Short Notes

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OTOLITH AND BODY SIZE RELATIONSHIPS IN THE MACKEREL ICEFISH (*CHAMPSOCEPHALUS GUNNARI*)

I. Everson, B. Bendall and A. Murray
British Antarctic Survey
High Cross, Madingley Road
Cambridge CB3 0ET, United Kingdom

Abstract

A large sample of otoliths from the mackerel icefish (*Champsocephalus gunnari*) was measured and weighed and their effectiveness as predictors of fish length and fish mass determined. The two measures, otolith length and otolith mass, provide good predictors of fish length, the latter being slightly better. The same measures did not predict fish total mass as accurately.

Résumé

Un échantillon important d'otolithes du poisson des glaces *Champsocephalus gunnari* est mesuré et pesé. À partir des valeurs obtenues, on étudie l'efficacité des otolithes pour déterminer la longueur et le poids des poissons. Les deux mesures, longueur et poids des otolithes, sont de bonnes valeurs prédictives de la longueur des poissons, le poids étant un indicateur lég̀erement plus précis. Les mêmes mesures ne permettent pas de déterminer avec la même précision le poids total des poissons.

Резюме

Было измерено и взвешено большое количество отолитов ледяной рыбы (*Champsocephalus gunnari*) и определена их эффективность в предсказании длины и массы рыб. Два показателя (длина и масса отолитов) хорошо предсказывают длину рыб, причем масса отолитов дает немного лучшие результаты. В то же время эти показатели не позволяют так же точно определить общую массу рыбы.

Resumen

Se midieron y pesaron numerosos otolitos del draco rayado (*Champsocephalus gunnari*) y se determinó la exactitud con la cual se puede predecir la talla y peso del pez a partir de las mediciones. Las dos mediciones del otolito (largo y masa) demostraron ser buenos indicadores de la talla del pez, siendo la última medición ligeramente superior. Estas mediciones no predijeron el peso total del pez con la misma exactitud.

Keywords: otolith size, fish length, body mass, relationship, mackerel icefish, CCAMLR

INTRODUCTION

Answering questions on the structure of food webs generally begins with a simple descriptive picture of major interactions. Extending such studies to ecosystem dynamics requires that each component in the system be quantified; this mainly concerns the type, size, mass and energetic content of the prey. The acquisition of such information on fish as prey often relies on the use of hard structures, such as otoliths. Compared to other parts of the prey species, otoliths appear to undergo relatively little change as a result of passing through all or part of the predator's digestive tract (Pitcher, 1980; Frost and Lowry, 1981). The question of otolith erosion, which has been highlighted by Jobling and Breiby (1986) and may be significant (Prime, 1979), is the subject of separate research studies within the British Antarctic Survey (BAS).

In the waters around South Georgia the mackerel icefish (*Champsocephalus gunnari*) is both a predator of krill (Kock et al., 1994) and prey for fur seals (*Arctocephalus gazella*) (North et al., 1983; Reid, 1995; North, 1996). Quantification of the interactions surrounding *C. gunnari* forms part of a major BAS program investigating the key interactions of harvested and dependent species around South Georgia.

In a previous study, otoliths obtained from *A. gazella* scat samples at South Georgia were compared with a relationship of otolith size to fish size obtained from a small sample of 24 *C. gunnari* to indicate the likely size of fish eaten by the seals (North et al., 1983). While that study provided a good first approximation, the studies by Reid (1995) and North (1996) indicate that information from a much larger sample and from different seasons would improve the quality of the information on the amount and size of *C. gunnari* eaten.

Information on the size of *C. gunnari* otoliths from a collection of 350 fish from Heard Island has been published by Williams and McEldowney (1990). An earlier study by Hecht (1987) was based on information from 52 otoliths, 25 of which came from South Georgia. We have used samples of otoliths obtained during a series of groundfish surveys and the commercial fishery to compare otolith size to fish size.

MATERIALS AND METHODS

A total of 1 022 *C. gunnari* otoliths were obtained during five separate surveys and one season of the commercial fishery around South Georgia. Sampling periods, designated by the year in which the samples were obtained, for the research surveys were: 6 to 26 January 1990, 22 January to 11 February 1991, 3 to 26 January 1992 and 4 to 28 September 1997. Sampling from the commercial fishery took place during the period 31 December 1997 to 3 January 1998, designated as 1998. The main sampling protocol remained the same for each survey; details of a typical example are set out in Everson et al. (1991). During the surveys the following information was obtained from the individual fish: total length L_t (cm), total mass W_t (g), sex and maturity stage. Sagittal otoliths were removed and stored dry for subsequent examination.

Otoliths were examined under a light microscope and, if they appeared to be undamaged, the otolith length, L_o (mm), was measured using an eyepiece graticule according to the method of Williams and McEldowney (1990). The total mass, W_o (mg), was measured using a standard analytical balance with a precision of 0.1 mg.

Statistical analyses were undertaken using the packages Minitab (1998) and Genstat (Payne et al., 1997). Linear regressions were fitted to $\log_{10}$-transformed data, and analyses of covariance were used to assess variability in model fits between years. Note that due to large samples, with consequently large numbers of degrees of freedom, critical values for statistical significance are very small; all statistically significant effects should be carefully scrutinised for biological significance.

RESULTS

Scatter plots of L_t on L_o (Figure 1) and L_t on W_o (Figure 2) indicate a curvilinear relationship between the variables with a relatively larger spread in the distribution for the larger fish.

Analysis of covariance confined to the range of otolith lengths common to all years (1.79 to 3.75 mm) showed that the $\log_{10}$-transformed data were best described by a linear regression model allowing for parallel lines for each year ($F_{4.846} = 30.57$, $p < 0.001$); including extra parameters for separate slopes for each year did not give a statistically significant improvement to the fit ($F_{4.846} = 1.86$, $p > 0.05$). The parallel-line model accounted for 85.1% of the variance in the data.

Analysis of covariance confined to the range of otolith mass common to all years (2 to 16 mg) showed that the $\log_{10}$-transformed data were best described by a linear regression model allowing for parallel lines for each year ($F_{4.889} = 36.7$, $p < 0.001$); including extra parameters for separate slopes for each year did not give a statistically significant improvement to the fit ($F_{4.889} = 1.85$, $p > 0.05$). The parallel-line model accounted for 92.0% of the variance in the data.

In all of the above analyses there was no significant difference between the results for male and female fish. Sex was not included as a factor in any of the other analyses.

The fitted models were used to generate predictions and standard errors for new observations over a range corresponding to fish total length from 10 to 65 cm. This range was chosen so as to encompass the size range of the smallest, and exceed the size of the largest, fish likely to be encountered in the wild. The standard errors were then used to calculate 95% confidence limits. The predictions and associated confidence limits were back-transformed to natural units.

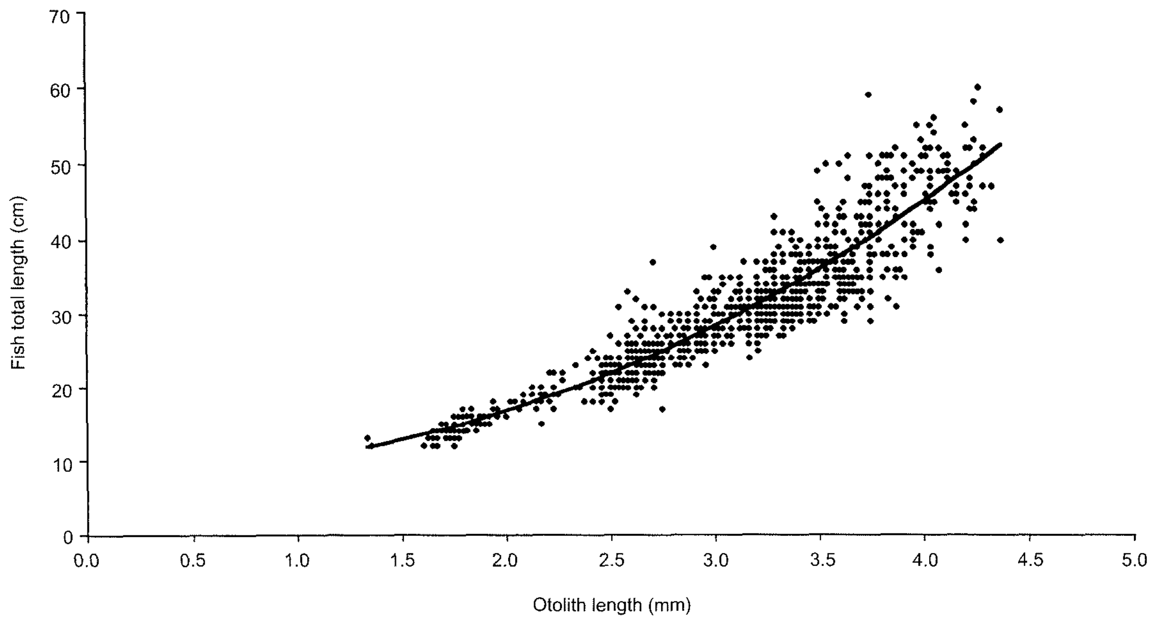

Figure 1: Scatter plots of fish total length against otolith length. The fitted line is $L_t = 6.275 \times L_o^{1.878}$.

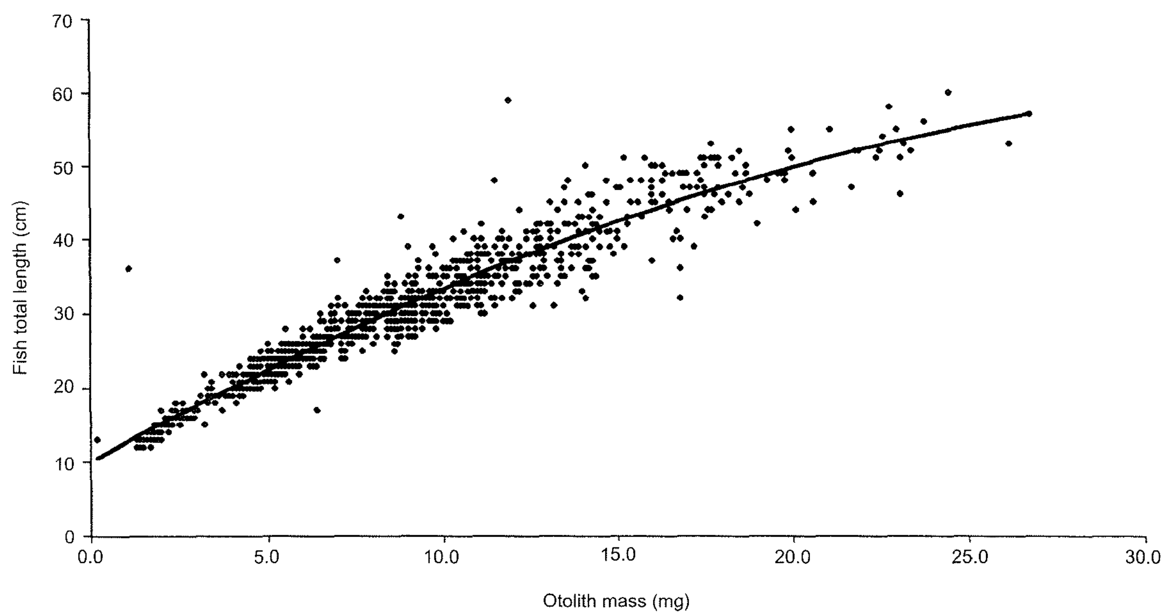

Figure 2: Scatter plots of fish total length against otolith mass. The fitted line is $L_t = 9.763 \times W_o^{0.532}$.

The results for parallel lines fitted to $\log_{10}$-transformed otolith length gave predicted fish total lengths a little higher (a maximum of some 3 to 4 cm at c. 60 cm) in 1990 and 1997; in other years predictions were very similar and close to predictions using a common line for all years. Note that the prediction limits are of the order ±11.5 cm at 60 cm length.

The analogous results using otolith mass showed less variation between years; only 1990 appeared to be higher than the other years (by some 4 cm at c. 60 cm) with prediction limits of the order ±9.5 cm at 60 cm length.

To give the best predictions of total length, we fitted simple linear regression models to $\log_{10}$-transformed data from all years with no restriction on range. The equation for all years using the full range of data for $\log_{10}$-transformed otolith length is:

$\log_{10}L_t = 0.798 + 1.388 \log_{10}L_o$
(SEs: constant 0.00738, slope 0.0151;
Df = 1 021).

The equation for all years using the full range of data for $\log_{10}$-transformed otolith mass is:

$\log_{10}L_t = 0.990 + 0.532 \log_{10}W_o$
(SEs: constant 0.00389, slope 0.00422;
Df = 1 021).

In order to compare ours with published results predicting fish mass from otolith length we fitted a simple linear regression model to $\log_{10}$-transformed data from all years with no restriction on range. The equation is:

$\log_{10}W_t = -0.0177 + 4.57 \log_{10} L_o$
(SEs: constant 0.0276, slope 0.0567;
Df = 1 021).

DISCUSSION

The results from this study indicate that otolith size, whether measured as length or mass, is a good indicator of fish length, and also that these relationships are not affected by the sex of the fish. When otolith mass is used as the predictor of fish length the regression explained 92% of the variation in the data, an improvement on the analysis using otolith length. In all cases the confidence limits for predictions based on otolith mass were narrower than those for predictions based on otolith length. Thus, as there is less prediction error associated with using otolith mass, we recommend that the latter be used to estimate total length from otoliths.

Comparison with Other Results

Two studies have provided equations relating otolith length to fish length for *C. gunnari*. Williams and McEldowney (1990) give the relationship:

Standard length =
(96.67 x otolith length) - 20.02
($n = 350$, $r^2 = 0.96$).

These results are for fish from Heard Island ranging in size from 5 to 35 cm, a smaller size range than for our results from South Georgia, which may explain why the simple linear relationship provides such a good fit. For direct comparison, standard length can be converted to total length using the relationship derived from our data at South Georgia:

Total length =
(1.1017 x standard length) + 0.611
($n = 1\,247$, $r^2 = 0.98$).

The results of Hecht (1987) are from 52 fish varying from 20 to 51 cm total length, a range which is closer to that of our results, and give the following relationship:

Total length = 12.55 x otolith length$^{0.95}$
($n = 93$, $r^2 = 0.81$).

Those samples were obtained from the South Shetlands, Kerguelen, South Georgia and Elephant Island, a wide geographical area which may have added a further source of variation to the results.

Comparing the results of Williams and McEldowney (1990) and Hecht (1987) with our own from South Georgia (Table 1) indicates a reasonable level of agreement. In spite of this, we would advocate that an otolith size to fish size relationship that is derived from the fish population on which the predator species are thought to be feeding, should be used whenever possible.

The study by North et al. (1983) used otolith length to predict fish mass directly using the following relationship:

Fish total mass = 3.087 x $L_o^{4.048}$
($n = 24$, $r^2 = 0.77$).

The equivalent relationship from our results is:

Fish total mass = 0.960 x $L_o^{4.57}$
($n = 1\,023$, $r^2 = 0.86$).

These two equations give substantially different results as indicated in Table 2, which may be a result of the small sample size in the North et al. (1983) result or might reflect differences in condition or spawning status of the fish.

We are not in favour of using otolith size to estimate fish total mass directly for two reasons. Firstly, the fish mass will vary with condition (Everson et al., 1997) and secondly, if a relationship is determined during the spawning season when the gonad mass may increase the total mass by 20% (Kock, 1992), this is likely to

Table 1: Comparison of the results presented in this paper with those of previously published values of fish length estimated from otolith length. The numbers in parenthesis fall outside the range of the samples used in that study.

Otolith Length (mm)	Lower CI	Mean (This Paper)	Upper CI	Hecht (1987)	Williams and McEldowney (1990)
1.5	9.2	11.2	13.8	(18.4)	14.4
2.0	13.5	16.6	20.3	24.2	19.7
2.5	18.2	22.3	27.4	30.0	25.0
3.0	23.3	28.5	35.0	35.6	30.4
3.5	28.6	35.1	43.0	41.3	35.7
4.0	34.3	42.0	51.5	46.8	(41.0)
4.5	40.1	49.2	60.3	(52.4)	(46.3)

Table 2: Comparison of fish total mass predicted from otolith length using the equations of North et al. (1983) and those in this paper.

Otolith Length (mm)	Estimated Fish Mass (g)	
	This Paper	North et al. (1983)
2	23	51
3	145	264
4	542	845
5	1 502	2 085

overestimate the biomass of fish consumed when compared to standard fisheries methods of estimating standing stock.

CONCLUSIONS

1. Otolith size can be used as a reliable predictor of fish length in *C. gunnari*.

2. Otolith mass provides a better predictor of fish length than otolith length. These conclusions are based on results from fresh fish of known size.

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Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras