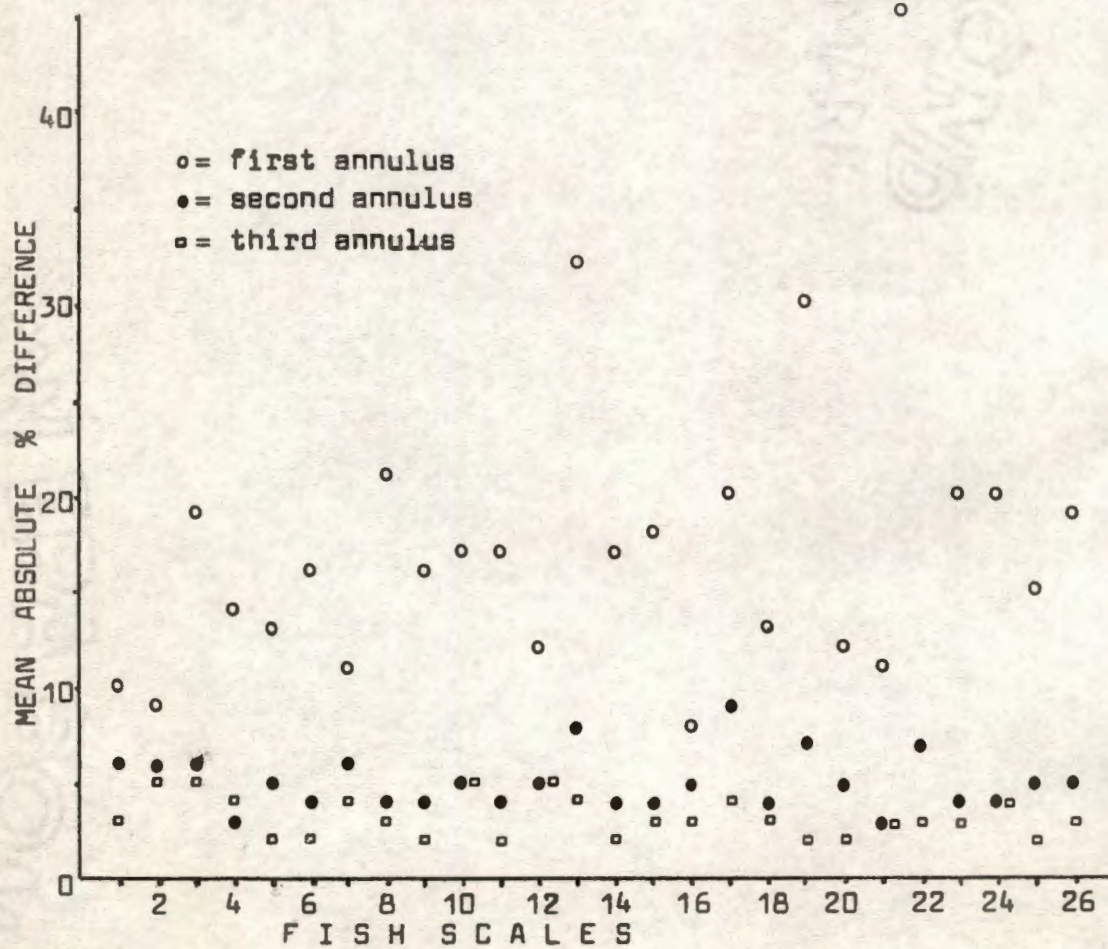


Fig.8 NEL'S PAN



### 3.2 VARIATION AMONGST SCALES FROM THE FISH OF GILFILLAN DAM AND AMONGST THOSE FROM THE FISH OF NEL'S PAN

The absolute percentage variation from the mean calculated fish lengths averaged for each scale number appears in table A9 for Gilfillan dam fish and in table A10 for Nel's Pan fish. The results are graphically represented in figure 7 for the Gilfillan dam and in figure 8 for Nel's Pan. It is immediately clear that back calculations based on the first annulus are much more variable in both cases than those based on the second and third annuli. The mean values for the annuli are respectively 13,6; 5,3; and 5,0 % for the Gilfillan dam and 17,5; 5,1; and 3,2 % for Nel's Pan. It is interesting to note that the mean percentage variation for the first annulus is considerably higher for Nel's Pan than for Gilfillan dam but that the values for the other two annuli are lower. This supports the idea that the first annulus on the scales from the two different impoundments were caused by different stimuli.

In order to select the scale numbers with the smallest variation, the mean values themselves for each annulus were regarded as upper and lower limits of tolerable variation from the means. The resultant selections appear in tables 1 and 2.

Table 1. GILFILLAN DAM. SCALES WITH THE SMALLEST PERCENTAGE DEVIATION FROM THE MEAN  
(Equal to or smaller than the annulus mean)

Scale No.	1st Annulus	2nd Annulus	3rd Annulus	1st, 2nd, 3rd
1.	0	0		
2.	0			
3.			0	
4.				
5.	0	0	0	0
6.	0	0		
7.	0		0	
8.	0		0	
9.	0	0	0	0
10.	0		0	
11.	0	0		
12.	0			
13.	0		0	
14.	0	0	0	0
15.	0		0	
16.	0		0	
17.				
18.	0	0	0	0
19.		0	0	
20.	0	0	0	0
21.		0	0	
22.		0	0	
23.		0		
24.				
25.		0	0	
26.		0	0	

Table 2. NEL'S PAN. SCALES WITH THE SMALLEST  
 PERCENTAGE DEVIATION FROM THE MEAN  
 (Equal to or smaller than the annulus mean)

Scale No.	1st Annulus	2nd Annulus	3rd Annulus	1st, 2nd, 3rd
1.	0		0	
2.	0			
3.				
4.	0	0		
5.	0	0	0	0
6.	0	0	0	0
7.	0			
8.		0	0	
9.	0	0	0	0
10.	0	0		
11.	0	0	0	0
12.	0	0		
13.				
14.	0	0	0	0
15.		0	0	
16.	0	0	0	0
17.				
18.	0	0	0	0
19.			0	
20.	0	0	0	0
21.	0	0	0	0
22.			0	
23.		0	0	
24.		0		
25.	0	0	0	0
26.		0	0	

The fourth columns in tables 1 and 2 identify the scale numbers with acceptable small variations for all three annuli. Accordingly, the scales most suited for back calculations are numbers 5, 9, 14, 18 and 20 for Gilfillan dam, and numbers 5, 6, 9, 11, 14, 16, 18, 20, 21 and 25 for Nel's Pan.

All the most suitable scale numbers from Gilfillan dam also appear from Nel's Pan, but there are twice as many suitable ones from Nel's Pan, i.e. ten. From figure 5 it can be seen that scale numbers 5, 9, 14, 18, 25 are all above the lateral line while numbers 6, 11, 16, 20 and 21 are immediately below it. Considering the results from both impoundments, it can be concluded that the most suitable scales are numbers 5, 9, 14, 18 and 20, or those mainly from an area just below, in front of and behind the dorsal fin.

### 3.3 ANALYSES OF VARIANCE OF THE SCALES FROM THE FISH OF GILFILLAN DAM AND NEL'S PAN

The calculated fish lengths for each impoundment were subjected to a two-way orthogonal analysis of variance for each annulus according to the model given below :

Source	d.f.	Sum of squares	Mean square
Fish	$f-1$	$T_1 - T_0$	
Scales	$s-1$	$T_2 - T_0$	<u>Sum of squares</u>
Error	$N-f-s+1$	$T - T_1 - T_2 + T_0$	d.f.
Total	$N-1$	$T - T_0$	

Where: d.f. = degrees of freedom

and where :  $f$  = the number of fish

$s$  = the number of scales per fish

$N$  = the total number of scales

$T$  = the total term =  $\sum(X_i^2)$

$T_1$  = the fish term =  $\frac{1}{s} \{ \sum(X_{f1}^2) + \dots + \sum(X_{f10}^2) \}$

$T_2$  = the scale term =  $\frac{1}{f} \{ \sum(X_{s1}^2) + \dots + \sum(X_{s26}^2) \}$

$T_0$  = correction term =  $\frac{1}{N}(\sum x_i)^2$

Sample standard error:  $S_E = \sqrt{\left(\frac{1}{f} + \frac{1}{f}\right) \text{ (Error mean square)}}$

Confidence limits for sample mean:

At  $2p = 0,33$ :  $\bar{x} \pm S_E$

At  $2p = 0,05$ :  $\bar{x} \pm 2S_E$

At  $2p = 0,001$ :  $\bar{x} \pm 3S_E$

Sample standard deviation:  $S_x = \sqrt{\text{Error mean square}}$

Coefficient of variation:  $Cv. = \frac{100S_x}{\bar{x}}$

Sample standard deviation of differences from the mean:

$$S_D = \sqrt{2} (S_x)$$

The results of the analyses appear below in tables 3, 4 and 5 for the Gilfillan dam and in tables 6, 7 and 8 for Nel's Pan.

Table 3 GILFILLAN DAM. ANALYSIS OF VARIANCE  
LENGTHS ACCORDING TO THE FIRST ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	12603,8	1400,42	7,41
Scales	25	10785,8	431,43	2,28
Error	225	42535,7	189,05	
Total	259	65925,3		

$S_E = 6,15$   
 $S_x = 13,75$   
 $C_v. = 17,75\%$   
 $S_D = 19,44$   
 $\bar{x} = 77,42$

Table 4 GILFILLAN DAM. ANALYSIS OF VARIANCE.  
LENGTHS ACCORDING TO SECOND ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	40562,44	4506,94	20,46
Scales	25	10288,35	411,53	1,87
Error	225	49562,96	220,28	
Total	259	100413,75		

$S_E = 6,64$   
 $S_x = 14,84$   
 $C_v. = 6,52$   
 $S_D = 20,98$   
 $\bar{x} = 227,57$

Table 5 GILFILLAN DAM. ANALYSIS OF VARIANCE  
LENGTHS ACCORDING TO THE THIRD ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	107177,77	11908,64	28,9
Scales	25	14950,26	598,01	1,45
Error	225	92749,43	412,22	
Total	259	214877,46		

$S_E$	=	9,08
$S_x$	=	20,30
$C_v.$	=	6,24%
$S_D$	=	28,70
$\bar{x}$	=	325,42

Table 6 NEL'S PAN. ANALYSIS OF VARIANCE  
LENGTHS ACCORDING TO FIRST ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	19481,54	2164,62	20,64
Scales	25	13182,99	527,32	5,03
Error	225	23593,36	104,86	
Total	259	56257,89		

$S_E$	=	4,58
$S_x$	=	10,24
$C_v.$	=	21,48%
$S_D$	=	14,48
$\bar{x}$	=	47,67

Table 7      NEL'S PAN.      ANALYSIS OF VARIANCE  
LENGTHS ACCORDING TO SECOND ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	40472,07	4496,90	28,74
Scales	25	5106,45	204,26	1,31
Error	225	35203,93	156,46	

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Total      259      80782,45

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$$S_E = 5,59$$

$$S_x = 12,51$$

$$C_v. = 6,46\%$$

$$S_D = 17,69$$

$$\bar{x} = 193,55$$

Table 8      NEL'S PAN.      ANALYSIS OF VARIANCE  
LENGTHS ACCORDING TO THIRD ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	103248,01	11472,00	63,62
Scales	25	6105,46	244,22	1,40
Error	225	39179,39	174,03	

---

Total      259      148532,86

---

$$S_E = 5,90$$

$$S_x = 13,19$$

$$C_v. = 4,56\%$$

$$S_D = 18,65$$

$$\bar{x} = 289,32$$

The F-values for a 1% and 5% level of significance from the F-tables for

$$F_{1\%} ; 9 ; 225 = 2,43$$

and for  $F_{5\%} ; 9 ; 225 = 1,92$

i.e.  $P(\underline{F} \leq 2,43) = 0,99$

and  $P(\underline{F} \leq 1,92) = 0,99$

That is, F-values in tables 3 to 8 for fish will indicate a highly significant difference at the different levels between different fish as far as age determination is concerned, if they are greater than the above F-values obtained from the tables.

The F-values for the scales at a 1% and 5% level of significance for scales, i.e. for  $F_{1\%} ; 25 ; 225 = 1,87$   
and  $F_{5\%} ; 25 ; 225 = 1,56$

From tables 3 to 8 it can be seen that there is a highly significant difference between the "fish" from both impoundments as far as back calculations from their scale annuli are concerned. There is only a highly significant difference between "scales" when the first annulus is used for back calculations of fish length. For the other annuli at the 1% level of significance, there is no significant difference between scales. At a 5% level of significance, only the second annulus scales from the Gilfillan dam show a significant difference. In the other five cases, i.e. tables 3, 5, 6, 7 and 8, there is no significant difference between scales at the 5% level of significance. At a 1% level, one scale is as good as another for back calculating fish lengths from second and third annuli.

The F-values for scales in tables 3 to 8 also show that the reliability of back calculations of fish length from scale annuli increases as the younger or more recent annuli are used, i.e. F-values decrease for the more recent annuli. The oldest annulus on a scale is the one nearest the focus, i.e. the first annuli, as indicated in tables 3 and 6.

The F-values for fish in tables 3 to 8 show that the younger fish have a far smaller variation between them than the older ones, i.e. the F-values increase with fish age. (When the third annulus is formed, the fish is older than when the first is formed.) This tendency can be expected because older fish have more time for variations to set in.

In order to eliminate the differences in fish lengths and to apply a more sensitive series of tests, the data of table A3 (Nel's Pan fish lengths according to each scale, first annulus) was transformed to a central value of 60; for example, the values for fish no. 39 were multiplied by the factor  $60/51$ . Thus the transformed version of table A3 contains the same average of 60 for each of the ten fish. Similarly the second annulus values (table A4) were transformed to a central value of 200, and the third annulus values (table A5) to a value of 300. Subsequently the means for the ten replicates of each scale number were obtained for each annulus (table A11).

The data in tables A6, A7 and A8 for Gilfillan dam was treated in a similar way but the first-annulus fish length (table A6) was transformed to a central value of 70, the second (table A7) to a central value of 225 and the third

(table A8) to one of 325. The means for the ten replicates of each scale number were obtained as before for each annulus and are represented in table A12.

The transformed data was also subjected to a two-way orthogonal analysis of variance for each annulus according to the model given on page 26. The results of the analyses appear below in tables 9, 10, and 11 for the Nel's Pan fish and in tables 12, 13 and 14 for the Gilfillan dam fish.

Table 9 NEL'S PAN. ANALYSIS OF VARIANCE  
ADJUSTED LENGTHS ACCORDING TO FIRST ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	1	0,11	0,008
Scales	25	21 896	875,84	6,25
Error	222	31 103	140,10	
Total	256	63 000		

$$S_E = 5,29$$

$$\bar{x} = 60,02 \pm 5,29 \text{ at } 2p = 0,33$$

$$\bar{x} = 60,02 \pm 10,58 \text{ at } 1p = 0,05$$

$$\bar{x} = 60,02 \pm 15,88 \text{ at } 2p = 0,001$$

$$S_x = 13,27$$

$$C_v. = 22,12\%$$

$$S_D = 18,76$$

Table 10 NEL'S PAN. ANALYSIS OF VARIANCE  
ADJUSTED LENGTHS ACCORDING TO SECOND ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	2	0,22	0,001
Scales	25	5 279	211,16	1,26
Error	225	37 695	167,53	
Total	259	42 976		

$$S_E = 5,78$$

$$\bar{x} = 200,04 \pm 5,79 \text{ at } 2p = 0,33$$

$$\bar{x} = 200,04 \pm 11,58 \text{ at } 2p = 0,05$$

$$\bar{x} = 200,04 \pm 17,37 \text{ at } 2p = 0,001$$

$$S_x = 12,94$$

$$C_v. = 6,47\%$$

$$S_D = 18,30$$

Table 11 NEL'S PAN. ANALYSIS OF VARIANCE  
ADJUSTED LENGTHS ACCORDING TO THIRD ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	5	0,56	0,003
Scales	25	6 655	266,20	1,42
Error	225	42 056	186,92	
Total	259	48 716		

$$S_E = 6,11$$

$$\bar{x} = 300,06 \pm 6,11 \text{ at } 2p = 0,33$$

$$\bar{x} = 300,06 \pm 12,23 \text{ at } 2p = 0,05$$

$$\bar{x} = 300,06 \pm 18,34 \text{ at } 2p = 0,001$$

$$S_x = 13,67$$

$$C_v. = 4,56\%$$

$$S_D = 19,61$$

Table 12 GILFILLAN DAM. ANALYSIS OF VARIANCE  
ADJUSTED LENGTHS ACCORDING TO FIRST ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	28,08	3,12	0,02
Scales	25	8628,46	345,13	2,32
Error	225	33529,92	149,02	
Total	259	42186,46		

$$S_E = 5,46$$

$$\bar{x} = 69,92 \pm 5,46 \text{ at } 2p = 0,33$$

$$\bar{x} = 69,92 \pm 10,92 \text{ at } 2p = 0,05$$

$$\bar{x} = 69,92 \pm 16,38 \text{ at } 2p = 0,001$$

$$S_x = 12,21$$

$$C_v. = 17,46\%$$

$$S_D = 17,26$$

Table 13 GILFILLAN DAM. ANALYSIS OF VARIANCE  
ADJUSTED LENGTHS ACCORDING TO SECOND ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	30,34	3,37	0,01
Scales	25	10321,60	412,86	1,91
Error	225	48553,36	215,79	
Total	259	58905,30		

$$S_E = 6,57$$

$$\bar{x} = 224,88 \pm 6,57 \text{ at } 2p = 0,33$$

$$\bar{x} = 224,88 \pm 13,14 \text{ at } 2p = 0,05$$

$$\bar{x} = 224,88 \pm 19,71 \text{ at } 2p = 0,001$$

$$S_x = 14,69$$

$$C_v. = 6,53\%$$

$$S_D = 20,77$$

Table 14      GILFILLAN DAM.      ANALYSIS OF VARIANCE  
 ADJUSTED LENGTHS ACCORDING TO THIRD ANNULUS

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	20,06	2,23	0,005
Scales	25	15673,78	626,95	1,46
Error	225	96708,14	429,81	
Total	259	112401,98		

$$S_E = 9,27$$

$$\bar{x} = 325,01 \pm 9,27 \text{ at } 2p = 0,33$$

$$\bar{x} = 325,01 \pm 18,54 \text{ at } 2p = 0,05$$

$$\bar{x} = 325,01 \pm 27,81 \text{ at } 2p = 0,001$$

$$S_x = 20,73$$

$$C_v = 6,38\%$$

$$S_D = 29,31$$

The F-values for fish as source in tables 9 to 14 are all very small because the variations due to different fish-lengths were eliminated. As before, for scales,

$$F_{1\%} ; 25 ; 225 = 1,87$$

$$P (F \leq 1,87) = 0,99$$

$$\text{and } F_{5\%} ; 25 ; 225 = 1,56$$

$$P (F \leq 1,87) = 0,95$$

Table 15 gives the F-values for scales from tables 3 to 8 and from the transformed fish lengths in tables 9 to 14 for easy comparison.

Table 15      A COMPARISON OF F-VALUES FOR SCALES FROM  
TABLES 3 TO 8 WITH THOSE FROM TABLES 9 TO 14

	1st annulus		2nd annulus		3rd annulus	
	Gilfillan Dam	Nel's Pan	Gilfillan Dam	Nel's Pan	Gilfillan Dam	Nel's Pan
Tables 3 to 8	2,28	5,03	1,87	1,31	1,45	1,40
Tables 9 to 14	2,32	6,25	1,91	1,26	1,46	1,42

The levels of significance for scales has not changed due to the transformations of fish lengths, therefore it is of no advantage to transform the various fish lengths to a common length. Back calculations of fish lengths from scale annuli are not unduly affected by the variations of fish lengths when caught. In other words, one fish is as good as another as far as back calculations according to annuli are concerned. It is also clear that variations due to scales become less with increasing age for the fish from the Gilfillan dam but not for the fish of Nel's Pan, i.e. F-values are lowest for the 3rd annulus in the former case but lowest for the 2nd annulus in the latter. It can be concluded from these results that the variations under discussion are caused by the environment and not by variations within the species.

Another interesting item in tables 9, 10 and 11 for Nel's Pan, is the confidence limits of the means at the three probability levels, i.e. 67%, 95% and 99,9%. For any specimen from this impoundment (strictly speaking with

lengths between 60 and 300 mm) the confidence limits would be roughly  $\pm 6$  mm (67% level),  $\pm 12$  mm (95% level) and 17 mm (99,9% level). Similarly from tables 12, 13 and 14 for the Gilfillan dam, specimens with a length between 70 and 325 mm should have confidence limits of roughly  $\pm 7$  mm (67% level),  $\pm 14$  mm (95% level) and 21 mm (99,9% level). If the averages of the above levels are taken, a ready rule of thumb becomes evident for confidence limits when back calculations based on an appropriate number of scales from a specimen of B. holubi are made. The rule is that for any specimen (strictly speaking with a length between 60 and 325 mm) the confidence limits would be  $\pm 6$  mm at the 67% level,  $\pm 13$  mm at the 95% level and  $\pm 19$  mm at the 99,9% level. The appropriate number of scales to be sampled shall be discussed later on.

An examination of tables A11 for Nel's Pan and A12 for Gilfillan dam reveals that some of the means for scale numbers lie outside the 95% and 67% confidence limits for the central value for each annulus and consequently these scale numbers can be considered less suitable for back calculations. In tables 16 and 17, scale numbers that do not differ significantly from the mean at the 95% and 67% confidence levels for each annulus are identified for Nel's Pan and Gilfillan dam respectively.

Table 16 NEL'S PAN. SCALE NUMBERS THAT DO NOT DIFFER SIGNIFICANTLY FROM THE MEANS AT THE 95% and 67% CONFIDENCE INTERVALS

Scale no.	95% confidence levels				67% confidence levels			
	1st ann.	2nd ann.	3rd ann.	ann. 1,2,3	1st ann.	2nd ann.	3rd ann.	ann. 1,2,3
1.	0	0	0	0	0		0	
2.	0	0	0	0	0	0	0	0
3.		0	0			0		
4.	0	0	0	0		0		
5.	0	0	0	0	0		0	
6.	0	0	0	0		0	0	
7.	0	0	0	0	0	0	0	0
8.		0	0			0	0	
9.	0	0	0	0		0	0	
10.	0	0	0	0	0	0	0	0
11.	0	0	0	0		0	0	
12.	0	0	0	0	0	0		
13.		0	0				0	
14.	0	0	0	0		0	0	
15.	0	0	0	0		0		
16.	0	0	0	0	0	0	0	0
17.	0	0	0	0				
18.	0	0	0	0	0	0	0	0
19.		0	0			0	0	
20.	0	0	0	0	0	0	0	0
21.	0	0	0	0	0	0	0	0
22.		0	0					
23.	0	0	0	0		0	0	
24.	0	0	0	0	0	0	0	0
25.	0	0	0	0			0	
26.	0	0	0	0			0	

Table 17 GILFILLAN DAM. SCALE NUMBERS THAT DO NOT DIFFER SIGNIFICANTLY FROM THE MEANS AT THE 95% AND 67% CONFIDENCE INTERVALS

Scale no.	95% confidence levels				67% confidence levels			
	1st ann.	2nd ann.	3rd ann.	ann. 1,2,3	1st ann.	2nd ann.	3rd ann.	ann. 1,2,3
1.	0	0	0	0	0	0		
2.	0	0	0	0	0	0		
3.		0	0				0	
4.	0	0	0	0			0	
5.	0	0	0	0	0	0	0	0
6.	0	0	0	0		0	0	
7.	0	0	0	0			0	
8.	0	0	0	0		0	0	
9.	0	0	0	0	0	0	0	0
10.	0	0	0	0	0	0		
11.	0	0	0	0	0	0	0	0
12.	0	0	0	0		0	0	
13.	0	0	0	0	0	0		
14.	0	0	0	0	0		0	
15.	0		0		0			
16.	0	0	0	0	0	0	0	0
17.	0	0	0	0		0		
18.	0	0	0	0	0	0	0	0
19.	0	0	0	0		0	0	
20.	0	0	0	0	0		0	
21.	0	0	0	0			0	
22.	0	0	0	0		0	0	
23.	0	0	0	0	0	0		
24.	0	0	0	0	0	0	0	0
25.	0	0	0	0	0	0	0	0
26.	0	0	0	0		0	0	

Since too many scale numbers qualify for all three annuli at the 95% level (fourth column of tables 16 and 17), it was decided to use the data from the 67% level for a stricter selection, (last column of tables 16 and 17). The scale numbers that do not differ significantly from the central values of all three annuli are numbers 2, 7, 10, 16, 18, 20, 21 and 24 for Nel's Pan and numbers 5, 9, 11, 16, 18, 24 and 25 for the Gilfillan dam. The scale numbers common to both impoundments are 16, 18 and 24. These three, then, are in this test the most suitable for back calculations for B. holubi generally. It may be noted that the numbers found most suitable as selected according to the percentage deviation from the mean (page 26) were 5, 9, 14, 18 and 20. The only common scale to both methods of selection is number 18 which represents a very limited selection.

In a similar manner, scale numbers that do not differ significantly from the central values of only two annuli are 1, 2, 5, 6, 8, 9, 10, 11, 12, 14, 16, 18, 19, 20, 23 and 24. All suitable scales according to the previous method of selection are included in these scale numbers, but this selection is too wide. A better selection is one which includes the Nel's Pan scales and the Gilfillan dam scales, i.e. numbers 2, 5, 7, 9, 10, 11, 16, 18, 20, 21, 24 and 25. This gives four scales in common with the selection according to the percentage deviation from the mean, i.e. numbers 5, 9, 18 and 20.

### 3.4 SCALE SHAPE

The ratio of scale width to scale radius was calculated for all the scales from each fish and tabulated in table A13 for the Gilfillan dam and in table A14 for Nel's Pan. The results were then subjected to a two-way orthogonal analysis of variance as before. The data from both impoundments together was then subjected to a similar analysis. The results appear below in tables 18, 19 and 20.

Table 18      GILFILLAN DAM.      ANALYSIS OF VARIANCE  
RATIOS OF SCALE WIDTH TO SCALE LENGTH

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	1,93	0,21	4,04
Scales	25	16,51	0,66	12,69
Error	225	11,71	0,05	
Total	259	30,15		

$$S_E = 0,72$$

$$\bar{x} = 2,53$$

$$S_x = 0,23$$

$$C_v. = 9,09\%$$

$$S_D = 0,33$$

Table 19      NEL'S PAN.      ANALYSIS OF VARIANCE  
RATIOS OF SCALE WIDTH TO SCALE LENGTH

Source	d.f.	Sum of squares	Mean square	F-value
Fish	9	5,57	0,62	10,33
Scales	25	23,13	0,93	15,50
Error	225	13,59	0,06	
Total	259	42,29		

$$S_E = 0,24$$

$$\bar{x} = 2,66$$

$$S_x = 0,24$$

$$C_v. = 9,02\%$$

$$S_D = 0,34$$

Table 20      GILFILLAN DAM AND NEL'S PAN TOGETHER  
ANALYSIS OF VARIANCE OF RATIOS OF SCALE  
WIDTH TO SCALE LENGTH

Source	d.f.	Sum of squares	Mean square	F-value
Fish	19	9,83	0,52	8,81
Scales	25	36,84	1,47	24,92
Error	475	28,10	0,06	
Total	519	74,77		

$$S_E = 0,24$$

$$\bar{x} = 2,60$$

$$S_x = 0,24$$

$$C_v. = 9,23\%$$

$$S_D = 0,34$$

The high F-values show that there is a highly significant difference between the same scales from each fish and between all the scales from the different fish. The differences are greater for fish from Nel's Pan than from the Gilfillan dam. The scales from both impoundments together show an even greater significant difference in shape. In

this case  $F_{1\%}; 19; 475 = 1,92$

and  $F_{5\%}; 19; 475 = 1,60$  for fish,

for scales  $F_{1\%}; 25; 475 = 1,85$

and  $F_{5\%}; 25; 475 = 1,53$

The F-values in table 20 are far above these.

The mean ratios of scale width to scale length for each scale number are given in table A15. The ratios were calculated separately for the fish from the two localities, then totalled and averaged for each scale number. The adding and averaging of the two sets of data are to some extent justified since there is a positive correlation between them of  $r = + 0,3898$  which is significant ( $0,05 > 2\alpha > 0,01$ ).

The scale numbers with the smallest ratios were selected by regarding the mean ratio of 2,6 for all the scale numbers as the upper and lower acceptable limits. The last column of table A15 then yielded the following scale numbers with the best shape: 3, 4, 5, 6, 8, 9, 10, 11, 14, 15, 18, 19, 20, 23, 24, 25 and 26 which include those from the previous selections.

### 3.5 READABILITY OF THE SCALES

The classification of the 520 scales according to their readability and scale numbers is given in table A16. Calculations made from table A16 show that about 46% of the scales could be classified as clearly readable. About 45% were fair and about 9% were poor. In 32% of the 520 scales some annuli were either double or in the form of dark bands.

In cases where the annuli were double, it was found that the average distance from focus to these two lines was the closest to the general pattern. In such cases it was necessary to identify the annuli by examining the striae where they started on each side of the focus. Here a degree of 'cutting over' could be observed, i.e. a new stria cut across a number of previous ones so that they ended abruptly against it, and not into the unmarked half of the scale (lunula). By following this line of 'cutting over' around to the other side of the scale, the annulus could be distinguished from other circuli. The striae did not usually run parallel to the annuli and scale margin. Apparently the middle section of each stria was first formed and the ends were formed later but not always at the same time. The result was that in these cases the annulus was in the form of two halves which overlapped in the centre, but which did not meet. If read in the centre, such scales showed two annuli instead of one, but on the sides there was only one.

Some scales had extra circuli and some had none at all, but instead there were dark bands caused by the concentric

striations being very close together. These appear to be caused by periods of slow growth corresponding to the winter season. This phenomenon has also been observed in scales of some marine fishes, such as the herring and salmon (Paget and Savage, 1916). In the chum salmon, Oncorhynchus keta (Walbaum) two main types of circuli are formed, one being the annulus; however, scales taken from various parts of the body had the same number of annuli (La lanne and Safsten, 1969).

Scales of the pike Esox lucius L. show annuli on both the anterior and posterior halves (Frost and Kipling 1959). In the case of B. holubi some scales have one or two annuli continuing through the posterior half of the scale to form a ring. However, these scales are the exceptions.

The number of scales in each category as given in table A16 shows the following: From the 26 areas chosen, those which gave 10 or more 'good' scales include nos. 3, 4, 6, 7, 8, 9, 10, 12, 14, 15, 16 and 17. Of these twelve, nos. 6, 7, 12, 16 and 17 are below the lateral line while the seven others are from above it. By referring to fig. 5 it will be seen that scales 8, 9, 10, 14 and 15 came from the area above the lateral line and below the anterior region of the dorsal fin. The most 'good' scales came from areas 8, 9 and 10, and the least from areas 23 and 25. The most 'poor' scales came from the areas 23 to 26 with a group from areas 18, 19 and 20, as well. The scales with the least number of extra lines came from areas 4, 8, 9, 16 and 22. However, it can be seen from table A16 that some scales from all areas had extra lines. It can also be seen that

only scales from areas 12 and 25 had no dark bands. All other areas had scales with bands, the highest number coming from areas 10 and 15.

### 3.6 THE MOST SUITABLE SCALE NUMBERS FOR AGE DETERMINATION ACCORDING TO BACK CALCULATIONS OF FISH LENGTHS, SCALE SHAPE AND READABILITY.

The scale numbers selected according to their suitability for back calculations, shape and readability are given in table 21.

Table 21 BEST SCALES FOR AGE DETERMINATION ACCORDING TO BACK CALCULATIONS OF FISH LENGTH, SCALE SHAPE AND READABILITY

Scale no.	Calculations	Shape	Readability	C, S, R
1.				
2.				
3.		0	0	
4.		0	0	
5.	0	0		
6.		0	0	0
7.			0	
8.		0	0	
9.	0	0	0	0
10.		0	0	0
11.		0		
12.			0	
13.				
14.		0	0	0
15.		0	0	
16.			0	
17.			0	
18.	0	0		
19.		0		
20.	0	0		
21				
22.				
23.		0		
24.		0		
25.		0		
26.		0		

Only one scale, namely number 9, qualifies for all three of the above criteria. This scale lies in front of the dorsal fin and above the lateral line. If scales qualifying for at least two of the criteria are considered then numbers 3, 4, 5, 6, 8, 9, 10, 14, 15, 18 and 20 are suitable. Of these eleven scales, only two (6 and 20) lie below the lateral line. Of the remainder, eight lie in front of the dorsal fin (3, 4, 5, 8, 9, 10, 14 and 15) and only one behind it (18). From this it may be concluded that the best area from which to remove scales of B. holubi for age determination is, generally speaking, just below and anterior to the anterior margin of the dorsal fin but above the lateral line. In the case of the chum salmon Oncorhynchus keta, the best scales were found two rows above the lateral line and in the region around the posterior section of the dorsal fin (La lanne and Safsten 1969).

### 3.7 CORRELATIONS

The calculated correlation coefficients are given below in table 22.

Table 22 CORRELATIONS

The following correlations were calculated for the samples from Nel's Pan and Gilfillan dam: Between the lengths of the fish when caught (x) and the mean calculated fish lengths according to the three annuli  $y_1$ ,  $y_2$  and  $y_3$ .

$$\text{Model for calculations : } r = \frac{\sum \Delta X \Delta Y}{\sqrt{\{\sum (\Delta X^2)\} \{\sum (\Delta Y^2)\}}}$$

where  $r$  = the correlation coefficient

$\Delta X$  = variation from the mean fish length

$\Delta Y$  = variation from the calculated mean fish length

GILFILLAN DAM

Correlation between:	Value of r	$H_0:r=0$
x and $y_1$	+ 0,2319	$2\alpha > 0,1$
x and $y_2$	+ 0,3111	$2\alpha > 0,1$
x and $y_3$	+ 0,8087	$0,01 > 2\alpha > 0,001$
$y_1$ and $y_2$	+ 0,8395	$0,01 > 2\alpha > 0,001$
$y_1$ and $y_3$	+ 0,6667	$0,05 > 2\alpha > 0,01$
$y_2$ and $y_3$	+ 0,8328	$0,01 > 2\alpha > 0,001$

NEL'S PAN

Correlation between:	Value of r	$H_0:r=0$
x and $y_1$	+ 0,1740	$2\alpha > 0,05$
x and $y_2$	+ 0,4991	$2\alpha > 0,05$
x and $y_3$	+ 0,4228	$2\alpha > 0,05$
$y_1$ and $y_2$	+ 0,8467	$0,01 > 2\alpha > 0,001$
$y_1$ and $y_3$	+ 0,0481	$2\alpha > 0,1$
$y_2$ and $y_3$	+ 0,0303	$2\alpha > 0,1$

All the correlation coefficients are positive but only some of them are significant. In the case of the Gilfillan dam data, the correlations between fish lengths when caught and calculated fish lengths according to the annuli become closer to unity with increasing age or as the annulus in question approaches the scale margin. The only significant r-value is for fish lengths when caught and the third annulus lengths. From this it may be concluded that the growth rates of the individual fish differ from year to year in a

manner peculiar to the specimen and not necessarily common to the group. This difference in growth rate is also reflected in the correlations between lengths according to the three annuli. All three correlation coefficients are significant and the correlation is best between adjacent annuli (first and second, second and third). The correlation between annuli once removed from each other (first and third) is the lowest amongst the three values.

The data from Nel's Pan gave rather disappointing results. The only significant correlation is between fish lengths according to the first and second annuli. This correlation coefficient compares very well with the corresponding value for the Gilfillan dam fish. It can only be concluded that the Gilfillan dam fish had largely differing growth rates after the second annulus was formed.

The various insignificant correlations may also be due to a differing appropriateness of the back calculation formula for each annulus. The hypothesis that the formula may not be a good fit in all cases is also indicated by the already mentioned excessively low values for the first annulus of the Nel's Pan fish. If the formula provides a perfect fit, the regression lines of the values that correlate significantly with each other should have a 1 in 1 slope. These regression lines have been calculated further on in the text and a slope of 1 in 1 has not been found.

### 3.8 THE NUMBER OF SCALES THAT SHOULD BE SAMPLED PER FISH

The appropriate calculations were carried out according to the formula in table 23 below, which also contains the results of the calculations.

Table 23 NUMBERS OF SCALES PER FISH THAT SHOULD BE MEASURED TO OBTAIN 95% CONFIDENCE INTERVALS. CALCULATIONS BASED ON THE DATA FROM NEL'S PAN

Model for calculations: 
$$\delta = \frac{S_D(t)}{\sqrt{N}}$$

where:  $\delta$  = Minimum detectable difference in calculated fish lengths

$S_D$  = Standard deviation of differences from the means

t = Value from t-distribution of the appropriate probability level

N = Number of scales

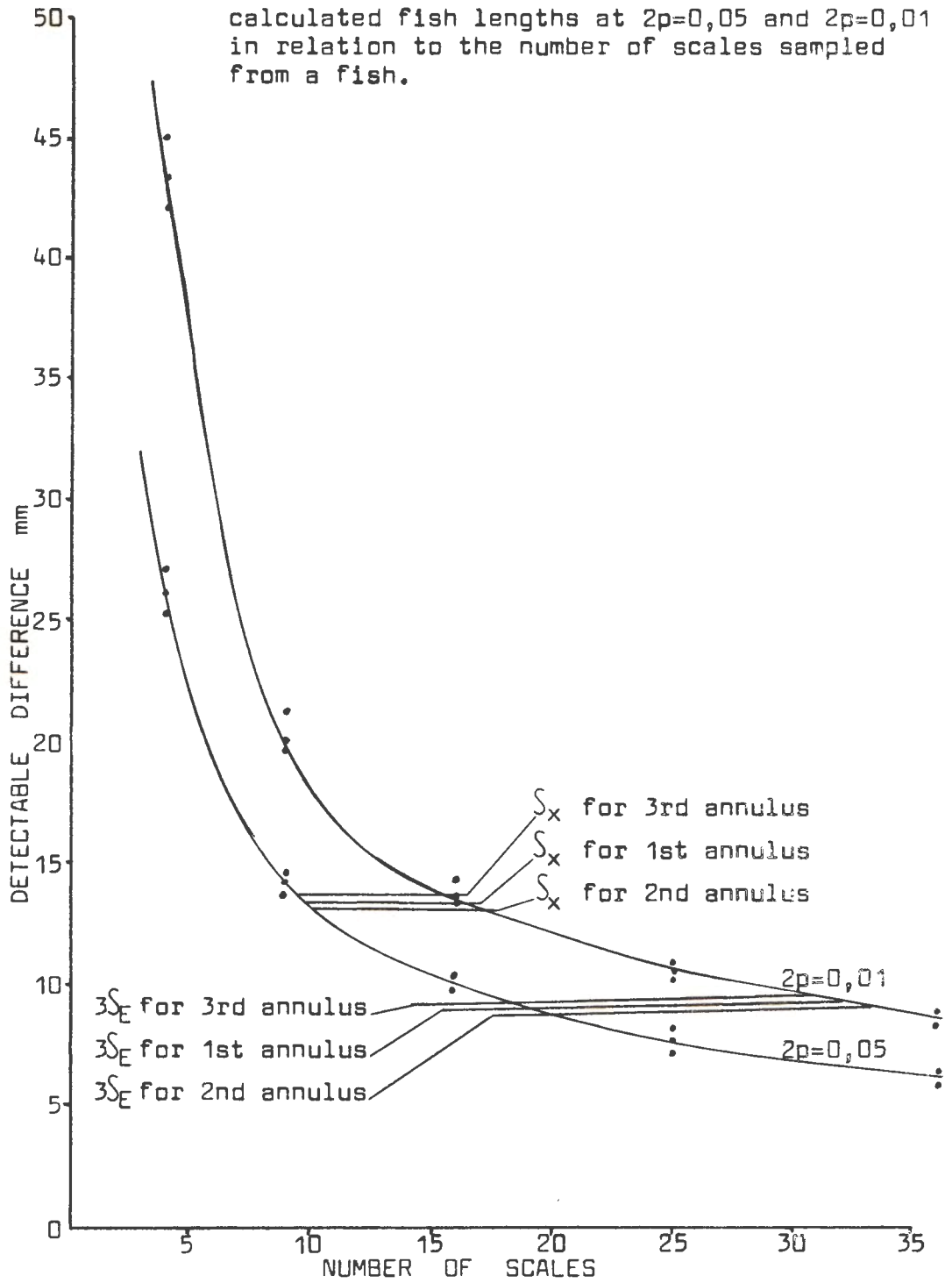
#### 95% CONFIDENCE INTERVAL

N	$\delta$ 1st annulus	$\delta$ 2nd annulus	$\delta$ 3rd annulus
4	26,1	25,4	27,2
9	14,2	13,8	14,7
16	10,01	9,7	10,4
25	7,7	7,5	8,1
36	6,4	6,1	6,6

#### 99% CONFIDENCE INTERVAL

N	$\delta$ 1st annulus	$\delta$ 2nd annulus	$\delta$ 3rd annulus
4	43,3	42,1	45,0
9	20,0	19,6	21,2
16	13,7	13,3	14,3
25	10,5	10,2	11,0
36	8,5	8,3	8,9

Fig. 9 . The minimum detectable difference ( $\delta$  mm) between calculated fish lengths at  $2p=0,05$  and  $2p=0,01$  in relation to the number of scales sampled from a fish.



The information from table 23 is graphically represented in fig. 9, the lines being drawn through mean values for the three annuli. It has already been mentioned that the standard errors as well as standard deviations of differences for the three annuli are very nearly identical for each statistic and having one line for all three annuli considerably simplifies matters. From fig. 9 the number of scales that should be sampled in order to detect a specified difference can be read off. If, for instance, a minimum detectable difference equal to the standard deviation ( $S_x$ ) is required, about ten scales per fish should be sampled for a 95% probability level and 16 to 18 scales for the 99% level. If the difference required equals  $3S_E$  (three times the standard error), 18 to 20 scales and 31 to 34 scales should be sampled for the 95% and 99% confidence limits respectively.

#### 4. CONCLUSIONS

It may be concluded that age determination and back calculations of fish length according to scale annuli is quite feasible with B. holubi as far as the present evidence goes. About half of the scales studied were clearly readable and in the cases of poorly readable scales, the correct annuli could be identified by comparing calculated lengths with those from other scales on the same fish. There exists some doubt as to the suitability of the back calculation formula but this matter has been fully examined later in this text.

According to the criteria of suitability for back calculations, shape and readability, the best scales for age determination of B. holubi are to be found on the fish in a region below and anterior to the anterior margin of the dorsal fin above the lateral line. Correlations between actual and back calculated lengths for the Gilfillan dam fish were fairly well defined and understandable. Those for Nel's Pan were inexplicably low but may be accounted for in terms of differing growth rates and a possible bad fit of the back calculation formula.

Besides the correlations for Nel's Pan fish, other inexplicable variations were found in 'back calculations due to scales'. As expected, these became less with increasing age for the fish from Gilfillan dam, but not for those from Nel's Pan. When scales were chosen for back calculations according to the 'smallest percentage deviation from the mean', there were twice as many suitable ones from the Nel's Pan fish as from the Gilfillan dam fish. The 'mean percentage variation' for back calculated fish lengths for the first annuli were nearly half as much again for the Nel's Pan fish, compared to the Gilfillan dam fish, i.e. 17,5% compared to 13,6%. Only 30 scales from the Gilfillan dam fish had no 4th annulus, as opposed to 134 for Nel's Pan. The average calculated fish length for the first annulus was nearly twice as much for the Gilfillan dam compared to Nel's Pan and the growth generally was much faster. These variations show clearly how two groups of fish of the same age are affected by different environments.

The number of scales to be examined per fish for a specified detectable difference between mean fish lengths according to annuli vary, of course, with the specified confidence level, but the whole matter is considerably simplified by the fact that the standard errors are of the same absolute magnitude for the three annuli. Perhaps a number of ten scales per fish should be specified as a reasonable amount since it would give a mean fish length with detectable difference equal to the standard deviation for each annulus, while not involving too many scale measurements for the examiner.

## SECTION II

### 5. THE BODY-SCALE RELATIONSHIP OF BARBUS HOLUBI

In this investigation about 800 fish of unknown age from Barberspan were used in contrast to only 60 in Section I. Whereas the 60 fish were living under near ideal conditions, the opposite was true for the 800. Barberspan is situated in the western Transvaal  $26^{\circ} 35'S$   $25^{\circ} 35'E$  and competition from other fish species in the pan is strong. Göldner (1967) found that there were 9 other species belonging to three different families living in the pan besides B. holubi. In 1956 Groenewald estimated the total fish population of the pan to be 138,000. The result of all this is that the growth rate of the 800 has been found to be one-third less than that of the 60 which makes scales even more difficult to read in many respects.

In this section a study has been made of the body length/scale radius relationship of B. holubi at various

lengths and ages. The validity of the formula  $l = \frac{sL}{S}$  for back calculations has been checked and found to be inaccurate. (All tables in the appendix prefixed by B concern this section.)

In many other fish species the growth rate of scales is not proportional to that of the body and in many it is not even a linear relationship (Huntsman 1918). However, for practical reasons it is desirable to keep the formula representing this ratio as simple as possible. Unlike marine fish, large numbers of freshwater fish are never involved. For this reason a little inaccuracy in the formula can be tolerated in favour of simplicity.

Lea was one of the first workers to have used the formula  $L = a S$

where  $L$  is the fish length  
 $S$  is the scale measurement, and  
 $a$  is a constant.

This is generally known as the Dahl-Lea formula and the scale reading may be the diameter or radius, (Hile 1968). Best results were obtained from fish with cycloid scales and B. holubi falls among these. In the cyprinids good results were obtained by using scale radii and B. holubi is classified under the family Cyprinidae. This formula, therefore, may fit the growth of B. holubi.

The simple proportional equation is not accurate because a newly hatched fish has no scales. These only develop in the herring, for example, at a length between 3 and 5 cm. (Lea 1938). At what length B. holubi forms

its first scales was not known at this stage of the investigation.

To cope with heteromorphous growth in the herring, Lea drew up a 'compensation table' and used scales from just behind the gill cover. He wanted to keep the formula as simple as possible. As an alternative he determined which scales on the body grew in accordance with the simple proportion formula, but these were not the best for age determination. This method, therefore, involved removing two sets of scales from each fish, one for back calculation and one for age determination. This was not practical. He then worked out a lengthy alternative which, in my opinion, is not practical to apply to B. holubi.

On this subject Hile (1968) has the following to say:-

"Most calculations of fish growth from scale measurements are made from one of four types of curves; straight line through the origin (Dahl-Lea); straight line with intercept (Lea); logarithmic line (Monastyrsky); empirically derived curve (Segerstråle). Occasionally different curves are used for different length intervals of fish."

These formulae were calculated to suit marine fish where large numbers of individuals are caught annually. This will never be the case with B. holubi and for this reason no attempt has been made to test the latter three methods on this fish species.

Huntsman (1918) made back calculations of length from scales from different parts of the body for the flat-fish or long rough dab using the formula  $l = \frac{s L}{S}$ . One large

scale from the side of the tail gave a first-year length of 22 mm and a small scale from near the posterior fin gave a first year length of 12 mm for the same fish. He worked out a method for back calculating involving a movable curve on a graph which gave a first-year length of 44 mm. This he believed, was the correct length. This is a good indication of the kind of variation that one has to deal with in this type of investigation. To achieve a high degree of accuracy is very difficult indeed.

Smith (1955) found that the Kamloops trout develops its first scales at a fork length of 35 mm. Up to a length of 45 mm the proportional scale growth rate is far greater than the fish-length increase. After this the scale/body relationship is almost directly proportional and back calculations can be read off from a  $45^{\circ}$  constant slope on a double logarithmic plot or from a constant zero-zero intercept on an arithmetic plot. He believes that the steelhead trout Salmo gairdneri gairdneri (Richardson) and the cutthroat Salmo clarki clarki (Richardson) will show a similar relationship. The scale/body relationship of B. holubi is also nearer to directly proportional for fish longer than 100 mm than for those shorter than this, as will be seen later on.

Segerstråle (1933) found that the scales of Leuciscus indus L. grow proportional to the body length after a fish length of 250 mm. He used body length and not fork length because he found that the tails varied in size and were often damaged. He found that in Abramis brama L. only the caudal

scales grew proportional to body lengths above 160-180 mm. In Perca fluviatilis L. these scales grew proportional to body length up to 220 mm in length, this being the length of the largest fish which he examined. In all three species which he examined, he found that the scales from different parts of the body grew at different rates compared to body growth rate.

In B. holubi the scales which were used for this study were taken from the lateral region of the body above the lateral line and anterior to the dorsal fin. It is not known whether these scales are the best to use for this study or whether those from some other body area will show a growth rate more in proportion to body growth rate. A future study will have to be made to determine this, but these scales have been shown to be the best for age determination. The length used was fork length and not body length, but body length may turn out to give more accurate results.

## 6. MATERIAL AND METHODS

Scales were collected from 794 fish, caught in Barberspan from 1950 to 1965 during each month of the year except January, June and December. Each scale was treated as before and from two to six scales from each fish were then mounted between two microscope slides. The scales of B. holubi are fairly large and no more than two from a large fish will fit onto a microscope slide. As before, a microfilm reader was then used to project these scales with a magnification of 19 times. Measurements were taken from the best scale on each slide. These measurements were then

Table 24 AVERAGE FISH LENGTH OF EACH CLASS WITH ITS AVERAGE SCALE RADIUS, STANDARD DEVIATION AND STANDARD ERROR

Fish group in mm	Average Fish length in mm $\bar{x}$	Average projected scale r. in mm $\bar{y}$	Standard deviation of scale readings S	Standard error of scale readings $S_e$
50-59	59	9,0		3,0
60,69	60	5,0	1,73	1,0
70-79	74	7,5	1,62	0,35
80,89	84	9,7	1,83	0,53
90,99	94	11,3	2,02	0,45
100-109	103	14,2	2,29	0,66
110-119	113	15,6	2,50	0,46
120-129	124	18,0	3,17	0,60
130-139	134	20,6	3,41	0,76
140,149	143	23,5	3,22	0,66
150,159	153	28,9	2,59	0,69
160-169	164	30,9	5,31	1,06
170-179	174	33,6	5,06	1,23
180-189	184	33,5	6,95	1,64
190-199	194	41,4	6,99	1,04
200-209	204	44,3	7,00	0,98
210-219	214	49,1	10,96	1,69
220-229	223	50,2	6,47	1,14
230-239	234	53,1	8,67	1,34
240,249	244	56,3	8,75	1,46
250,259	254	59,4	8,61	1,33
260-269	264	63,1	9,54	1,87
270-279	273	64,9	10,73	1,72
280-289	283	69,9	9,76	1,61
290-299	292	75,6	7,50	1,44
300-309	303	77,3	10,84	2,09
310-319	312	84,1	13,92	3,28
320-329	324	90,7	21,84	6,91
330,339	335	84,7	10,66	3,37
340,349	344	83,5	15,34	5,42
350,359	352	92,4	12,18	3,85
360-369	367	96,7	16,15	6,59
370,379	373	104,8	9,26	3,78
380,389	380	109,5	12,02	8,50
390-399	391	116,0	16,54	7,40
400-409	402	100,7	16,63	5,54
410.419	416	104,0		10,2
420-429	423	127,0	6,16	3,08
430-439	433	111,5	0,71	0,50
440,449	441	101,5	27,58	19,50
470-479	471	132,3	8,03	2,84
500-509	505	150,5	14,85	10,50

recorded with the fork length of the fish and the date when caught.

To determine the relationship between the fish length and anterior scale radius at various ages, the fish lengths were arranged in 10 mm classes with their corresponding projected scale radii in mm, as in table B1. The average fish length for each class was then calculated with its corresponding average scale radius. The standard deviation,  $S_y$ , and the standard error,  $S_{e_y}$ , for the scale readings were also calculated and all this was tabulated in table 24.

The formula used for calculating the standard deviation was :- 
$$S^2 = \frac{\sum(y^2) - n(\bar{y}^2)}{n - 1}$$

where  $S$  = standard deviation

$y$  = scale readings, and

$n$  = number of scales involved.

The standard error formula used was :-

$$S_{e_y} = \frac{S_y}{\sqrt{n}}$$

In cases where only one fish fell into a particular length group, the square root of the scale reading was taken to be the standard error. The 430-439 mm group was treated in a similar way because only two fishes were involved and these were very similar to one another.

A graph showing the average fish length for each class plotted against average scale radius was drawn. The standard error about each point on the graph was also indicated by a vertical line through that point, its length

indicating the magnitude of the error (fig. 10 later in the text).

The best linear representation of this graph was then calculated and superimposed on the above-mentioned graph. The reasons for this and the formula used will be discussed further on in this text. The 95% confidence interval of this straight line was also calculated and is represented by two straight lines, parallel to the first, but one on each side of it. This was done by calculating the variance of estimate about the above-mentioned straight line.

To find out whether the fish/scale relationship could not be better represented by two linear graphs, fish below a length of 150 mm were examined separately from those above this length. For a comparison of these two linear representations with the one for all the fish, the linear correlation coefficient for each group was calculated. The nearer the value of  $r$  to 1 or -1, the more linear will be the points on the graph when joined. The formula used to calculate the linear correlation coefficient of  $x$  and  $y$  was :-

$$r = \frac{S_{xy}}{S_x S_y}$$

where  $S_{xy}$  = the covariance  
 $S_x$  or  $S_y$  = the standard deviation (appropriate)  
 $x$  = the fish lengths, and  
 $y$  = scale radii

The formula representing each straight line was also calculated. For this purpose tables B2, B3 and B4 were drawn up.

For fish below 150 mm in length, table B2 for example, was compiled as follows :- Fish were divided into 10 mm length groups from 50 to 149 mm, each group going from 0 to 9 mm. Scale radii were divided into 3 mm groups, the first going from 3 to 5 mm. Each fish was then placed in its correct length class and corresponding scale radius class. From this data, the best linear representation of fork length to scale radius was calculated. The same procedure was followed for fish from 150 mm and longer and for fish from 50 mm and longer. The results are represented in tables B3 and B4.

Although the points on the graph show that a linear line cannot represent them all accurately, it will be of great future practical value to regard them as being in a single straight line.

To calculate the relationship of regression line of fish length to scale radius, the following formula was used:-

$$x = \bar{x} + r \frac{S_x}{S_y} (y - \bar{y})$$

where  $x$  = fish lengths

$y$  = scale radii

$\bar{x}$  = average fish length

$r$  = linear correlation coefficient of  $x$  and  $y$

$S_x$  = standard deviation of fish lengths

$S_y$  = standard deviation of scale radii

$\bar{y}$  = average scale radius

The formulae for each of the above are :-

$$r = \frac{S_{xy}}{S_x S_y}$$

$$\bar{x} = \frac{1}{N} \sum fx$$

$$\bar{y} = \frac{1}{N} \sum fy$$

$$S_y^2 = \frac{1}{N} \sum y^2 f_y - \bar{y}^2$$

$$S_x^2 = \frac{1}{N} \sum x^2 f_x - \bar{x}^2$$

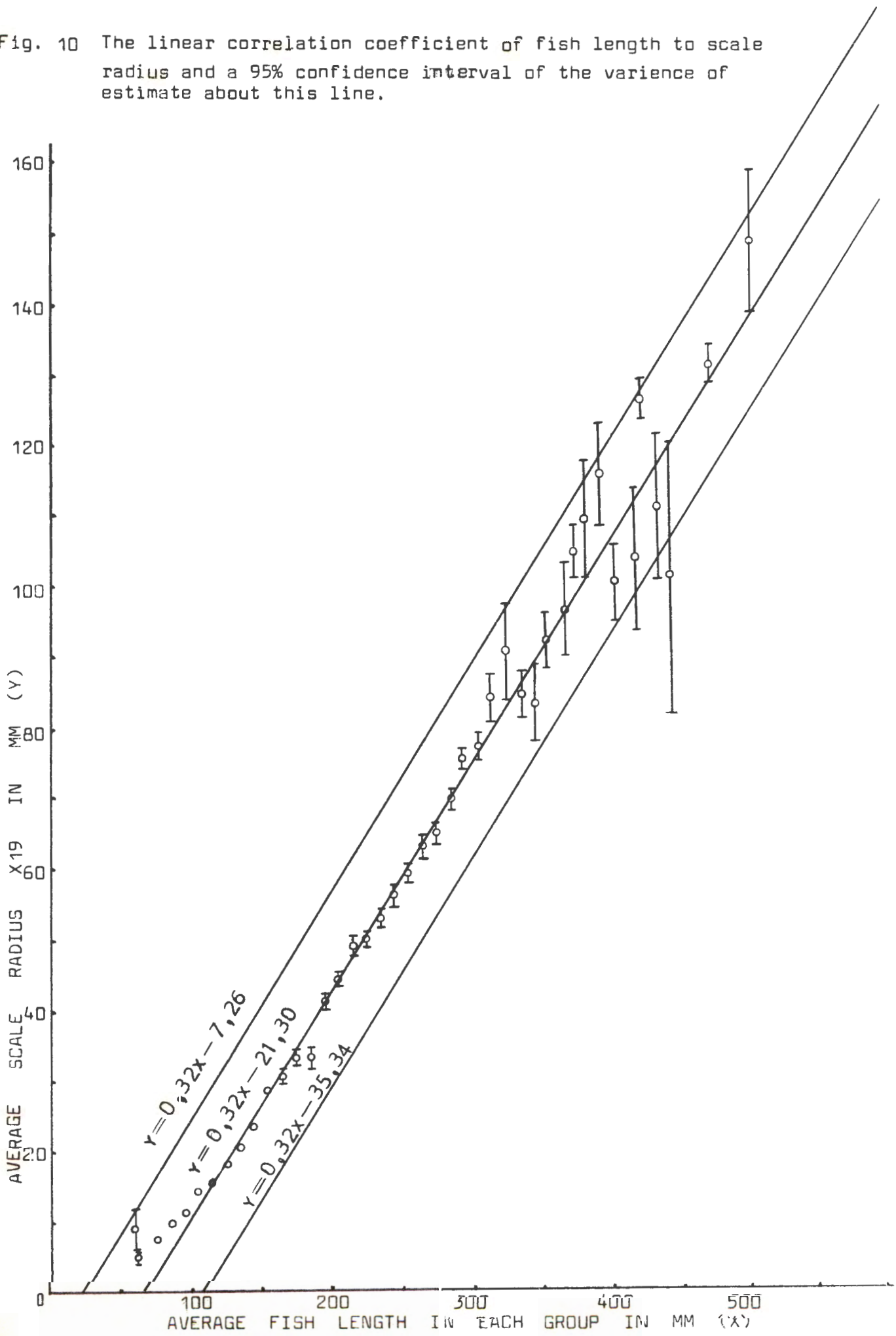
$$S_{xy} = \frac{1}{N} \sum \sum f_{xy} - \bar{x} \bar{y}$$

The 95% confidence interval was only calculated for the straight line which represents all the data together.

This was done by calculating the variance of estimate about that line. The formula used was :

$$S_{e_x}^2 = S_x^2 (1 - r^2)$$

Fig. 10 The linear correlation coefficient of fish length to scale radius and a 95% confidence interval of the variance of estimate about this line.



## 7. RESULTS

The 'standard error of scale readings' as set out in table 24 shows that as the fish become older, the standard error increases. This can be expected for two main reasons. Firstly the number of fish involved was far greater among the younger fish groups, and, secondly, the older the fish became, the more time there was for variations to develop between fish length and scale radius. The standard errors for fish below a length of 300 mm are relatively small. This tendency is graphically illustrated in fig. 10. It also shows clearly that the fish length/scale-radius relationship is nearly a straight line, especially for fish above 100 mm and below 300 mm in length.

The first two points on the graph show a fairly high standard error. This is because the number of fish involved here was very small. Only one fish fell into the 50-59 mm length group and only 3 into the 60-69 mm group. The number of fish falling into each length group can be seen in table B1.

No group above a length of 320 mm contained more than ten fish. The 380 mm, 430 mm, 440 mm and 500 mm groups each only contained two fishes, while the 410 mm group only had one fish.

The straight lines best representing the points on the graph were calculated from the formula already mentioned. The relationships of fish lengths, in 10 mm groups, from 50 mm to 149 mm, to the corresponding scale radii in 3 mm groups gave the following values for the various formula components :

$$\begin{aligned}
\bar{x} &= 111,17 \\
\bar{y} &= 15,49 \\
s_{xy} &= 115,27 \\
s_x^2 &= 565,34 \\
s_x &= 23,78 \\
s_y^2 &= 35,40 \\
s_y &= 5,95 \\
r &= 0,81 \\
x &= 4,90 y + 35,20 \\
y &= 0,20 x - 7,18
\end{aligned}$$

The relationship of fish lengths in 10 mm groups, from 150 mm to 449 mm, to the corresponding scale radii in 4 mm groups gave the following values :

$$\begin{aligned}
\bar{x} &= 252,53 \\
\bar{y} &= 60,52 \\
s_{xy} &= 981,32 \\
s_x^2 &= 3618,44 \\
s_x &= 60,15 \\
s_y^2 &= 532,49 \\
s_y &= 23,08 \\
r &= 0,71 \\
x &= 3,69 y + 29,37 \\
y &= 0,27 x - 7,97
\end{aligned}$$

The relationship of fish lengths in 10 mm groups, from 50 mm to 449 mm, to the corresponding scale radii in 4 mm groups gave the following values :

$$\begin{aligned}
\bar{x} &= 221,84 \\
\bar{y} &= 49,98 \\
S_{x,y} &= 2041,22 \\
S_x^2 &= 6352,61 \\
S_x &= 79,70 \\
S_y^2 &= 716,98 \\
S_y &= 26,78 \\
r &= 0,96 \\
x &= 3,12 y + 66,4 \\
y &= 0,32 x - 21,30
\end{aligned}$$

From the results it can be seen that for fish up to 149 mm in length,  $r = 0,81$ . In the group of fish larger than 149 mm,  $r = 0,71$  and for all the fish together,  $r = 0,96$ . This latter value is very close to one and shows that the straight line formula,  $y = 0,32 x - 21,3$  calculated from all the data together, is the best representation of the linear correlation coefficient of  $x$  to  $y$ . It has also been drawn on fig. 10 and it now becomes clear that all fish with a length above about 100 mm and below 290 mm have a body/scale relationship which is almost linear. This relationship is very well represented by the above formula.

To calculate the 95% confidence interval for this regression line for the fish population examined, the formula  $S_{e_x}^2 = S_x^2 (1 - r^2)$  gave two straight lines. These two lines are calculated by substituting  $x - 1,96 S_{e_x}$  and  $x + 1,96 S_{e_x}$  for  $x$  in the above formula.

$$\begin{aligned}
\text{Therefore } y &= \bar{y} + r \frac{S_y}{S_x} \left( (x \pm 1,96 S_{e_x}) - \bar{x} \right) \\
&= 0,32 (x - 1,96 S_{e_x}) - 21,3 \\
&= 0,32x - 0,32 (1,96 S_{e_x}) - 21,3 \\
S_{e_x} &= 6352,61 (1 - (0,96)^2) \\
&= 22,32 \\
\text{therefore } y &= 0,32 x - 35,34 \\
\text{and } y &= 0,32 x - 7,26
\end{aligned}$$

Between these two lines there is a 95% confidence interval. It is evident that for this degree of accuracy, the calculated fish length from a scale can be incorrect by as much as 87,75 mm. Alternatively, the projected scale reading with a magnification of 19 times may vary by 28,04 mm among fish of the same length. It is, therefore, not possible to make back calculations of fish lengths from their scales with a high degree of accuracy.

The formula  $y = 0,32x - 21,30$  is only valid if a magnification factor of 19 is used when measuring the scale statistics. In order to standardize the formula, the following alteration is necessary, all values still being kept in mm :

$$\text{If in } y = 0,32x_{19} - 21,30$$

$x_{19}$  represents the magnified measurement

it then follows that in

$$y = 19 (0,32x_1) - 21,30 = 6,08x_1 - 21,30$$

$x_1$  represents the actual, unmagnified scale measurement.

## 8. CONCLUSIONS

The growth increment of the scales of B. holubi is a constant proportion of the growth increment of the fish, especially so for the fish-length range between 100 mm and 300 mm. Most fish of this species in the Barberspan population fall within this length range and this will probably also be the case in other large impoundments. When the scales are enlarged 19 times, the body/scale relationship can be represented by the straight line :

$$y = 0,32x - 21,30, \text{ or projected scale radius}$$

$S = 0,32 \text{ fish length} - 21,30$ . This will change, however, if any other enlargement is used when measuring scales; for a magnification factor of one, the formula reads :

$$y = 6,08x - 21,30.$$

When calculating fish lengths at the time of annulus formation, a practical degree of accuracy can be expected when these lengths fall within the range 100 - 300 mm. If greater numbers of fish above 300 mm in length had been examined, it is very likely that they too would have shown a body/scale relationship closer to the above straight line. Lee (1920) found this to be the case in many species of fish which he examined. Natarajan and Jhingran (1936) found the same for some Indian fresh water fishes.

Lee's (1920) formula:  $l = a \frac{S}{S_0} (L - a)$  will thus give good results when making back calculations of fish length from scale annuli in the case of B. holubi.

'a' is a constant and is the fish length where the above calculated regression line cuts the x - axis i.e. where a fish has a scale radius of nil. The value of 'a' is

66,4 mm and the formula now reads :

$$l = 66,4 \frac{s}{S} (L - 66,4)$$

where  $l$  = fish length when annulus was formed  
 $s$  = radius of scale when annulus was formed  
 $S$  = scale radius when caught  
 $L$  = fish fork length when caught

In actual fact, the value for 'a' is a bit too high. The smallest fish caught in this study was 59 mm long and it already had scales. The graph also shows that the body/scale ratio of fish below 100 mm cannot be represented by a straight line. It must, therefore, be remembered that any calculated fish lengths below 100 mm will tend to be too high. The results from Section I show that only about 50% of scales examined are suitable for age determination and here fig. 10 shows that back calculations are not very accurate for a 95% confidence limit. However, had the data from Section I been treated with the above formula instead of the directly proportional one, the results may have been better.

### SECTION III

#### 9. A COMPARISON OF THE SCALE METHOD WITH THE LENGTH-FREQUENCY METHOD OF AGE DETERMINATION

##### 9.1 INTRODUCTION

In this investigation the same scales were used as in Section II. The experience gained from Section I was used to read the annuli on these scales as accurately as possible. The degree of accuracy with which the age of Barbus holubi from Barberspan can be determined by the use of their scales is unknown, but it will probably not be higher than that of

the 60 fish first examined. Because of their slower growth, the annuli were much more crowded and often difficult to distinguish from one another. The number of scales from each fish which was examined depended on the size of the fish. Beamish and Harvey (1969) found that age determination according to scales from Canadian white suckers, Catostomus commersoni, (Lacépède), becomes less accurate with age. Graham (1928) reports that Walter (1901) found it impossible to determine the age of carp from one scale in many cases. Huntsman (1918) found that many scales grow much more in some years than in others. This is also the case with B. holubi where the growth during the first year is always much more than in subsequent years. This growth rate also varies greatly among different fishes as will be seen later. Carlander (1950) found a similar phenomenon in the sauger Stizostedion canadense canadense (Smith) which is a fresh water fish from North America. For example, he found that some 4-year-olds were 50 per cent longer than others and 300 per cent heavier. He also found that there was a definite correlation between the numbers of saugers and the June rainfall. To what extent climatic conditions affect the biology of B. holubi is yet to be discovered, but the amount of rainfall must surely affect the food supply and thus the growth rate of this species. Carlander found the variations in growth rates of the yellow perch, Perca flavescens (Mitchill) to be similar to those of saugers. In this species the growth rate was about the same each year, after the third year, but some individual fish showed a faster growth rate between the 4th and 6th years than between the

2nd and 4th years. This tendency is also seen in B. holubi. However, the numbers of fish involved in the older year classes were too low to draw definite conclusions in this connection.

## 9.2 TIME OF ANNULUS FORMATION

Another important factor in this type of investigation is to determine at what time of the year the annuli are formed. As will be seen later, this does not occur at exactly the same time in the different age groups of B. holubi. Joeris (1957) found that the annuli on yellow perch scales were laid down at different times of the year, depending on the calendar year, which probably involves the climatic conditions of that year, and on the age of the fish. He found that new growth starts earlier in the younger fish. Some of these fish had already started new growth during late May while others had not yet started with new growth at the end of July. Bhimachar (1959) found that the fresh water fish Cirrhina mrigala (Ham) lays down its annuli during the spring and summer months, i.e. March-June in the northern hemisphere. Ovchynnyk (1965) found that in the white sucker Catostomus commersoni the annuli are laid down in summer or autumn or not at all. It is strongly suspected that B. holubi does not always lay down annuli, but this has not yet been proved. Beamish and Harvey (1969) found that the age of the white sucker as determined by the scales was often one year less than if determined by the fin rays, if the determination was done in early spring. This was caused by the annuli not being laid down at the same time of the year in these two anatomical structures. An examination of

the fin rays, operculi, etc., of B. holubi has not yet been undertaken, but it may turn out to be a good way of checking the age as determined by the scales. An alternative method would be to mark and release fish of a definite age and then to recapture them at a later stage, as June and Roithmayr (1960) did with the Atlantic menhaden. These fish were kept in a pond and scales periodically removed. They found that no annuli were formed before March 18th. By May 2nd all the fish had formed a new annulus. It would appear that many fish lay down their annuli over a period of about 3 months.

### 9.3 LENGTH FREQUENCY MODES

As a result of his study of the Barberspan fish populations, Gldner was able to draw a number of length-frequency graphs for B. holubi for various months. From the modes on these graphs he was able to estimate year classes and these are now to be compared with age determination as read from scales.

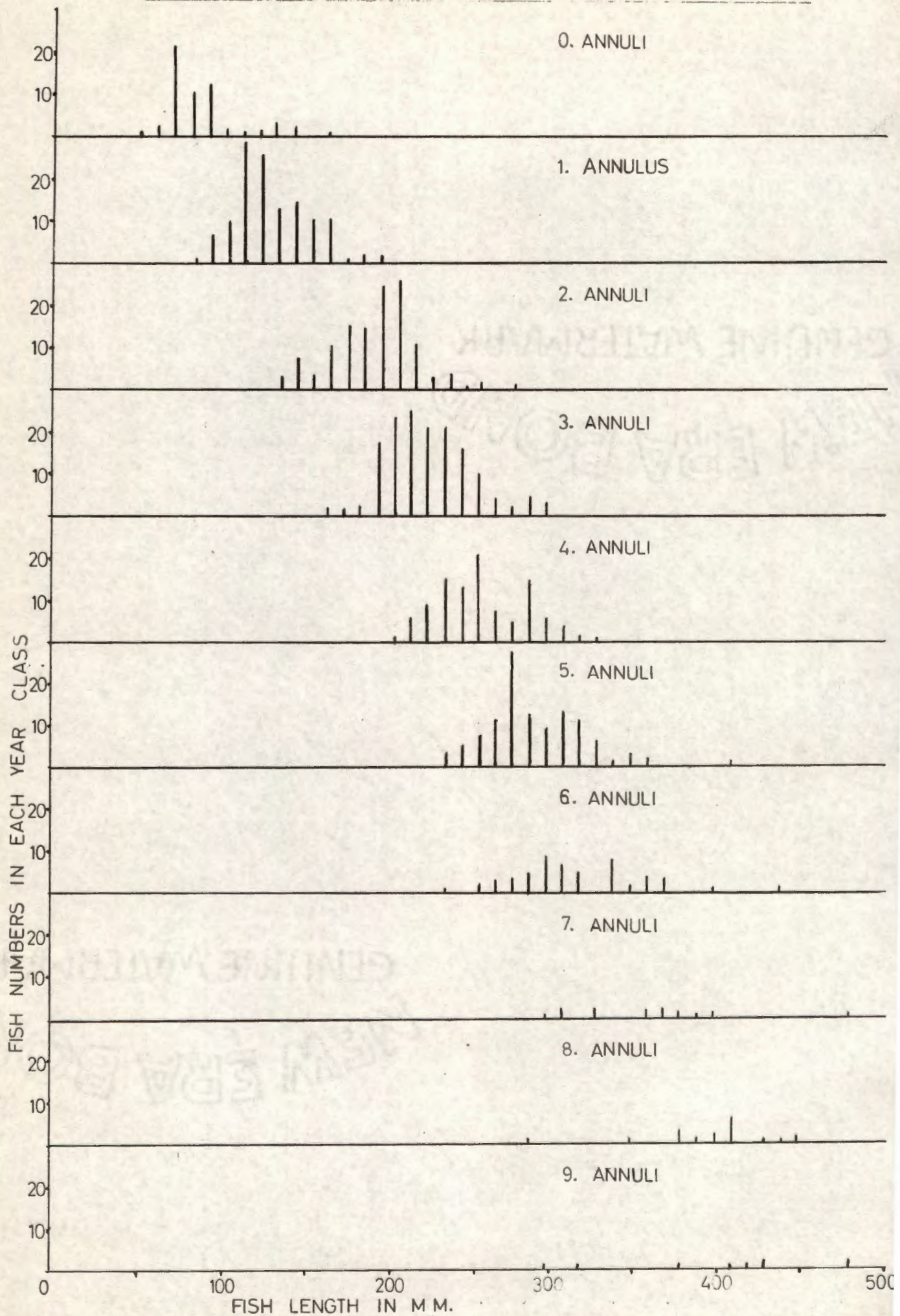
## 10. MATERIAL AND METHODS

Scales from the 794 fish involved in the previous study were used for this study. The age of each fish was estimated from the annuli on the scales by magnifying them 19 times with the same microfilm reader used in Section I. Each enlarged scale was measured as before (fig. 6). All the readings were recorded with details of the fish concerned. (All tables in the appendix prefixed by C concern this section).

All fish with the same number of annuli were then arranged in 10 mm length classes, starting from the 50-59 mm

Fig. 11

LENGTH FREQUENCIES OF FISH IN SCALE ANNULUS CLASSES



class, as seen in table C1. A total of 46 classes was needed. The length frequencies of the fish with the same number of annuli were then represented graphically in fig.11. Each annulus class represents a year class of fish.

To facilitate comparisons, the number of fish in each annulus class was calculated and tabulated in table 25. The average fish length in mm in each class was also recorded as well as the average annual growth for each year class, the standard deviation for fish lengths in each year class, and the standard error. To calculate the average fish length in each annulus class, the formula  $\bar{x} = \frac{\sum x}{N}$  was used,

where  $x$  = fish length (class mark)

$N$  = number of fish in annulus class

The standard deviation was calculated from the formula

$$S_x^2 = \frac{\sum(x^2) - N\bar{x}^2}{N - 1}$$

$$S_x = \sqrt{S_x^2}$$

where  $S_x$  = standard deviation

The standard error was calculated from the formula

$$S_{e_x} = \frac{S_x}{\sqrt{N}}$$

Table 25 NUMBERS OF FISH IN EACH ANNULUS-CLASS WITH THEIR AVERAGE LENGTHS, ANNUAL GROWTH, STANDARD DEVIATION AND STANDARD ERRORS

Number of annuli	Number of fish in each annulus class	Average fish length in each annulus class in mm x	Average annual growth in mm	Standard Deviation of fish length S <sub>x</sub>	Standard error S <sub>e</sub> <sub>x</sub>
0	63	91,3		23,49	2,96
1	130	131,0	131,0	23,23	2,04
2	125	191,2	60,2	25,35	2,27
3	153	224,4	33,2	25,73	2,08
4	105	256,5	32,1	26,09	2,55
5	112	288,3	31,8	29,16	2,76
6	55	311,2	22,9	37,03	4,99
7	19	360,8	49,6	49,76	11,42
8	18	394,5	33,7	36,51	8,61
9	9	400,1	5,6	59,28	19,76
10	4	462,5	62,4	36,74	18,37
12	2	470,0		21,68	
15	1	500,0		22,36	

Fish with no annuli on their scales were included in table 25, but the value of this data is limited because, due to their small size, many of these fish must have slipped through the nets when being caught. The number of these fish in each month class was counted. From February to August, 63 of these fish were caught, while between September and January, none were caught. However, Barberspan was not examined during every month of the year, the missing data being for January, March and December, and in June too few fish were caught to be of any value. It is known that the yellow fish spawn in spring, so by this time one year old fish should have one annulus on their scales.

In a further attempt to determine the time of the year when the annuli are laid down, the radius of the last annulus was divided into the radius of the scale for each fish. Because of the fact that the growth rate of the Barberspan yellow fish is not the same for each year class, the scale ratios were arranged in month classes and annulus-number classes. The number of scales in each category and their average ratios for the first 6-year classes were calculated and tabulated in their month and year classes in table 26. The reason why these ratios were used and not straight measurements, is because the scales examined from the same fish and from fishes of the same length are not necessarily the same size and also because the annual growth rate is not the same for fishes of different ages.

Table 26 AVERAGES OF SCALE RADII + LAST-ANNULUS RADII ARRANGED IN MONTH CLASSES AND ANNULUS-FREQUENCY CLASSES WITH THE NUMBER OF SCALES INVOLVED IN EACH CLASS

Month when Caught	1 annulus class		2 annulus class		3 annulus class		4 annulus class		5 annulus class		6 annulus class	
	No. Scales	average ratio	No. Scales	average ratio	No. Scales	average ratio	No. Scales	average ratio	No. Scales	average ratio	No. Scales	average ratio
February	24	2,44	47	1,44	68	1,16	30	1,16	7	1,12	2	1,13
April	8	3,14	5	1,39	7	1,21	10	1,23	7	1,16	4	1,10
May	0		5	1,33	5	1,24	2	1,13	3	1,04	2	1,07
July	9	5,83	7	1,50	12	1,14	4	1,13	3	1,10	2	1,07
August	1	2,80	5	1,24	9	1,15	16	1,06	9	1,06	4	1,02
September	4	1,28	0		4	1,12	1	1,07	2	1,13	0	
October	3	1,68	5	1,15	6	1,10	16	1,10	9	1,10	13	1,07
November	81	1,77	48	1,43	41	1,23	29	1,11	72	1,08	26	1,06

The data in table 26 was plotted in histogram form in fig. 12. Only the first 6 year classes were used because the numbers involved in the other year classes were too low to give valid results. The average ratio for each month was plotted for each year class. Some months show no ratio because no fish occurred in that year class for that month.

## 11. RESULTS

From table C1 and fig. 10 it can be seen that if the fish involved had been used to draw a length frequency curve, it would have been very difficult to recognise the age groups by modes from the third year onwards. It can be seen that fish of the same age as determined by the scale method show a wide length range in all classes. These have been expressed as standard deviations in table 25. For the first five year classes the standard deviations are about equal, but after this age there is a general increase. Table 25 also shows that only two and one fish respectively were involved in the 12 and 15 year classes. The standard deviation for these classes was taken to be the square root of the average fish lengths concerned.

Table 25 also shows that the average growth rate in the first year is about twice that during the second year and that for the second year is about twice that for the third year. From the third to the fifth year the growth rate is about equal but in the sixth year, a sharp drop occurs once more. However, it can be seen that from this year onwards there is also a sharp drop in fish numbers involved, so that these results are suspect. There were over 100 fishes involved in each of the first 5 year groups. The sixth

Fig. 12

SCALE RADIUS

LAST ANNULUS RADIUS

Averages Arranged In Month Classes And Annulus - Frequency Classes

F=FEBRUARY

A=APRIL

M=MAY

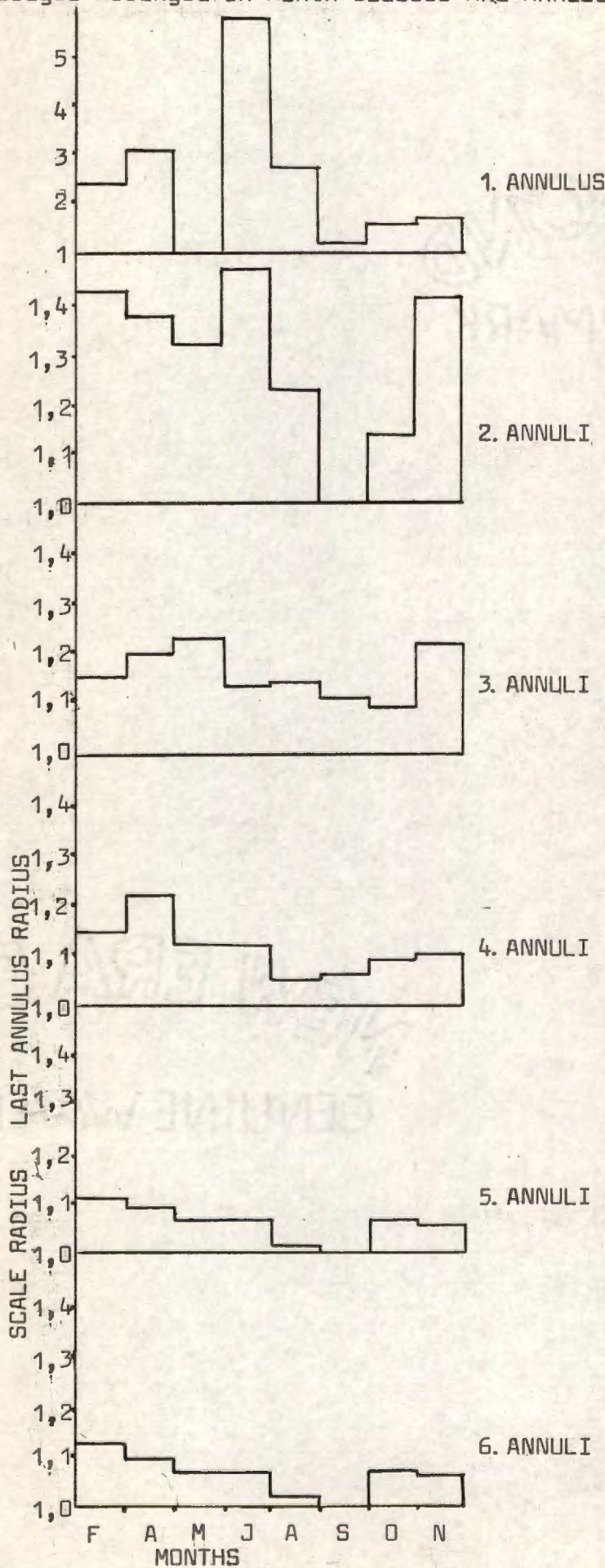
J=JULY

A=AUGUST

S=SEPTEMBER

O=OCTOBER

N=NOVEMBER



year class only included 55 fish and the subsequent classes less than 20 each.

By examining length frequency curves for the Barberspan B. holubi population Göldner (1967) found that the average fish lengths for fish in their second year of life and subsequent years was as follows: 13 cm, 20 cm, 24 cm, 28 cm, and 30 cm. Age determination by scales gave lengths of 13,1 cm, 19,1 cm, 22,4 cm, 25,7 cm and 28,8 cm. The sixth group and older gave average lengths of 31,1 cm, 36,1 cm, 39,5 cm, 40,0 cm and 46,3 cm. Fish with 12 annuli had an average length of 47,0 cm and those with 15, an average length of 50 cm.

It can be seen that fish older than five years according to the length frequency method of age determination used by Göldner have an average length of 30 cm while those older than six years, according to the scale method, have an average length of 31 cm. In other words, fish of about 30 cm long appear to be one year older by the scale method of age determination than by the length frequency method.

In spite of the fact that certain month classes, in table 26, fig. 12, had no fish in them, the histograms do show a certain tendency. As a fish grows in time after the formation of an annulus, one would expect the ratio of 'last annulus length to scale radius' to progressively increase until the next annulus is formed. Just after this point the ratio should suddenly drop once more. In the one-annulus group the histogram shows a rapid drop from the July group down into the August and September groups. The same

tendency is seen in the second-annulus histogram. The third-annulus histogram shows the drop to start one month earlier with the lowest ratio in October. The 4th, 5th and 6th annulus groups all show the smallest ratios to occur in August.

Another indication of when an annulus is formed can be obtained by examining the times when fish with no annuli were caught. During February 44 such fish were caught. In April 1, May 7, July 0 and August 11. None were caught in September, October, November or January.

## 12. CONCLUSION

From the fairly high standard deviations in table 25 of average fish length in each annulus class, it can be concluded that the age of a large population of B. holubi can be determined, but that the age of one or a few individuals may be fairly inaccurate as indicated by the scales. There is a large overlap of fish lengths in each annulus class which can easily lead to a misinterpretation of age by the length frequency method used by Göldner, especially as fish become older. It has been seen that by the scale method, fish of 31 cm are 6 years old while by the length frequency method those of 30 cm are 5 years old. This difference is, however, very small over a period of six years and it can be concluded that age of B. holubi can be determined from the scales. Average annual growth rates by the scale method are slightly less than by the length frequency method. In the second year they are 6 cm and 7 cm respectively, followed by 3,3 cm and 4 cm, 3,3 cm and 4 cm, 3,1 cm and 2 cm, 2,3 cm and 3 cm respectively.

Annuli appear to start forming in August and may continue until October, though most are formed before this. This conclusion is born out by the fact that after August no more fish with no annuli were caught until February. As spawning begins in spring, the young fry would be too small to get caught until at least February, according to these results. As in many other fish species, the growth of the young fish is very much faster than in older fish.

### 13. GENERAL DISCUSSION OF RESULTS

Fish from three different environments were examined in this investigation and the results show clearly that it is very dangerous to draw fixed conclusions at this stage. Each group of fish gave different results and for this reason it is necessary to specify from which source the material has come when making statements about B. holubi. Both Nel's Pan and Gilfillan dam were grossly underpopulated with fish and yet the results from the two differed in almost every respect. For example, correlations between actual and back calculated fish lengths were regular and understandable for Gilfillan dam, but definitely erratic for Nel's Pan.

When scales were chosen for back calculations according to the smallest percentage deviation from the mean, there were twice as many suitable ones from the Nel's Pan fish as from the Gilfillan dam fish. The mean percentage variation for back calculated fish lengths for the first annulus, were nearly half as much again for the Nel's Pan fish, compared to the other group. More than four times more fish from Nel's Pan had a fourth annulus on their scales compared to

those from the Gilfillan dam. By the time that the first annulus had been formed on the scales, Gilfillan dam fish were nearly twice the size of the other group. This does not necessarily mean that their growth rate was so much faster, but rather that this annulus was formed at a different time of the year. It must be remembered that the fingerlings released in the two impoundments were about the same size and age and came from the same breeding pond, i.e. they were genetically the same. Variations were, therefore, mainly due to different environments.

The above tests were not carried out on the Barberspan fish, so here comparisons are not possible. However, the growth rate of the fish from the three different impoundments was somewhat different. After three and a half years, the average length of the fish from the Gilfillan dam was 381,2 mm and for Nel's Pan 361,0 mm. Fish of the same age from Barberspan were only about 230 mm long, which is only about two-thirds the length of the other groups. The limited number of large fish from Barberspan shows that there is an underpopulation of this species in the pan. The slow growth of these fish must therefore be attributed to too much competition from other species occupying the same ecological niche as B. holubi, or to very poor living conditions in the pan generally.

The Gilfillan dam is probably one of the most fertile dams in which B. holubi is ever likely to be reared and the growth rate of these fish is probably, therefore, close to the maximum that is possible for this species, without artificial feeding. By using this information as a

yardstick, it now becomes possible to gauge the suitability of an impoundment for the rearing of B. holubi by simply examining the scales for annuli and determining the growth rate of the fish over a period of three and a half years or less. Without examining the populations of B. holubi from other impoundments, it is not possible to say exactly how close to the poorest possible condition Barberspan is. However, it does give one an idea of a condition which is far from ideal and it can be used for a comparison.

Generally speaking the age determination of B. holubi from its scales is difficult and not very accurate. This was illustrated by the graphs of length frequencies of fish from Barberspan in scale annulus classes. The average length range of fish in the one to nine annulus classes was 157 mm. In other words, the average difference in length between the longest and shortest fish in any one age group from one year to nine years old was 157 mm. The average length of two year old fish from the same source was 191 mm. This means that in the lowest two age groups, the length range can be expressed as nearly a two year age range. In the higher age groups it becomes progressively more, i.e. the degree of accuracy decreases with an increase in age. Until annuli on scales are compared with annuli on various bones, it can only be concluded that age determination by the scale method is only possible on B. holubi if large numbers of fish from a population are examined as a group.

The fact that the body length/scale radius relationship is very close to a straight line for fish from about one

year old to about five years old, simplifies back calculations. The linear formula  $y = 6,08x - 21,30$  for a scale magnification of one is very easy to use compared to one representing a curve. The fish length used in this study was fork length, but standard length (body length) or total length may even give a better relationship. This formula was only calculated after the back calculations had been made on the first group of fish, i.e. those of known age. The results would have been slightly different had this formula been used from the start, but the ratios between the results from the different annuli would have remained the same. Comparisons of results are more important than the actual calculated lengths but for future studies the above formula should be used when making back calculations of fish length at the time of annulus formation.

With regard to annulus formation generally, it can be concluded that they form in late winter and early spring. Various tests on the scales from all fish groups indicate that they are mainly formed in August and September. If spawning forms an interruption in scale growth, as well as the winter conditions, then the two would almost coincide, but not quite. This may be the cause of the double annuli and other confusing marks on the scales so often encountered. Only about 50% of the fish scales of known age were clearly marked. In this respect again, comparisons of scale annuli with bone annuli would be very helpful.

#### 14. SUMMARY OF RESULTS

- (1) An examination of the 520 scales from fish of known age showed that 32% had no fourth annulus. Only about 6% came from Nel's Pan and the rest from Gilfillan dam.
- (2) Fish from Nel's Pan formed their first annulus earlier than those from Gilfillan dam and the latter showed a faster growth rate throughout their lives.
- (3) Back calculations of fish length from scale annuli were far more variable for the first annulus than for the other two annuli and this variation was even greater for the Nel's Pan fish scales than for the other group.
- (4) The best area on B. holubi from which to remove scales for age determination and back calculations is one just below and anterior to the anterior margin of the dorsal fin but above the lateral line.
- (5) At least ten scales should be sampled from a fish if a reasonable degree of accuracy is expected in age determination and back calculations of length.
- (6) Yellow fish reared under favourable conditions grew three times faster than those living under unfavourable conditions over a period of three and a half years.
- (7) Fish with a length above 100 mm and below 300 mm have a body length/scale radius relationship which is virtually linear. This relationship is represented by the formula  $y = 6,08x - 21,30$  for a scale magnification factor of one.

(8) Age determination of fish from Barberspan by the scale method gave an age of five years for fish which were aged six years by the length frequency method.

(9) From various tests it appears that the annuli on the scales of B. holubi are laid down in late winter and early spring each year.

(10) Age determination of B. holubi is possible and the bigger the population sample examined, the more accurate will be the results.

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17. APPENDIX OF TABLES

- A1 Scale measurements in mm x 19. Nel's Pan.
- A2 Scale measurements in mm x 19. Gilfillan dam.
- A3 Calculated fish lengths in mm when first annulus was formed. Nel's Pan.
- A4 Calculated fish lengths in mm when second annulus was formed. Nel's Pan.
- A5 Calculated fish lengths in mm when third annulus was formed. Nel's Pan.
- A6 Calculated fish lengths in mm when first annulus was formed. Gilfillan dam.
- A7 Calculated fish lengths in mm when second annulus was formed. Gilfillan dam.
- A8 Calculated fish lengths in mm when third annulus was formed. Gilfillan dam.
- A9 The absolute percentage variation from the mean calculated fish lengths averaged for each scale number. Gilfillan dam.
- A10 The absolute percentage variation from the mean calculated fish lengths averaged for each scale number. Nel's Pan.
- A11 The calculated fish lengths according to each scale adjusted to a common mean value per annulus for the ten fish. Only the means for the ten replicates of each scale number are given. Nel's Pan.
- A12 The calculated fish lengths according to each scale adjusted to a common mean value per annulus for the ten fish. Only the means for the ten replicates of each scale number are given. Gilfillan dam.
- A13 Ratio of scale width to scale length. Gilfillan dam.
- A14 Ratio of scale width to scale length. Nel's Pan.
- A15 Mean ratio of scale width through focus to distance from focus to scale margin along the longitudinal axis.
- A16 Readability of the 520 scales examined.

- B1 Fish lengths in 10 mm classes with their corresponding projected scale radii in mm.
- B2 Fish numbers falling into each 10 mm fish length class and 3 mm scale class for the fish population 50 mm to 149 mm.
- B3 Fish numbers falling into each 10 mm length class and 4 mm scale class for the fish population 150 mm and longer.
- B4 Fish numbers falling into each 10 mm fish length class and 4 mm scale radius class for the fish population 50 mm and longer.
- C1 Fish with similar numbers of scale annuli arranged in length classes.
- C2 Scale radii + last-annulus radii arranged in month classes and annulus-frequency classes.

Table A1 SCALE MEASUREMENTS IN mm x 19 NEL'S PAN

R = regenerated scale with first ring absent.

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
39	1	268	11	55	78	100
32	1	231	14	44	57	74
47	1	265	8	59	83	100
52	1	264	10	41	66	95
48	1	249	12	51	76	99
44	1	289	18	60	95	115
42	1	264	14	42	75	94
46	1	204	11	45	65	76
43	1	249	10	50	75	90
35	1	237	10	50	78	100
39	2	295	13	56	86	104
32	2	251	13	50	63	78
47	2	262	7	52	77	100
52	2	267	10	41	63	88
48	2	258	14	56	82	100
44	2	294	15	45	70	89
42	2	270	10	34	60	73
46	2	220	10	40	59	69
43	2	253	10	51	77	92
35	2	272	12	50	74	92
39	3	246	11	54	80	98
32	3	270	10	43	60	78
47	3	252	7	50	70	100
52	3	224	11	52	74	107
48	3	220	9	40	70	87
44	3	192	10	50	78	95
42	3	248	9	37	65	90
46	3	168	7	48	50	65
43	3	261	9	44	70	83
35	3	222	10	43	67	85
39	4	261	10	61	88	106
32	4	219	10	50	70	90
47	4	258	10	55	90	113
52	4	248	12	50	76	105
48	4	226	12	52	70	94
44	4	259	16	58	85	108
42	4	263	14	50	68	95
46	4	190	8	44	57	75
43	4	235	8	48	74	90
35	4	255	14	54	80	103
39	5	295	20	66	99	118
32	5	279	14	60	76	95
47	5	316	13	69	108	130
52	5	291	10	54	80	112
48	5	255	12	65	100	121
44	5	299	20	70	100	118
42	5	296	16	70	85	110
46	5	228	10	55	81	90
43	5	277	13	60	93	113
35	5	290	10	65	92	115

Table A1 continued

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
39	6	258	12	60	89	106
32	6	246	10	49	70	86
47	6	271	8	50	91	111
52	6	272	10	50	73	101
48	6	240	12	60	90	107
44	6	298	14	55	85	105
42	6	279	15	45	70	96
46	6	217	10	52	78	86
43	6	255	11	51	79	100
35	6	250	15	55	83	105
39	7	239	10	40	72	85
32	7	228	10	42	51	65
47	7	217	8	40	64	84
52	7	205	8	37	48	71
48	7	212	12	47	64	81
44	7	238	15	44	61	75
42	7	228	11	38	50	70
46	7	178	10	40	65	69
43	7	210	9	35	60	71
35	7	208	10	42	60	76
39	8	223	12	58	83	104
32	8	208	7	50	65	84
47	8	243	6	42	70	81
52	8	282	7	44	59	91
48	8	245	9	40	65	78
44	8	264	15	57	86	105
42	8	222	12	48	75	99
46	8	211	7	41	65	71
43	8	236	10	49	74	91
35	8	205	8	43	66	86
39	9	263	15	54	93	111
32	9	220	17	51	69	88
47	9	274	8	52	92	110
52	9	269	10	54	85	114
48	9	250	12	59	80	105
44	9	305	15	64	93	112
42	9	266	12	50	76	100
46	9	203	9	51	75	86
43	9	245	10	55	80	100
35	9	233	10	55	80	101
39	10	257	12	55	89	108
32	10	254	25	55	74	91
47	10	335	12	60	115	135
52	10	380	15	60	90	115
48	10	268	13	73	103	122
44	10	351	18	65	102	122
42	10	284	14	59	84	109
46	10	211	11	54	85	96
43	10	276	11	61	90	111
35	10	276	13	62	91	115

Table A1 continued

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
39	11	250	13	58	90	108
32	11	240	11	48	62	85
47	11	270	7	56	97	115
52	11	253	8	51	70	100
48	11	237	11	53	85	109
44	11	285	15	53	90	110
42	11	262	13	45	73	98
46	11	200	10	50	72	81
43	11	241	10	50	80	100
35	11	253	12	50	80	101
39	12	228	10	40	58	74
32	12	250	11	32	42	55
47	12	235	10	39	65	77
52	12	208	10	37	53	76
48	12	206	10	40	56	69
44	12	259	11	40	64	81
42	12	236	11	40	55	76
46	12	198	9	40	62	69
43	12	201	7	35	42	60
35	12	199	10	39	49	65
39	13	158	10	28	35	44
32	13	122	R	28	35	42
47	13	177	5	23	41	54
52	13	144	6	22	33	46
48	13	141	9	26	42	49
44	13	145	9	25	37	44
42	13	161	10	26	35	46
46	13	137	7	29	38	43
43	13	141	6	22	31	42
35	13	172	8	27	39	52
39	14	225	12	60	89	105
32	14	216	10	50	66	82
47	14	254	12	55	92	110
52	14	272	10	56	85	115
48	14	241	10	60	85	106
44	14	278	15	55	88	106
42	14	255	12	48	75	97
46	14	190	9	46	68	76
43	14	231	9	46	76	91
35	14	205	8	48	66	86
39	15	233	16	57	88	102
32	15	207	13	50	70	86
47	15	249	15	58	98	117
52	15	277	20	55	85	114
48	15	237	15	70	95	113
44	15	303	20	56	89	108
42	15	257	16	50	75	97
46	15	208	10	48	72	80
43	15	243	R	61	91	104
35	15	252	10	51	80	99

Table A1 continued

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
39	16	239	14	50	75	94
32	16	205	12	46	64	79
47	16	269	13	57	90	110
52	16	145	13	52	79	103
48	16	230	15	64	90	116
44	16	279	17	55	89	108
42	16	253	15	47	78	99
46	16	190	10	42	64	71
43	16	228	11	46	78	95
35	16	240	10	50	72	91
39	17	202	8	30	44	51
32	17	160	11	31	33	42
47	17	209	5	24	48	56
52	17	178	6	27	46	51
48	17	182	10	36	54	63
44	17	271	15	35	58	68
42	17	208	9	30	44	54
46	17	177	6	26	41	44
43	17	158	6	36	50	60
35	17	191	9	34	48	62
39	18	215	7	45	70	87
32	18	208	11	48	62	83
47	18	200	11	40	79	92
52	18	231	10	49	69	93
48	18	230	11	55	76	95
44	18	256	15	56	91	105
42	18	241	12	50	77	99
46	18	189	8	36	60	65
43	18	218	11	49	75	92
35	18	206	10	44	66	81
39	19	203	8	41	65	82
32	19	188	21	38	51	65
47	19	244	20	54	87	103
52	19	230	13	51	70	96
48	19	218	10	52	75	91
44	19	263	16	56	76	95
42	19	226	12	45	60	80
46	19	183	10	44	65	70
43	19	180	10	42	70	83
35	19	205	10	45	68	85
39	20	182	8	45	65	77
32	20	174	13	35	50	64
47	20	194	8	35	65	82
52	20	218	10	40	60	82
48	20	186	10	45	68	82
44	20	229	16	45	68	83
42	20	221	10	36	56	72
46	20	163	10	40	59	65
43	20	186	10	39	68	81
35	20	200	13	53	74	92

Table A1 continued

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
39	21	194	10	42	62	76
32	21	181	10	36	46	60
47	21	214	5	35	60	75
52	21	184	8	30	42	65
48	21	194	10	35	55	65
44	21	236	12	36	57	67
42	21	205	8	31	48	62
46	21	179	7	35	50	57
43	21	193	9	35	54	67
35	21	206	9	44	60	73
39	22	133	9	26	41	51
32	22	104	8	20	30	38
47	22	143	16	25	53	60
52	22	115	10	20	27	35
48	22	140	9	30	45	56
44	22	162	10	30	50	60
42	22	145	7	24	37	48
46	22	125	5	25	40	42
43	22	128	6	22	35	44
35	22	132	8	28	39	48
39	23	177	15	43	62	75
32	23	174	10	35	51	63
47	23	199	9	40	65	86
52	23	199	9	43	64	85
48	23	185	9	45	65	78
44	23	225	12	45	71	86
42	23	219	12	40	56	72
46	23	148	7	35	51	58
43	23	174	5	36	60	72
35	23	181	11	43	61	73
39	24	167	10	38	53	70
32	24	147	8	29	41	54
47	24	180	4	35	62	76
52	24	181	6	35	56	75
48	24	159	8	38	53	69
44	24	210	11	40	60	74
42	24	175	12	34	46	57
46	24	134	8	34	52	56
43	24	158	9	36	56	66
35	24	174	8	39	59	71
39	25	142	9	35	50	61
32	25	166	R	33	49	63
47	25	164	6	35	64	80
52	25	173	9	38	56	78
48	25	135	R	30	49	60
44	25	191	14	45	70	86
42	25	185	9	36	52	71
46	25	130	6	39	54	63
43	25	145	9	35	58	70
35	25	161	6	32	50	64

Table A1 continued

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
39	26	133	9	31	48	57
32	26	133	R	25	37	50
47	26	154	5	30	57	69
52	26	151	6	35	51	71
48	26	140	5	34	45	61
44	26	192	10	40	60	75
42	26	166	7	30	43	54
46	26	117	8	32	55	62
43	26	132	5	27	43	52
35	26	147	10	38	57	69

Table A2 SCALE MEASUREMENTS IN mm x 19 GILFILLAN DAM

R = Regenerated scale with the first ring absent

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
30	1	284	25	76	112	123
1	1	258	22	60	89	104
9	1	267	20	65	100	110
15	1	241	25	71	90	100
19	1	244	20	58	95	100
13	1	262	16	49	72	98
10	1	251	18	47	70	95
26	1	226	15	52	76	81
21	1	258	16	55	80	100
25	1	255	19	63	83	100
30	2	247	20	63	90	102
1	2	261	21	59	81	94
9	2	306	24	56	56	80
15	2	234	21	64	89	95
19	2	245	20	57	90	98
13	2	257	20	53	88	95
10	2	286	20	62	94	114
26	2	284	22	62	85	91
21	2	287	25	70	100	115
25	2	268	16	48	70	78
30	3	250	12	56	90	102
1	3	198	10	49	78	88
9	3	261	20	55	80	92
15	3	233	16	64	88	95
19	3	181	17	50	80	90
13	3	208	19	50	64	87
10	3	266	13	51	85	115
26	3	246	10	46	70	77
21	3	249	14	45	60	90
25	3	248	21	60	83	98
30	4	267	19	69	100	111
1	4	234	18	57	90	95
9	4	269	26	69	103	117
15	4	243	20	60	90	98
19	4	250	17	60	92	97
13	4	254	20	48	70	100
10	4	263	16	46	70	96
26	4	220	12	54	85	91
21	4	245	15	55	88	102
25	4	260	19	50	80	95
30	5	302	20	64	113	123
1	5	287	22	70	106	119
9	5	298	23	79	113	127
15	5	292	28	70	100	110
19	5	282	27	75	110	116
13	5	285	25	60	90	117
10	5	296	19	60	98	120
26	5	285	24	76	106	115
21	5	281	22	68	105	120
25	5	276	20	70	90	112

Table A2 continued

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
30	6	292	19	60	95	106
1	6	252	19	62	88	98
9	6	302	30	61	89	110
15	6	230	34	55	85	87
19	6	250	20	58	85	96
13	6	252	16	51	85	91
10	6	273	17	65	80	107
26	6	269	16	58	83	90
21	6	278	19	62	88	113
25	6	254	16	56	73	95
30	7	247	20	50	80	91
1	7	118	17	31	42	52
9	7	217	24	48	70	80
15	7	210	19	45	67	74
19	7	219	19	49	74	83
13	7	213	13	40	64	82
10	7	220	16	38	64	79
26	7	180	14	41	64	71
21	7	220	15	50	65	80
25	7	200	17	46	58	75
30	8	271	16	68	99	110
1	8	239	17	61	86	94
9	8	235	25	70	101	115
15	8	198	24	69	91	97
19	8	231	20	61	89	96
13	8	219	15	50	74	95
10	8	252	19	52	75	107
26	8	198	15	59	68	84
21	8	240	16	50	85	95
25	8	215	15	50		91
30	9	274	25	71	101	112
1	9	251	22	59	93	105
9	9	268	26	70	102	113
15	9	241	24	70		99
19	9	250	23	70	95	103
13	9	256	15	49	75	94
10	9	268	20	60	88	114
26	9	235	17	67	77	96
21	9	251	15	63	92	111
25	9	242	21	59	79	100
30	10	274	20	81	110	123
1	10	283	20	77	109	121
9	10	325	22	70	110	124
15	10	230	26	70	100	111
19	10	249	24	70	100	112
13	10	242	31	60	88	97
10	10	290	22	66	101	124
26	10	254	20	68	102	107
21	10	262	20	62	100	117
25	10	261	25	75	88	109

Table A2 continued

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
30	11	293	22	60	90	101
1	11	258	22	61	96	107
9	11	261	22	64	95	108
15	11	223	22	51	73	82
19	11	244	20	60	75	100
13	11	244	18	52	90	99
10	11	262	19	58	89	108
26	11	254	19	61	76	95
21	11	274	19	64	95	110
25	11	253	22	66	91	101
30	12	234	15	42	71	80
1	12	200	17	50	75	85
9	12	199	17	47	58	74
15	12	180	19	40	58	62
19	12	214	19	50	63	82
13	12	212	15	40	55	77
10	12	226	26	45	63	80
26	12	187	R	40	65	77
21	12	219	20	49	78	85
25	12	192	R	43	60	69
30	13	135	6	25	40	46
1	13	112	R	29	38	44
9	13	111	7	27	38	42
15	13	139	15	39	52	56
19	13	131	10	30	37	46
13	13	129	10	26	34	45
10	13	141	9	23	35	47
26	13	148	R	20	35	42
21	13	103	5	16	24	29
25	13	113	8	24	32	42
30	14	227	23	72	99	108
1	14	213	20	60	84	98
9	14	245	27	72	104	116
15	14	216	23	60	84	89
19	14	248	22	62	90	98
13	14	215	16	50	70	90
10	14	244	20	58	81	111
26	14	229	20	67	80	96
21	14	225	20	63	93	105
25	14	219	14	60	86	94
30	15	270	22	79	110	120
1	15	231	26	66	92	101
9	15	262	29	75	105	117
15	15	230	26	70	98	105
19	15	216	20	60	86	95
13	15	229	19	56	88	99
10	15	255	19	59	78	108
26	15	250	20	69	94	100
21	15	225	20	66	90	107
25	15	236	23	68	89	101

Table A2 continued

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
30	16	258	35	66	89	98
1	16	244	20	60	95	105
9	16	265	35	69	100	112
15	16	200	33	55	81	87
19	16	220	20	58	78	92
13	16	227	17	55	68	93
10	16	245	20	59	85	108
26	16	220	19	59	68	86
21	16	246	20	67	95	107
25	16	233	25	51	69	100
30	17	215	15	35	45	60
1	17	199	10	29	44	62
9	17	234	18	51	71	80
15	17	176	16	41	55	59
19	17	192	13	40	55	66
13	17	222	11	34	48	59
10	17	203	14	36	48	62
26	17	170	11	30	36	46
21	17	191	12	37	51	64
25	17	202	16	36	49	56
30	18	238	18	55	82	90
1	18	224	19	55	81	89
9	18	238	18	66	98	110
15	18	225	19	50	68	76
19	18	180	19	51	74	86
13	18	216	19	50	79	86
10	18	209	18	45	74	88
26	18	217	16	50	66	81
21	18	217	16	45	65	79
25	18	208	15	45	70	81
30	19	221	19	49	82	88
1	19	219	30	53	75	84
9	19	217	33	45	96	106
15	19	193	22	59	76	82
19	19	162	17	45	65	79
13	19	165	15	41	53	68
10	19	197	12	45	70	88
26	19	207	20	60	73	92
21	19	206	16	55	75	90
25	19	193	14	53	68	85
30	20	196	18	52	72	82
1	20	187	16	50	71	80
9	20	209	16	60	85	97
15	20	180	20	55	70	76
19	20	158	17	46	60	79
13	20	170	9	40	50	71
10	20	202	15	42	65	81
26	20	186	15	50	63	74
21	20	183	12	51	70	78
25	20	173	10	40	50	68

Table A2 continued

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
30	21	223	15	37	58	65
1	21	184	17	44	66	72
9	21	222	22	56	83	89
15	21	158	17	42	55	60
19	21	158	13	41	57	61
13	21	193	9	36	51	55
10	21	222	17	40	56	74
26	21	187	15	50	50	60
21	21	189	12	43	62	71
25	21	191	20	38	49	65
30	22	165	10	25	40	47
1	22	126	10	21	42	45
9	22	140	9	36	52	59
15	22	127	7	30	41	44
19	22	131	14	34	41	51
13	22	133	9	24	35	42
10	22	156	10	24	37	47
26	22	97	5	26	34	40
21	22	128	13	26	39	48
25	22	164	10	30	43	50
30	23	204	19	52	65	83
1	23	188	18	52	75	86
9	23	213	20	58	94	97
15	23	179	18	49	66	74
19	23	154	10	44	56	69
13	23	192	10	40	65	72
10	23	209	10	40	58	83
26	23	183	16	49	58	73
21	23	177	10	42	55	70
25	23	169	20	44	53	75
30	24	187	16	48	56	72
1	24	166	12	40	60	67
9	24	190	16	52	83	90
15	24	165	19	46	62	67
19	24	143	15	44	54	68
13	24	165	14	38	46	65
10	24	179	12	35	58	67
26	24	156	16	40	62	70
21	24	149	15	40	55	66
25	24	153	15	32	46	60
30	25	182	10	43	66	77
1	25	160	13	48	72	81
9	25	168	11	56	88	92
15	25	112	16	40	53	58
19	25	139	11	29	37	49
13	25	141	11	34	56	62
10	25	171	11	40	57	69
26	25	133	14	39	51	61
21	25	111	14	27	37	47
25	25	144	10	42	55	70

Table A2 continued

Fish No.	Scale No.	Scale width through focus	Focus to 1st ring	Focus to 2nd ring	Focus to 3rd ring	Focus to scale margin
30	26	176	15	40	63	68
1	26	157	19	42	59	67
9	26	179	12	45	70	81
15	26	139	19	35	57	63
19	26	137	12	35	47	59
13	26	128	10	28	43	52
10	26	156	12	35	52	64
26	26	137	15	42	54	66
21	26	138	11	30	46	54
25	26	140	16	39	52	61

Table A3 CALCULATED FISH LENGTHS IN mm WHEN FIRST ANNULUS WAS FORMED. NEL'S PAN

R = regenerated scale with the first annulus absent  
 L = length when caught

Fish No.	39	32	47	52	48	44	42	46	43	35
L	379	342	366	379	369	401	379	300	356	339
Scale No.										
1	42	65	29	40	45	63	56	43	40	34
2	47	57	26	43	52	68	52	43	40	44
3	43	44	26	39	38	42	38	32	39	40
4	36	38	32	43	47	59	56	32	32	46
5	64	50	37	34	37	68	55	33	41	29
6	43	40	26	38	41	53	59	35	37	48
7	45	53	35	43	55	80	60	43	45	45
8	44	28	27	29	43	57	46	30	39	32
9	51	66	27	33	42	54	45	31	36	34
10	42	94	33	49	39	59	49	34	35	38
11	46	44	22	30	37	55	50	37	36	40
12	51	68	48	50	53	54	55	39	42	52
13	86	R	34	49	68	82	82	49	51	52
14	43	42	40	33	35	57	47	36	35	32
15	59	52	47	66	49	74	63	37	R	34
16	56	52	43	48	48	63	57	42	41	37
17	59	90	33	45	59	88	63	41	36	49
18	30	45	44	41	43	57	46	37	43	42
19	37	110	71	51	41	91	57	43	43	40
20	39	69	36	46	45	77	53	46	44	48
21	50	57	24	47	57	72	49	37	48	42
22	67	72	98	108	59	67	55	36	49	56
23	76	54	38	40	43	56	63	36	74	51
24	54	51	19	30	43	60	80	43	49	38
25	56	R	27	39	R	65	48	29	46	32
26	60	R	27	32	30	53	49	39	34	49
Average	51	58	37	44	46	64	55	38	42	42

Table A4 CALCULATED FISH LENGTHS IN mm WHEN SECOND ANNULUS WAS FORMED. NEL'S PAN

L = length when caught

Fish No.	39	32	47	52	48	44	42	46	43	35
L	379	342	366	379	369	401	379	300	356	339
Scale No.										
1	208	203	183	163	190	209	173	178	198	169
2	223	219	190	176	207	203	176	174	202	184
3	209	189	183	184	189	211	173	222	189	171
4	218	190	178	180	204	215	199	176	190	178
5	212	216	194	183	198	238	207	183	189	192
6	214	195	165	188	207	210	178	192	181	178
7	178	221	174	197	214	235	206	174	175	187
8	211	204	190	183	189	218	184	173	192	169
9	184	198	173	179	207	229	189	178	196	185
10	193	207	167	198	221	214	205	166	196	183
11	203	193	178	193	179	208	193	185	178	168
12	205	199	185	184	214	198	199	174	208	203
13	241	228	156	181	196	223	214	202	186	176
14	217	209	183	185	209	208	188	182	180	166
15	212	199	181	183	229	208	195	180	209	175
16	202	199	190	191	229	204	180	177	172	186
17	223	252	157	210	211	206	211	177	214	186
18	196	198	159	200	214	214	191	166	190	184
19	189	200	192	210	211	236	213	189	180	179
20	221	187	156	185	202	217	189	185	171	195
21	209	205	171	175	199	215	189	184	186	204
22	193	180	152	207	198	200	189	179	178	198
23	217	190	170	192	213	210	211	181	178	200
24	206	184	169	177	203	217	226	182	194	186
25	217	179	160	185	184	210	192	186	178	169
26	206	171	159	187	206	214	211	155	185	187
Average	208	201	174	187	205	214	195	181	188	183

Table A5 CALCULATED FISH LENGTHS IN mm WHEN THIRD ANNULUS WAS FORMED. NEL'S PAN

L = length when caught

Fish No.	39	32	47	52	48	44	42	46	43	35
L	379	342	366	379	369	401	379	300	356	339
Scale No.										
1	296	263	304	263	283	331	302	257	297	264
2	313	276	282	271	358	315	255	257	305	273
3	309	263	256	262	297	329	274	231	300	267
4	315	266	291	274	275	316	271	228	293	263
5	318	274	304	271	305	340	293	270	293	271
6	318	278	300	274	310	325	276	272	281	268
7	321	268	274	256	292	326	271	283	301	268
8	302	265	316	246	307	328	287	275	289	260
9	318	268	306	283	281	333	288	262	285	269
10	312	278	312	297	312	335	292	266	208	268
11	316	249	309	265	288	328	282	267	285	269
12	297	261	335	264	299	317	274	270	249	256
13	301	285	278	264	316	337	288	265	263	254
14	321	275	306	280	296	333	293	268	297	260
15	327	278	307	283	310	330	293	270	311	274
16	302	277	299	291	286	330	299	270	292	268
17	327	269	314	260	316	342	309	280	297	262
18	305	255	314	281	295	348	295	277	290	276
19	300	268	309	276	304	321	284	279	300	271
20	320	267	290	277	306	329	295	272	299	273
21	309	262	293	245	312	341	293	263	287	279
22	305	270	323	292	297	334	292	286	283	275
23	313	277	277	285	307	331	295	264	297	283
24	287	260	299	283	283	325	306	279	302	282
25	311	266	293	272	301	326	278	257	295	265
26	319	253	302	272	272	321	302	266	294	280
Average	311	268	300	273	300	330	288	267	288	269

**Table A6** CALCULATED FISH LENGTHS IN mm WHEN FIRST ANNULUS WAS FORMED, GILFILLAN DAM

L = length when caught

Fish No.	30	1	9	15	19	13	10	26	21	25
L	399	399	400	360	361	379	399	341	382	392
Scale No.										
1	81	84	73	90	72	62	76	63	61	74
2	78	89	95	80	74	80	70	82	83	80
3	47	45	87	61	68	83	45	44	59	84
4	68	76	89	73	63	76	66	45	56	78
5	65	74	71	92	84	81	63	71	70	70
6	72	77	73	83	75	67	63	61	64	66
7	88	130	90	92	83	60	81	67	72	89
8	58	72	87	89	75	60	71	61	64	65
9	89	71	92	87	81	60	70	60	52	82
10	65	66	71	84	77	66	71	64	65	90
11	87	82	81	97	72	69	70	68	66	85
12	75	80	92	110	84	74	75	76	90	84
13	52	80	67	96	78	84	76	71	66	75
14	85	81	93	93	81	67	72	71	73	58
15	73	103	99	89	76	73	70	68	71	89
16	98	76	64	91	78	69	74	75	71	98
17	100	64	90	98	71	71	90	82	72	112
18	80	85	65	90	80	84	82	67	77	73
19	86	142	125	97	78	84	54	56	68	65
20	88	80	66	95	78	48	74	69	59	58
21	92	94	99	102	77	62	92	85	65	121
22	85	151	61	57	99	81	85	43	103	78
23	91	84	82	88	52	53	48	75	55	105
24	89	71	71	102	80	82	71	78	87	98
25	52	64	48	99	81	67	64	78	114	56
26	88	113	59	109	73	73	75	77	78	103
Average	78	86	80	90	77	71	71	68	72	82

**Table A7** CALCULATED FISH LENGTHS IN mm WHEN SECOND ANNULUS WAS FORMED. GILFILLAN DAM

L = length when caught

Fish No.	30	1	9	15	19	13	10	26	21	25
L	399	399	400	360	361	379	399	341	382	392
Scale No.										
1	246	230	236	255	209	189	197	218	210	247
2	246	250	280	242	210	211	217	232	232	204
3	219	222	239	242	200	218	177	204	191	240
4	248	239	236	220	223	182	191	202	206	206
5	208	235	249	229	233	194	199	225	216	245
6	226	252	222	228	218	212	242	220	210	231
7	219	238	240	219	213	185	192	197	239	240
8	247	259	243	256	229	199	194	239	201	215
9	253	224	248	254	245	298	210	238	217	231
10	263	254	226	227	226	234	212	217	202	270
11	237	227	237	224	217	199	214	219	222	256
12	209	235	254	232	220	197	224	177	220	244
13	217	263	257	251	235	219	195	162	211	224
14	266	244	248	243	228	211	208	238	229	250
15	263	260	256	240	228	214	218	235	236	264
16	257	228	246	228	228	224	218	234	239	200
17	233	189	255	250	219	218	232	222	221	252
18	244	247	240	237	214	220	204	210	218	218
19	222	252	245	259	206	229	204	222	233	244
20	253	249	247	260	210	213	207	230	250	231
21	227	244	252	252	243	248	216	222	231	229
22	212	248	244	245	241	217	204	222	207	235
23	250	241	239	238	230	211	192	229	229	230
24	266	238	231	247	234	222	208	195	231	210
25	223	236	243	248	214	208	231	218	219	235
26	234	250	222	200	214	204	218	217	212	251
Average	238	241	244	239	223	211	209	217	220	235

Table A8 CALCULATED FISH LENGTHS IN mm WHEN THIRD ANNULUS WAS FORMED. GILFILLAN DAM

L = length when caught

Fish No.	30	1	9	15	19	13	10	26	21	25
L	399	399	400	360	361	379	399	341	382	392
Scale No.										
1	363	341	364	324	343	278	378	320	306	325
2	352	344	339	337	332	351	329	319	332	352
3	352	354	348	333	321	279	295	310	255	332
4	359	378	352	331	342	265	291	319	330	330
5	367	355	356	327	342	292	326	314	334	315
6	358	358	324	352	320	354	298	314	297	301
7	351	322	350	326	322	296	323	307	310	303
8	359	365	351	338	335	295	280	276	342	327
9	360	353	361	324	333	302	308	274	317	310
10	357	359	355	324	322	344	325	325	326	316
11	356	351	352	320	271	345	329	273	330	353
12	354	352	314	337	277	271	314	289	351	340
13	347	345	362	334	290	286	297	284	316	299
14	366	342	359	340	332	295	291	284	338	359
15	366	363	359	336	327	337	288	321	321	345
16	362	361	357	335	306	277	314	270	339	270
17	299	283	355	336	279	308	309	267	304	343
18	364	363	356	322	311	348	336	278	314	339
19	372	356	362	334	297	295	317	271	318	314
20	350	354	351	332	274	267	320	290	343	288
21	356	366	373	330	337	351	302	284	334	295
22	340	372	353	335	290	316	314	290	310	337
23	312	348	388	321	293	342	279	271	300	277
24	310	357	369	333	287	268	345	302	318	301
25	342	355	383	329	273	342	330	285	301	308
26	370	351	346	326	288	313	324	279	325	334
Average	352	352	355	331	309	308	314	293	320	320

Table A9

THE ABSOLUTE PERCENTAGE VARIATION FROM THE  
MEAN CALCULATED FISH LENGTHS AVERAGED FOR  
EACH SCALE NUMBER. GILFILLAN DAM.

Scale No.	First annulus	Second annulus	Third annulus
1	7	5	7
2	9	6	6
3	25	7	5
4	15	7	6
5	10	5	4
6	10	5	6
7	13	6	4
8	11	6	5
9	11	5	3
10	9	7	4
11	5	4	6
12	12	6	6
13	12	8	3
14	8	4	5
15	7	6	5
16	10	6	5
17	17	6	7
18	8	3	4
19	23	5	3
20	13	5	5
21	19	5	5
22	29	4	3
23	18	3	8
24	13	6	6
25	24	3	5
26	15	5	3
Total	353	138	129
Mean	13,6	5,3	5,0

Table A10

THE ABSOLUTE PERCENTAGE VARIATION FROM THE  
MEAN CALCULATED FISH LENGTHS AVERAGED FOR  
EACH SCALE NUMBER. NEL'S PAN

Scale No.	First annulus	Second annulus	Third annulus
1	10	6	3
2	9	6	5
3	19	6	5
4	14	3	4
5	13	5	2
6	16	4	2
7	11	6	4
8	21	4	3
9	16	4	2
10	17	5	5
11	17	4	2
12	12	5	5
13	32	8	4
14	17	4	2
15	18	4	3
16	8	5	3
17	20	9	4
18	13	4	3
19	30	7	2
20	12	5	2
21	11	3	3
22	45	7	3
23	20	4	3
24	20	4	4
25	15	5	2
26	19	5	3
Total	455	132	83
Average	17,5	5,1	3,2

Table A11

THE CALCULATED FISH LENGTHS ACCORDING TO EACH SCALE ADJUSTED TO A COMMON MEAN VALUE PER ANNULUS FOR THE TEN FISH. ONLY THE MEANS FOR THE TEN REPLICATES OF EACH SCALE NUMBER ARE GIVEN. NEL'S PAN

Scale No.	First annulus	Second annulus	Third annulus
1	57,1	193,8	296,5
2	59,2	202,1	301,3
3	48,6	199,1	288,8
4	53,3	199,4	289,5
5	55,6	207,9	304,6
6	53,2	196,9	301,2
7	63,4	202,4	296,7
8	47,2	197,8	298,1
9	52,0	198,1	300,1
10	58,5	201,4	298,8
11	49,7	194,4	296,3
12	65,3	203,9	292,7
13	78,2	206,6	295,7
14	50,8	198,9	303,7
15	66,7	203,7	309,4
16	61,8	199,7	302,6
17	69,2	210,2	308,2
18	54,8	197,5	304,3
19	73,1	205,7	302,3
20	63,3	197,1	303,6
21	60,3	200,2	298,7
22	86,8	193,9	306,9
23	67,4	202,9	303,9
24	58,0	200,9	301,9
25	54.1	192,3	296,9
26	53,4	194,2	298,8

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Value adjusted to:	60,00	200,00	300,00
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Table A12

THE CALCULATED FISH LENGTHS ACCORDING TO EACH SCALE ADJUSTED TO A COMMON MEAN VALUE PER ANNULUS FOR THE TEN FISH. ONLY THE MEANS FOR THE TEN REPLICATES OF EACH SCALE NUMBER ARE GIVEN. GILFILLAN DAM.

Scale No.	First annulus	Second annulus	Third annulus
1	66,4	220,7	334,3
2	73,6	229,6	339,2
3	56,5	212,4	317,5
4	62,2	212,4	321,8
5	67,2	220,6	332,6
6	63,3	223,9	327,8
7	76,5	215,4	321,0
8	63,4	225,2	326,1
9	67,0	229,0	323,5
10	65,0	230,4	335,5
11	70,0	222,6	327,5
12	75,9	218,5	319,5
13	67,5	220,3	315,2
14	70,0	233,6	330,1
15	73,0	238,4	336,2
16	71,8	227,9	318,0
17	77,0	226,8	308,4
18	71,0	222,5	332,7
19	76,4	228,9	322,6
20	64,5	232,1	316,1
21	80,1	234,0	332,3
22	76,2	224,9	325,2
23	65,7	226,1	312,4
24	75,1	225,5	318,6
25	65,9	225,0	324,1
26	76,3	219,8	325,0

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Value adjusted to:	70,00	225,00	325,00
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Table A13

RATIO OF SCALE WIDTH TO SCALE LENGTH.

GILFILLAN DAM

Fish No.	30	1	9	15	19	13	10	26	21	21
Scale No.										
1	2,3	2,5	2,4	2,4	2,4	2,7	2,6	2,8	2,6	2,5
2	2,4	2,8	3,8	2,5	2,5	2,7	2,5	3,1	2,5	3,4
3	2,5	2,2	2,8	2,4	2,0	2,4	2,3	3,2	2,8	2,5
4	2,4	2,5	2,3	2,5	2,6	2,5	2,7	2,4	2,4	2,7
5	2,4	2,4	2,3	2,6	2,4	2,4	2,5	2,5	2,3	2,9
6	2,7	2,6	2,7	2,6	2,6	2,8	2,5	3,0	2,5	2,7
7	2,7	2,3	2,7	2,8	2,6	2,6	2,8	2,5	2,7	2,7
8	2,5	2,5	2,0	2,0	2,4	2,3	2,3	2,3	2,5	2,4
9	2,4	2,4	2,4	2,4	2,4	2,7	2,3	2,4	2,3	2,4
10	2,2	2,3	2,6	2,1	2,2	2,5	2,3	2,4	2,2	2,4
11	2,9	2,4	2,4	2,7	2,4	2,5	2,4	2,7	2,5	2,5
12	2,9	2,3	2,7	2,9	2,6	2,7	2,8	2,4	2,6	2,8
13	3,0	2,5	2,4	2,5	2,8	2,9	3,0	3,5	3,5	2,7
14	2,1	2,2	2,1	2,4	2,5	2,4	2,2	2,4	2,1	2,3
15	2,2	2,3	2,2	2,2	2,3	2,3	2,4	2,5	2,1	2,3
16	2,6	2,3	2,4	2,3	2,4	2,4	2,3	2,5	2,3	2,3
17	3,6	3,2	2,9	3,0	2,9	3,8	3,3	3,7	3,0	3,6
18	2,6	2,5	2,2	3,0	2,1	2,5	2,4	2,7	2,7	2,6
19	2,5	2,6	2,0	2,3	2,0	2,4	2,2	2,2	2,3	2,3
20	2,4	2,3	2,1	2,4	2,0	2,4	2,5	2,5	2,3	2,5
21	3,4	2,5	2,5	2,6	2,6	3,5	3,0	3,1	2,7	2,9
22	3,5	2,8	2,4	2,9	2,6	3,2	3,3	2,4	2,7	3,3
23	2,4	2,2	2,2	2,4	2,2	2,7	2,5	2,5	2,5	2,2
24	2,6	2,5	2,1	2,5	2,1	2,5	2,7	2,2	2,2	2,5
25	2,4	2,0	1,8	1,9	2,8	2,3	2,5	2,2	2,4	2,0
26	2,6	2,3	2,2	2,2	2,3	2,5	2,4	2,1	2,5	2,3
Total	68,2	63,4	62,6	64,5	62,7	68,6	66,7	68,2	65,2	67,3
Squares	182,66	156,02	154,54	162,07	152,79	184,32	173,47	183,10	165,74	177,65

Table A14

RATIO OF SCALE WIDTH TO SCALE LENGTH.

NEL'S PAN

Fish No.	39	32	47	52	48	44	42	46	43	35
Scale No.										
1	2,7	3,1	2,6	2,8	2,5	2,5	2,8	2,7	2,8	2,4
2	2,8	3,2	2,6	3,0	2,6	3,3	3,7	3,2	2,8	2,9
3	2,5	3,5	2,5	2,1	2,5	2,0	2,7	2,6	3,1	2,6
4	2,5	2,4	2,3	2,4	2,4	2,4	2,8	2,5	2,6	2,5
5	2,5	2,9	2,4	2,6	2,1	2,5	2,7	2,5	2,4	2,5
6	2,4	2,9	2,4	2,7	2,2	2,8	2,9	2,5	2,5	2,4
7	2,8	3,5	2,6	2,9	2,6	3,2	3,2	2,6	3,0	2,7
8	2,1	2,5	3,0	3,1	3,1	2,5	2,2	3,0	2,6	2,4
9	2,4	2,5	2,5	2,3	2,4	2,7	2,7	2,4	2,4	2,3
10	2,4	2,8	2,5	3,3	2,2	2,9	2,6	2,2	2,5	2,4
11	2,3	2,8	2,3	2,5	2,2	2,6	2,7	2,5	2,4	2,5
12	3,1	4,5	3,0	2,7	3,0	3,2	3,1	2,9	3,3	3,1
13	3,6	2,9	3,3	3,1	2,9	3,3	3,5	3,2	3,3	3,3
14	2,1	2,6	2,3	2,4	2,3	2,6	2,6	2,5	2,5	2,4
15	2,3	2,4	2,1	2,4	2,1	2,8	2,6	2,6	2,3	2,5
16	2,5	2,6	2,4	2,4	2,0	2,6	2,5	2,7	2,4	2,6
17	4,0	3,8	3,7	3,5	2,9	4,0	3,8	4,0	2,6	3,1
18	2,5	2,5	2,2	2,5	2,4	2,4	2,4	2,9	2,4	2,5
19	2,5	2,9	2,4	2,4	2,4	2,8	2,8	2,6	2,2	2,4
20	2,4	2,7	2,4	2,6	2,3	2,7	3,1	2,5	2,3	2,2
21	2,5	3,0	2,8	2,8	3,0	3,5	3,3	3,1	2,9	2,8
22	2,6	2,7	2,4	3,3	2,5	2,7	3,0	3,0	2,9	2,7
23	2,4	2,8	2,3	2,3	2,4	2,6	3,0	2,5	2,4	2,5
24	2,4	2,7	2,4	2,4	2,3	2,8	3,1	2,4	2,4	2,4
25	2,3	2,6	2,0	2,2	2,2	2,2	2,6	2,1	2,1	2,5
26	2,3	2,7	2,2	2,1	2,3	2,6	3,1	1,9	2,5	2,1
Total	66,9	75,5	65,6	68,8	63,8	72,2	75,5	69,6	67,6	66,7
Squares	176,59	224,91	169,02	185,74	158,84	205,06	222,93	190,66	178,32	173,07

Table A15

MEAN RATIO OF SCALE WIDTH THROUGH FOCUS  
TO DISTANCE FROM FOCUS TO SCALE MARGIN  
ALONG THE LONGITUDINAL AXIS

Scale No.	Gilfillan Dam	Nel's Pan	Total	Mean
1	2,54	2,68	5,22	2,61
2	2,82	2,91	5,73	2,87
3	2,54	2,62	5,16	2,58
4	2,51	2,47	4,98	2,49
5	2,20	2,53	4,73	2,37
6	2,68	2,48	5,16	2,58
7	2,65	2,90	5,55	2,78
8	2,34	2,65	4,99	2,50
9	2,43	2,46	4,89	2,45
10	2,33	2,57	4,90	2,45
11	2,54	2,48	5,02	2,51
12	2,71	3,19	5,90	2,95
13	2,85	3,24	6,09	3,05
14	2,28	2,44	4,72	2,36
15	2,28	2,42	4,70	2,35
16	2,39	3,47	5,86	2,93
17	3,29	2,54	5,83	2,92
18	2,52	2,47	4,99	2,50
19	2,30	2,53	4,83	2,42
20	2,35	2,51	4,86	2,43
21	2,88	2,99	5,87	2,94
22	2,90	2,78	5,68	2,84
23	2,38	2,52	4,90	2,45
24	2,40	2,53	4,93	2,47
25	2,23	2,29	4,52	2,26
26	2,34	2,38	4,72	2,36
<b>Total</b>	<b>65,68</b>	<b>69,05</b>	<b>134,73</b>	
<b>Mean</b>	<b>2,5262</b>	<b>2,6558</b>		

Table A16

## READABILITY OF THE 520 SCALES EXAMINED

Scale No.	Good	Fair	Poor	Extra lines	Dark bands
1	9	9	2	3	4
2	9	9	0	3	6
3	10	10	0	4	4
4	13	7	0	1	6
5	8	10	1	2	3
6	11	7	2	3	4
7	14	5	1	2	2
8	15	5	0	1	4
9	15	4	1	1	2
10	14	5	1	3	7
11	6	13	1	4	5
12	11	9	0	3	0
13	7	12	1	5	5
14	10	10	0	3	4
15	11	5	2	3	7
16	10	10	0	1	3
17	11	8	1	8	3
18	7	9	4	3	2
19	6	12	1	1	4
20	6	12	2	3	3
21	8	9	1	7	2
22	6	13	1	1	4
23	4	9	7	3	1
24	6	11	3	5	2
25	5	10	4	2	0
26	7	9	4	3	1

Table B1

FISH LENGTHS IN 10 mm CLASSES WITH THEIR  
CORRESPONDING PROJECTED SCALE RADII IN mm

50-59 mm		60-69 mm		70-79 mm		80-89 mm		90-99 mm		100-109 mm	
Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii
59	9	60	6	70	9	81	8	90	12	105	15
		60	6	75	10	80	10	90	12	100	14
		60	3	75	8	85	8	90	12	102	18
				70	6	89	12	97	12	101	14
				70	7	80	9	97	15	101	16
				75	11	80	11	91	11	106	18
				70	6	81	10	98	11	104	12
				73	7	87	7	92	11	100	12
				75	8	87	11	97	9	100	14
				75	7	80	9	95	10	109	11
				70	5	89	13	96	8	103	14
				75	8	85	8	94	8	109	12
				79	9			90	11		
				70	10			91	15		
				70	6			96	11		
				70	9			90	10		
				70	5			99	12		
				78	7			95	10		
				78	6			92	15		
				76	8			94	10		
				74	7						
				79	7						



Table B1 continued

170-179 mm		180-189 mm		190-199 mm		200-209 mm		210-219 mm		220-229 mm	
Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii
178	34	180	32	190	37	200	34	216	61	224	55
171	30	180	27	198	44	200	45	215	37	224	54
170	32	185	41	198	33	208	45	212	40	226	58
170	26	188	28	198	43	209	48	210	45	225	56
174	36	185	45	195	38	205	60	212	47	220	50
175	29	180	33	198	61	200	45	214	52	224	41
174	33	188	35	194	46	200	53	212	52	221	40
176	32	185	32	196	50	202	48	210	57	225	47
173	40	187	25	190	58	206	53	215	50	220	53
174	29	189	42	196	37	209	45	214	57	220	56
175	32	185	34	192	43	200	44	218	52	220	46
179	38	182	43	193	37	207	50	210	41	225	61
171	39	187	45	193	27	202	45	216	45	220	59
179	32	184	34	192	45	209	50	216	44	220	45
172	36	189	26	194	46	203	42	219	55	225	42
175	28	180	28	195	32	205	52	211	34	220	42
176	46	184	27	190	47	200	40	215	41	228	41
		180	26	195	47	206	48	211	47	229	47
				190	44	205	35	215	54	221	50
				195	49	202	44	218	58	226	56
				190	41	201	50	210	43	225	60
				198	33	202	44	215	77	223	54
				192	40	203	43	210	50	222	55
				198	42	205	39	219	58	226	54
				198	50	202	37	214	52	225	47
				191	37	207	52	219	51	226	58
				190	35	205	47	212	38	223	46
				190	32	200	41	215	50	220	46
				195	39	200	42	214	56	220	55
				199	50	205	48	215	39	227	42
				190	46	200	43	212	48	224	47
				190	49	205	54	219	94	221	42
				196	46	206	53	216	41		
				194	34	207	44	213	46		
				193	36	206	40	215	46		
				197	32	205	52	213	40		
				191	37	205	50	215	37		
				195	40	205	53	215	46		
				190	44	205	30	219	57		
				195	43	200	34	211	44		
				199	38	206	42	211	34		
				192	31	204	43	217	48		
				193	39	201	46				
				197	38	200	56				
				199	35	202	38				
						200	39				
						200	36				
						200	42				
						204	30				
						207	39				
						208	28				

Table B1 continued

230-239 mm		240-249 mm		250-259 mm		260-269 mm		270-279 mm		280-289 mm	
Fish length	scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii
236	64	244	70	250	63	262	60	272	76	282	86
235	47	249	61	253	51	265	60	275	60	280	59
230	52	242	56	259	67	265	57	276	72	285	71
236	50	247	61	250	56	267	77	270	51	282	74
236	56	245	64	258	61	262	67	279	68	282	79
236	75	245	79	255	76	264	47	270	79	283	70
237	56	248	64	255	61	267	67	273	54	284	68
231	63	246	50	250	61	262	77	275	80	289	67
235	63	240	51	258	67	260	59	275	86	285	58
230	68	245	49	259	64	260	71	270	71	285	84
234	48	245	50	254	65	266	60	278	61	285	84
232	64	240	61	250	49	260	57	278	81	280	63
230	48	245	61	255	56	261	62	270	52	285	70
238	72	240	68	255	75	263	53	270	71	282	60
238	53	241	67	254	59	264	72	270	70	280	62
239	59	240	56	259	57	263	56	272	71	280	71
235	57	247	45	250	54	267	64	270	58	282	76
235	51	241	53	257	60	268	79	277	47	280	71
230	49	241	60	250	52	265	78	279	68	280	84
230	49	240	64	250	63	260	72	270	55	288	70
237	49	245	62	255	70	269	52	275	62	288	85
239	50	246	65	250	73	269	71	276	65	280	90
238	45	242	65	250	50	269	52	271	82	285	56
230	46	245	57	250	67	260	68	271	71	283	69
236	35	249	51	258	54	267	52	275	79	280	66
236	68	243	50	251	57	267	50	279	74	280	51
235	51	243	49	255	66			270	70	282	62
234	50	240	50	257	60			272	68	285	65
236	59	241	54	251	45			271	41	283	61
234	54	240	42	254	59			270	52	282	58
236	54	245	45	252	39			275	49	284	54
230	57	241	43	254	75			275	58	285	71
237	49	247	45	254	56			275	57	283	69
230	51	245	52	256	49			275	57	285	77
231	49	241	43	250	57			271	71	287	72
232	49	249	53	258	50			270	61	281	81
235	40			250	52			270	59	280	74
231	41			251	60			270	61		
233	48			257	64			279	62		
236	55			256	73						
235	43			256	56						
236	42			252	47						





Table B1 continued

410-419 mm		420-429 mm		430-439 mm		440-449 mm		470-479 mm		500-509 mm	
Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii	Fish length	Scale radii
416	104	421	118	430	112	441	121	470	134	500	161
		422	129	435	111	440	82	475	131	509	140
		425	129					470	120		
		425	132					470	133		
								470	135		
								470	131		
								470	148		
								470	126		









Table B4

FISH NUMBERS FALLING INTO EACH 10 mm FISH LENGTH CLASS AND 4 mm SCALE RADIUS CLASS FOR THE FISH POPULATION 50 mm AND LONGER

FISH LENGTHS FROM 50 mm TO 449 mm IN 10 mm GROUPS = x

Class Intervals	FISH LENGTHS FROM 50 mm TO 449 mm IN 10 mm GROUPS = x																																	
	50-59	60-69	70-79	80-89	90-99	100-109	110-119	120-129	130-139	140-149																								
	54,5	64,5	74,5	84,5	94,5	104,5	114,5	124,5	134,5	144,5																								
	1	3	22	12	20	11	29	28	20	24																								
Class Marks	FISH NUMBERS FALLING INTO EACH 4 mm SCALE RADIUS CLASS = y																																	
	1-4	5-8	9-12	13-16	17-20	21-24	25-28	29-32	33-36	37-40	41-44	45-48	49-52	53-56	57-60	61-64	65-68	69-72	73-76	77-80	81-84	85-88	89-92	93-96	97-100	101-104	105-108	109-112	113-116	117-120	121-124	125-128	129-132	133-136
	2,5	6,5	10,5	14,5	18,5	22,5	26,5	30,5	34,5	38,5	42,5	46,5	50,5	54,5	58,5	62,5	66,5	70,5	74,5	78,5	82,5	86,5	90,5	94,5	98,5	102,5	106,5	110,5	114,5	118,5	122,5	126,5	130,5	134,5
		1	2	16	4	2	7	15	4	5	2	6	3	12	16	6	10	3	1	1	2	5	9	8	2	5	9	9	8	2	5	9	8	2





Table B4 continued

Class Intervals	Class Marks	Class Marks									FREQUENCY
		364,5	374,5	384,5	394,5	404,5	414,5	424,5	434,5	444,5	
1-4	2,5										1
5-8	6,5										24
9-12	10,5										40
13-16	14,5										30
17-20	18,5										41
21-24	22,5										24
25-28	26,5										35
29-32	30,5										28
33-36	34,5										28
37-40	38,5										33
41-44	42,5										44
45-48	46,5										51
49-52	50,5										59
53-56	54,5										44
57-60	58,5										45
61-64	62,5										39
65-68	66,5										30
69-72	70,5					1					36
73-76	74,5										20
77-80	78,5	2									29
81-84	82,5					1				1	23
85-88	86,5										14
89-92	90,5										15
93-96	94,5	1	2		1	2					11
97-100	98,5	1									6
101-104	102,5		1	1	1		1				8
105-108	106,5					2					2
109-112	110,5								2		3
113-116	114,5	2	3			1					6
117-120	118,5			1	1	2		1			5
121-124	122,5									1	1
125-128	126,5				1						3
129-132	130,5							3			3
133-136	134,5				1						1





Table C1 continued

Fish length class intervals in mm	390-399	400-409	410-419	420-429	430-439	440-449	450-459	460-469	470-479	480-489	490-499	500-509	Average length in each annulus class
Class marks	394,5	404,5	414,5	424,5	434,5	444,5	454,5	464,5	474,5	484,5	494,5	504,5	
No. of fish with :-													
No annuli													91,3 mm
1 annulus													131,0 mm
2 annuli													191,2 mm
3 annuli													224,4 mm
4 annuli													256,5 mm
5 annuli		1											288,3 mm
6 annuli	1				1								311,2 mm
7 annuli	2								2				360,8 mm
8 annuli	2	6		1	1	2							394,5 mm
9 annuli		1	1	2					2				400,1 mm
10 annuli		1							2		1		462,5 mm
12 annuli									2				470,0 mm
15 annuli												1	500,0 mm

Table C2 SCALE RADII AND LAST-ANNULUS RADII ARRANGED  
IN MONTH CLASSES AND ANNULUS-FREQUENCY CLASSES

FEBRUARY						
1	2	3	3	4	5	6
Annulus	Annuli	Annuli	Annuli (cont.)	Annuli	Annuli	Annuli
2,82	1,30	1,197	1,156	1,452	1,136	1,071
1,79	1,56	1,212	1,042	1,276	1,145	1,181
2,86	1,45	1,071	1,442	1,25	1,098	
1,64	1,42	1,044	1,27	1,155	1,038	
1,74	1,55	1,04	1,217	1,236	1,094	
2,18	1,68	1,036	1,235	1,1	1,177	
3,57	1,5	1,087	1,283	1,13	1,118	
1,31	1,5	1,051	1,171	1,117		
2,4	1,27	1,053	1,297	1,196		
3,57	1,13	1,175	1,161	1,027		
2,89	1,15	1,395	1,244	1,094		
1,21	1,42	1,087	1,22	1,06		
2,08	1,52	1,163	1,085	1,167		
2,36	1,1	1,464	1,215	1,017		
2,5	1,33	1,222	1,28	1,018		
2,6	1,43	1,051	1,073	1,347		
2,14	1,53	1,059	1,109	1,175		
2,15	1,48	1,146	1,117	1,017		
2,93	1,66	1,071	1,185	1,2		
3	1,47	1,067	1,378	1,154		
2,73	1,5	1,364	1,157	1,358		
2,28	1,61	1,09		1,259		
2,6	1,48	1,18		1,164		
3,13	1,33	1,07		1,057		
	1,6	1,1		1,056		
	1,76	1,09		1,151		
	1,42	1,08		1,064		
	1,42	1,05		1,226		
	1,52	1,06		1,105		
	1,53	1,1		1,229		
	1,1	1,09				
	1,07	1,02				
	1,52	1,06				
	1,43	1,061				
	1,18	1,33				
	1,68	1,2				
	1,27	1,23				
	2,16	1,04				
	1,38	1,15				
	1,34	1,06				
	1,27	1,08				
	1,30	1,2				
	1,4	1,27				
	1,28	1,242				
	1,39	1,313				
	1,72	1,275				
	1,33	1,136				

Table C2 continued

APRIL					
1	2	3	4	5	6
Annulus	Annuli	Annuli	Annuli	Annuli	Annuli
2,091	1,368	1,415	1,292	1,093	1,108
2,462	1,132	1,5	1,542	1,135	1,13
2,2	1,146	1,2	1,254	1,113	1,138
3,6	1,862	1,087	1,12	1,268	1,024
3,444	1,441	1,07	1,305	1,232	
4,833		1,173	1,111	1,078	
4,833		1,052	1,2	1,182	
1,667			1,037		
			1,167		
			1,282		

MAY					
	1,606	1,023	1,186	1,019	1,084
	1,179	1,29	1,071	1,014	1,063
	1,4	1,061		1,083	
	1,061	1,525			
	1,417	1,304			

JULY					
1,692	1,143	1,04	1,035	1,125	1,1
5	1,114	1,094	1,047	1,143	1,039
12,5	1,167	1,021	1,265	1,016	
6,6	1,16	1,171	1,169		
6	2,474	1,082			
5,4	2,273	1,167			
5,8	1,154	1,105			
7,2		1,096			
2,316		1,109			
		1,089			
		1,5			
		1,188			

Table C2 continued

AUGUST					
1	2	3	4	5	6
Annulus	Annuli	Annuli	Annuli	Annuli	Annuli
2,80	1,222	1,053	1,04	1,029	1,013
	1,103	1,16	1,02	1,034	1,025
	1,143	1,034	1,043	1,127	1,026
	1,32	1,133	1,057	1,052	1,029
	1,414	1,146	1,178	1,033	
		1,042	1,02	1,026	
		1,027	1,023	1,067	
		1,289	1,022	1,111	
		1,5	1,129	1,094	
			1,035		
			1,036		
			1,019		
			1,091		
			1,104		
			1,092		
			1,092		
SEPTEMBER					
1,50		1,024	1,071	1,063	
1,286		1,136		1,188	
1,077		1,136			
1,24		1,191			
OCTOBER					
1,4	1,136	1,167	1,143	1,08	1,041
1,316	1,172	1,054	1,08	1,059	1,016
2,308	1,176	1,125	1,078	1,067	1,049
	1,121	1,025	1,102	1,032	1,026
	1,15	1,111	1,055	1,042	1,061
		1,119	1,085	1,047	1,092
			1,02	1,043	1,111
			1,157	1,037	1,16
			1,188	1,097	1,077
			1,089		1,049
			1,069		1,043
			1,204		1,064
			1,04		1,071
			1,045		
			1,123		
			1,044		

Table C2 continued

NOVEMBER						
1 Annulus	1 Annulus (cont.)	2 Annuli	3 Annuli	4 Annuli	5 Annuli	5 Annuli (cont.)
2,6	1,467	1,5	1,229	1,175	1,063	1,04
2,75	1,727	1,5	1,4	1,135	1,059	1,063
1,667	1,667	1,625	1,111	1,089	1,111	1,037
2	2,25	1,538	1,214	1,167	1,071	1,044
2	1,8	1,533	1,167	1,163	1,118	1,033
1,5	1,7	1,467	1,314	1,111	1,075	1,045
2	1,643	1,171	1,176	1,08	1,059	1,045
2,35	1,667	1,333	1,294	1,098	1,06	1,057
1,6	1,875	1,556	1,385	1,125	1,097	1,058
1,8	1,533	1,421	1,211	1,083	1,061	1,077
2,4	2	1,409	1,267	1,104	1,042	1,038
1,5	1,538	1,529	1,286	1,118	1,119	1,068
1,75	1,875	1,368	1,444	1,082	1,153	1,069
1,818	1,714	1,471	1,31	1,154	1,148	1,046
1	2,111	1,5	1,15	1,229	1,083	1,040
1,857	1,583	1,524	1,167	1,089	1,171	1,039
1,778	2,	1,478	1,233	1,064	1,044	1,053
1,727	1,9	1,147	1,289	1,083	1,026	1,064
1,458	1,88	1,391	1,179	1,111	1,098	1,048
2,333	1,9	1,243	1,333	1,085	1,156	1,082
2,2	1,643	1,433	1,213	1,123	1,030	1,111
1,455	1,444	1,225	1,189	1,12	1,07	1,081
1,7	1,714	1,324	1,214	1,083	1,138	1,05
1,857	2	1,357	1,455	1,106	1,097	1,098
2	1,455	1,258	1,278	1,196	1,063	
2	1,462	1,243	1,154	1,037	1,127	6
1,7	1,625	1,444	1,235	1,06	1,051	Annuli
1,875	1,5	2	1,122	1,1	1,089	1,037
1,6	1,667	1,185	1,081	1,043	1,115	1,088
2	1,778	1,233	1,108		1,125	1,083
1,7	1,667	1,28	1,143		1,061	1,014
1,889	1,818	1,276	1,25		1,167	1,08
1,6	1,545	1,229	1,303		1,036	1,038
2		1,333	1,28		1,14	1,053
1,375		1,647	1,14		1,131	1,083
1,636		1,52	1,111		1,14	1,051
1,6		1,3	1,167		1,091	1,041
2		1,55	1,344		1,145	1,015
1,75		1,421	1,303		1,109	1,256
1,71		1,458	1,147		1,113	1,068
1,545		1,444	1,2		1,052	1,031
1,44		1,462			1,066	1,063
1,636		1,909			1,088	1,037
1,455		1,484			1,057	1,04
1,727		1,314			1,129	1,06
1,5		1,143			1,08	1,063
2		1,765			1,034	1,042
1,667		1,3			1,143	1,042
						1,047
						1,103
						1,027
						1,082
						1,098