

## LARGE EYES AS INDICATORS OF REDUCED GROWTH.

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### Introduction

Lundberg (1875) noted in an investigation of the herring (*Clupea harengus*) in the Baltic Archipelago, that small herring had relatively large eyes. Generally the relative eye diameter of herring in the Baltic Sea seem to increase from the south to the north, while the mean length and growth rate seem to decrease (Parmanne, 1990).

Other examples of a relation between location and eye size are capelin (*Mallotus villosus*) from different locations in Canadian Atlantic waters (Sharp *et al.*, 1978), Indian carp (*Label dero*) in three rivers with different ecological conditions (Nasar *et al.*, 1983), *Coregonus peled* introduced in two Mongolian lakes (Dulmaa & Penaz, 1986) and charr (*Salvelinus leucomaenis*) in a Japanese river and a lake (Takami & Kinoshita, 1990).

In some cases have the morphological differences, including eye size, within a species, been so characteristic that the species has been separated into two forms. This have been shown for two forms of Alaska pollack (*Theragra chalcogramma*) (Kim & Huh, 1978), two types of Japanese jack mackerel (*Trachurus japonicus*) (Suda *et al.* 1987), and two forms of the salmon, *Oncorhynchus rhodurus* called the amago salmon and the biwa salmon (Fujioka, 1988).

Pankhurst (1989) found evidence among diurnal fish that species of small size generally develops large eyes. He also found that individuals of the New Zealand sweep (*Scorpius lineolatus*) and spotty (*Notolabrus celidotus*) subjected to a prolonged period of darkness in a tank, showed proportionally larger eyes than normal fish of similar body size. The large eye size could be an adaption to the low light intensity in the tank, but it could also be an effect of a reduced growth rate due to low prey density or low prey visibility (Pankhurst, 1992).

These studies all demonstrated differences in eye size, but only the studies by Kim & Huh (1978) and Pankhurst (1992), seem to relate the different eye size to differences in growth rate.

Further evidence that eye size can be dependent upon growth rate was provided by Pankhurst & Montgomery (1994). They performed a study of relative eye diameter and growth of rainbow trout *Oncorhynchus mykiss* in a controlled feeding experiment, and in two naturally occurring populations. Their results clearly demonstrated that slow growing fish can develop relatively larger eyes than normally growing fish. Based on their data it can be calculated that the eye diameter in the slow growing (low feed) group was approx. 20% larger than for fish of the same length in the fast growing (high feed) group.

It should therefore be investigated whether differences in eye size generally are reflections of differences in growth rate

The present study presents another example of a possible linkage between eye size and some indicators of reduced growth rate in the Africa fresh water sardine, *Limnothrissa miodon* in Lake Kariba, Zimbabwe.

*L. miodon* is naturally occurring in Lake Tanganyika and introduced into the artificial Lake Kariba, where it grows to only about half its normal length in Lake Tanganyika. Because of difficulties in age determinations using otolith readings (Chifamba, 1992) or cohort modal progression analysis, it is still unresolved whether the small size is due to a high mortality e.g. after spawning, or a cessation of growth. The difference in size was observed before a fishery began, and is therefore probably a function of the large differences between the two lakes. These differences and some possible explanations for the smaller size are described by Marshall (1993).

During a study of the feeding biology of *L. miodon* in Lake Kariba (Paulsen, 1994) it was accidentally observed that some individuals had remarkably larger eyes than others. In the absence of an established method to perform a direct age (and thereby growth rate) determination it was decided to try to relate the eye size to two known indicators of reduced growth, otolith size and mesenteric fat content.

Several authors have recently demonstrated a relation between otolith size and growth rate. Otolith growth seem to be influenced by an age dependent component and an growth dependent component. Relatively large otoliths indicates a reduced growth rate (Secor and Dean, 1989).

Mesenteric fat content has been widely used, also in clupeids (Rajasilta, 1992), as an indicator of nutritional status. Long term differences in mesenteric fat content is assumed to affect growth rate. Short term fluctuations, as a result of e.g. variations in food availability or gonad formation, could temporarily impair the link to growth rate and thereby to otolith and eye size.

## Material and Methods

*L. miodon* were sampled during nighttime from a commercial fishing boat using a 9m diameter circular lift-net and mercury lamps for light attraction of fish. During daytime *L. miodon* was sampled using a mid-water trawl (8m opening) from a research vessel. Fishing was carried out at depths from 0 - 30m. Samples were taken both at near-shore and at open-water locations on the lake. Informations from the commercial fishery indicates that there is no systematic variation between locations. The samples are therefore assumed to be representative for the population of *L. miodon*. In the period June - August 1992 400 *L. miodon* were sampled from a total of 48 lifts and 10 trawl hauls. The total body length, sex, eye diameter and fat index were registered for each individual. In July 1993 further 64 individuals were sampled from a total of 8 trawl hauls, and measurement of otolith size included in the analysis. The fish were immediately frozen (1992) or short term preserved in 4% formalin. The preservations had no effect on total body length.

The parameters were registered as follows:

**Length.** Measured as "total length" to the nearest mm below.

**Eye diameter.** The mean maximum diameter of both eyes measured across the eye cavity, within intervals of 0.1 mm, using a microscope eyepiece ruler.

**Otolith diameter.** The mean maximum diameter of both sagitta otoliths, measured within intervals of 0.01 mm, using a microscope eyepiece ruler.

**Mesenteric fat.** Expressed as a five step index for the content of fat around the interior organs. 0= No fat. 1= A thin string of fat along intestine. 2= Wider, removable string of fat along intestine, small amount of fat around stomach. 3= Fat around stomach removable in one piece. 4= All organs covered by fat.

The normal eye size and otolith size at different length were calculated from linear 1. order regressions. In order to identify deviations from the normal size, the "residual eye diameter" and

152

"residual otolith diameter" were calculated for each individual as the residual of the observed diameter to the value predicted by the regression model.

**Statistical analysis.** Regressions were performed as ordinary 1. order least-squares regressions. Regression lines were tested for linearity, slope different from zero, and differences between regression lines according to the methods described in Fowler & Cohen (1992). 95% confidence limits on the figures are calculated using the "SigmaPlot®" software (Jandel Scientific).

As fat content and gonad development stage were registered on relative scales, a statistical test suitable for observations on an ordinal scale had to be used. The relation between eye diameter (otolith diameter) and fat content was analysed using "Jonckheeres test for ordinal observations" (Siegel & Castellan, 1988). This test is basically an extension of the Kruskal-Wallis test to include the extra informations of an ordered scale.

## Results.

Fig. 1 shows the relation between eye diameter and total body length for the 1992 and 1993 samples. The lines do not deviate significantly from a straight line. As a deviation primarily would affect the largest and the smallest individuals and 90% of the observations are in the length range 55-77mm, it was decided to accept the regression line for calculation of normal eye size.

When comparing fish of the same length there seem to be a considerable variation in eye diameter. The eye diameter ranged from 74% to 145% of the diameter predicted by the regression model for the 400 individuals sampled in 1992. The length to eye diameter relationship differed significantly ( $p < 0.05$ ) between the two sampling years. (1992:  $y = -0.179 + 0.0716x$ ,  $r^2 = 0.52$ ,  $N = 400$ , 1993:  $y = -0.854 + 0.0882x$ ,  $r^2 = 0.58$ ,  $N = 64$ ).

Fig. 2 shows the relation between otolith diameter and total body length for the 1993 samples. Proportionality between fish length and otolith size is generally used when calculating growth rate dependent deviations in otolith size (Campana, 1990). In this study the diameter ranged from 84% to 112% of the diameter predicted by the otolith diameter - body length regression model. ( $y = 0.118 + 0.0245x$ ,  $r^2 = 0.71$ ,  $N = 64$ ).

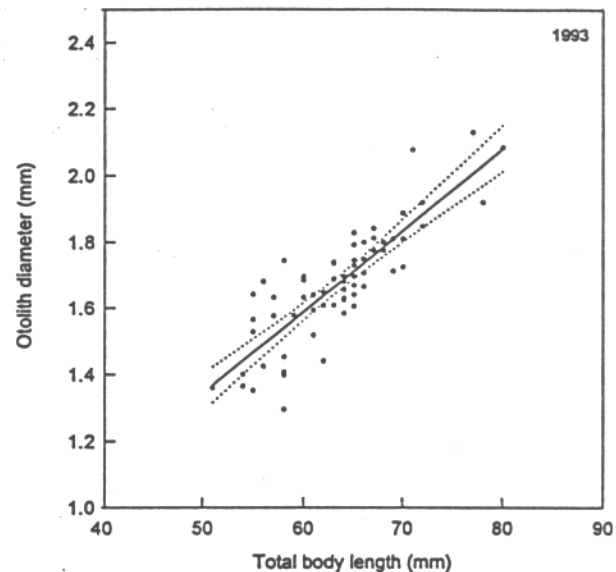
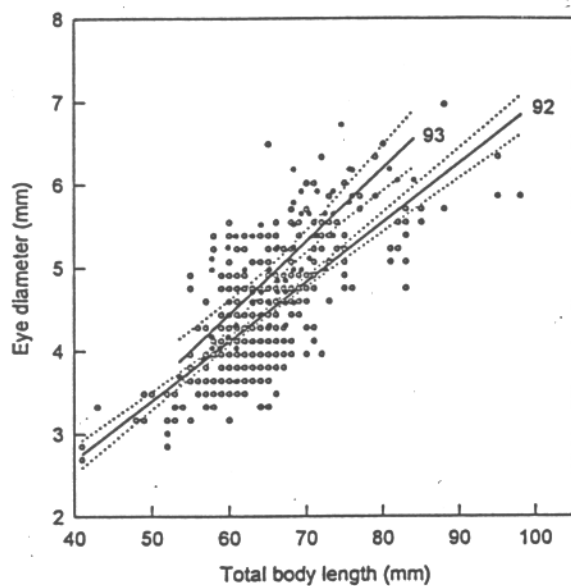


Figure 1. Total body length - eye diameter relation for *L. miodon*. 1992 (○) and 1993 (●). Regression lines with 95% confidence limits.

Figure 2. Total body length - otolith diameter relation for *L. miodon* 1993. Regression line with 95% confidence limits.

To investigate whether individuals with relatively large eyes also had relatively large otoliths, the two parameters were plotted against each other (Fig. 3). A regression line was calculated. The regression line is tested for linearity and the slope is significantly ( $p < 0.05$ ) different from zero indicating a covariation of the deviations from the predicted diameters of both otoliths and eyes. Both parameters are functions of fish length and a low precision in length measurements would in itself generate a covariation. The observed deviations from predicted diameter are, however, far larger than could be explained by inaccuracies in length measurements.

Fig. 4 and 5 show the relation between fat index and eye size, expressed as % of the predicted values from the regression model for the 1992 and 1993 datasets. The mean values are shown with number of observations and standard deviation.

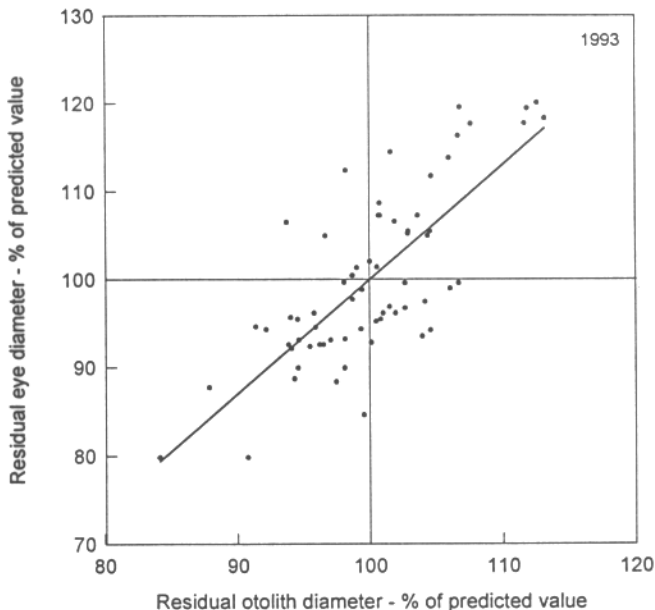


Figure 3. Relative otolith diameter - relative eye diameter for *L. miodon* 1993. Regression line with 95% confidence limits ( $y = -29.840 + 1.298x$ ,  $r^2 = 0.58$ ,  $N = 64$ ).

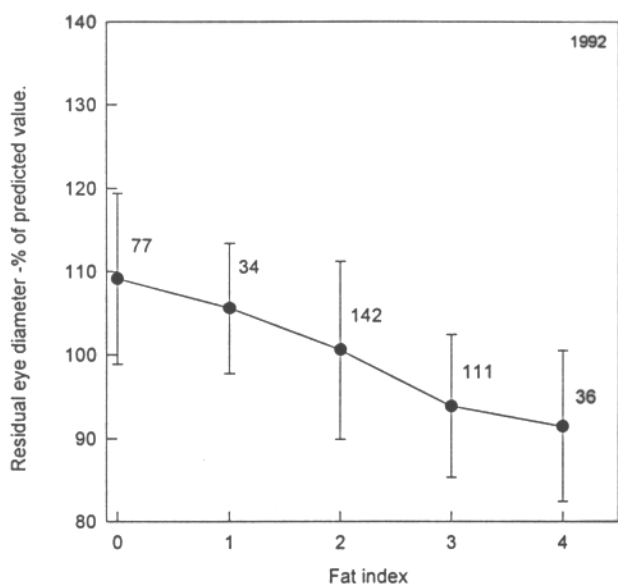


Figure 4. Fat index - eye diameter as % of predicted from the regression model for *L. miodon* 1992. Mean values  $\pm$  SD. Number of individuals in the fat index groups are indicated ( $N = 400$ ).

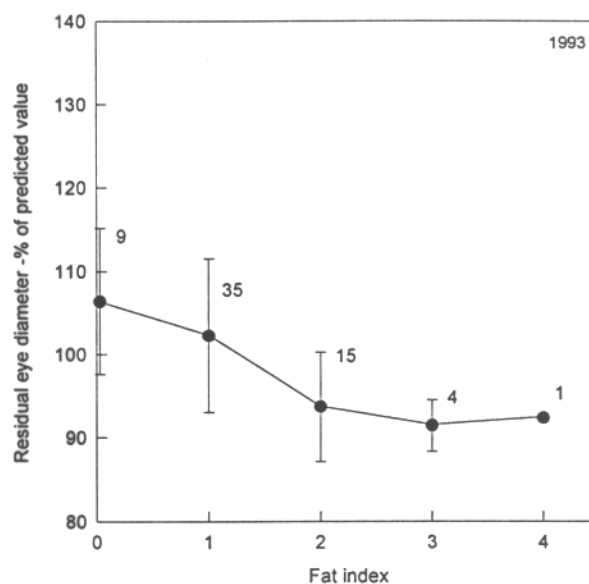


Figure 5. Fat index - eye diameter as % of predicted from the regression model for *L. miodon* 1993. Mean values  $\pm$  SD. Number of individuals in the fat index groups are indicated ( $N = 64$ ).

The relationship between eye diameter and fat index is significant ( $p < 0.05$ ) using Jonckheeres test for ordered data. Both for 1992 and 1993 the eye diameter residuals decreased from approx. 110% of the predicted diameter in individuals with fat index 0 to approx. 90% of the predicted in individuals with fat index 3 and 4. If the effect of fat index is included in the regression model it increases the correlation coefficient ( $r^2$ ) in the eye diameter - body length regression (Fig. 1) from

0.52 to 0.66 in 1992 and from 0.58 to 0.71 in 1993. Comparison of the 1992 and 1993 dataset shows that 146 of 400 individuals (37%) in 1992, and only 5 out of 64 individuals (8%) in 1993, had a fat index of 3 or 4. The higher fat index in 1992 is therefore in agreement with the observation of generally smaller eyes in the 1992 dataset (Figure 1).

Fig. 6 show the relation between fat index and otolith diameter, expressed as % of the predicted values from the regression model for the 1993 dataset. The mean values are shown with number of observations and standard deviation.

The decrease in eye diameter with increasing mesenteric fat content is significant ( $p < 0.05$ ).

## Discussion

The eye diameter of *L. miodon* in Lake Kariba was observed to vary from 74% to 145% of the normal diameter for fish of the same length in a sample of 400 fish. This variation is equal to a variation in the area of the eye of almost four times. Is this variation just "random variation" or is it related to some specific life conditions? Other studies have shown that eye size may vary with location, and a recent study (Pankhurst and Montgomery, 1994) has demonstrated a direct relation to fish growth rate. This situation seem to be comparable to the observations of a variation in otolith size, and the now well documented relation between otolith size and growth rate. The observations in this study of a covariation between relative otolith size and relative eye size suggests that individuals with large otoliths or large eyes could be particularly slow growing individuals.

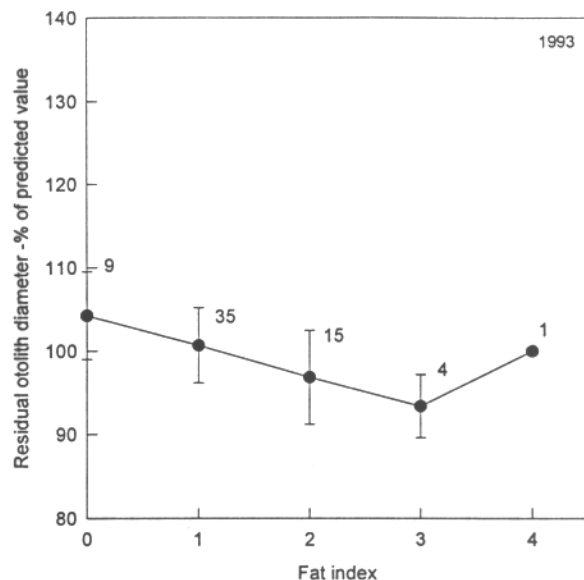


Figure 6. Fat index - otolith diameter as % of predicted from the regression model for *L. miodon* 1993. Mean values  $\pm$  SD. Number of individuals in the fat index groups are indicated (N=64).

Registration of mesenteric fat content also showed a clear relation to relative eye size. Individuals with low fat content had significantly larger eyes than individuals with high fat content. Also the fish in the 1992 samples had significantly less fat than the fish in the 1993 samples, and significantly larger eyes.

This observation supports the hypothesis of a linkage to growth. Other explanations are, however, also possible. Sex differences and gonad development stage were also registered in connection with this study, without any indication of a relation to eye size or mesenteric fat content. A relation was found between mesenteric fat content and otolith size with low fat individuals having larger otoliths than high fat individuals, supporting the view that fat content is related to growth rate.

If it is assumed that the eye size in *L. miodon* is related to growth rate one could consider the biological implications of this finding. A visual inspection of the large eyed individuals reveals that it is only the eyes, and not the whole head which is particularly large. This is in contrast with the situation eg. in old gadoids which develops large head in relation to body size. The large eyes could be an expression of a high priority of an organ, vital for a selective plankton feeding fish as *L. miodon*, which has been shown to be feeding primarily during dawn and dusk (Paulsen, 1994).

The present study provides evidence of a linkage between eye size, otolith size and mesenteric fat content, which all, independently, has been shown to be related to growth rate. In the absence of a

link to variations in growth rate. One could therefore ask whether there is a specific reason to expect a high variation in growth rate?

The catches of *L. miodon* in Lake Kariba generally consists of individuals of a very narrow size range. This length distribution does not seem to change much between years, over the year, between locations or between different fishing gears. A possible explanation for the apparent accumulation of 50-70 mm fish could be that fish in this size range more or less stops growing, leading to individuals of the same length with different age and nutritional condition.

The Lake Kariba population of *L. miodon* offers a unique opportunity to study a naturally growth stunted population, and morphological expressions of a reduced growth rate may be easier to find here than in most other places. The findings in other studies, of a relation between eye size or otolith size and differences in physical conditions, ecological conditions, between areas or between different forms of the same species may therefore, at least partly, be explained by differences in growth rate.

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