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SHORT NOTE

AGE, GROWTH AND SIZE AT SEXUAL MATURITY OF *MACROURUS CARINATUS* CAUGHT AS BY-CATCH IN AUSTRALIAN SUB-ANTARCTIC TRAWL FISHERIES

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Abstract

Estimates of age and growth were obtained from 156 *Macrourus carinatus* otolith samples collected during two research voyages to Heard and McDonald Islands (Division 58.5.2) in 1992 and 1993. The range of estimated ages was 4 to 25 years. There were no significant differences in growth parameters calculated for males and females. Von Bertalanffy growth parameters for both sexes combined were: L_∞ = 690 mm, K = 0.069 and t_0 = -2.4. The size at sexual maturity of *M. carinatus* was determined from 162 specimens collected during commercial trawl fishing operations in the Heard Island region in 2000. The length at first maturity (L_{50}) was 418 mm (total length) and the length at first spawning (L_{m50}) was 511 mm (total length), for both sexes combined. The length–weight relationship for *M. carinatus* from Heard and McDonald Islands was statistically different to that from Macquarie Island. Otolith and body size relationships are presented for *M. carinatus* from Heard and McDonald Islands.

Résumé

Des estimations d'âge et de croissance ont été dérivées de 156 échantillons d'otolithes de *Macrourus carinatus* collectés au cours de deux campagnes de recherche aux îles Heard et McDonald (division 58.5.2) en 1992 et 1993. Les âges estimés appartenaient à l'intervalle de 4 à 25 ans. Aucune différence significative dans les paramètres de croissance ne distinguait les mâles des femelles. Les paramètres de croissance de von Bertalanffy des deux sexes combinés étaient : L_∞ = 690 mm, K = 0,069 et t_0 = -2,4. La taille à la maturité sexuelle de *M. carinatus* a été déterminée à partir de 162 spécimens collectés au cours d'opérations de pêche commerciale au chalut menées dans la région de l'île Heard en 2000. La longueur à l'atteinte de la maturité (L_{50}) était de 418 mm (longueur totale) et la longueur à la première ponte (L_{m50}) était de 511 mm (longueur totale) pour les deux sexes combinés. Le rapport longueur–poids de *M. carinatus* des îles Heard et McDonald présentait des différences statistiques par comparaison avec celui de l'île Macquarie. Les rapports entre la taille des otolithes et la taille du corps de *M. carinatus* des îles Heard et McDonald sont donnés dans le présent document.

Резюме

Оценки возраста и роста были получены по 156 образцам отолитов *Macrourus carinatus*, собранным в ходе двух научно-исследовательских рейсов к о-вам Херд и Макдональд (Участок 58.5.2) в 1992 и 1993 гг. Оценки возраста лежали в диапазоне от 4 до 25 лет. Существенной разницы в параметрах роста, рассчитанных для самцов и самок, не было. Параметры роста по фон Берталанффи для обоих полов вместе составили: L_∞ = 690 мм, K = 0.069 и t_0 = -2.4. Размер *M. carinatus* по достижении половозрелости был определен по 162 образцам, собранным во время коммерческого тралового промысла в районе о-ва Херд в 2000 г. Длина при достижении половозрелости (L_{50}) составляла 418 мм (общая длина), а длина при первом нересте (L_{m50}) – 511 мм (общая длина), для обоих полов вместе. Соотношение длина–вес для *M. carinatus* из района о-вов Херд и Макдональд статистически отличалось от такого же соотношения для о-ва Маккуори. Для *M. carinatus* из района о-вов Херд и Макдональд приведены соотношения размера тела и отолитов.

Resumen

Se obtuvieron estimaciones de edad y crecimiento de 156 muestras de otolitos de *Macrourus carinatus* recogidas durante dos campañas científicas realizadas en 1992 y 1993 alrededor de las islas Heard y McDonald (División 58.5.2). El rango de edades estimado fue de 4 a 25 años. No hubo diferencias significativas en los parámetros de crecimiento calculados para machos y hembras. Los parámetros de crecimiento de von Bertalanffy para ambos sexos combinados fueron: L_∞ = 690 mm, K = 0,069 y t_0 = -2,4. La talla de madurez sexual de *M. carinatus* fue determinada de 162 ejemplares capturados durante las operaciones de pesca de arrastre comerciales realizadas en 2000 en la zona de la isla Heard. La talla de primera madurez (L_{50}) fue 418 mm (longitud total) y la talla de primer desove (L_{m50}) fue de 511 mm (longitud total), para ambos sexos combinados. La relación talla-peso de *M. carinatus* de las islas Heard y McDonald presentó diferencias estadísticas con relación a la isla Macquarie. Se presentan las relaciones entre el tamaño de los otolitos y la talla corporal de *M. carinatus* de las islas Heard y McDonald.

Keywords: *Macrourus carinatus*, grenadiers, age, growth, maturity, by-catch, length–weight, Division 58.5.2, Heard and McDonald Islands, CCAMLR

INTRODUCTION

Macrourids (rattails and grenadiers) are relatively abundant deepwater fish in temperate and sub-Antarctic waters of the Southern Ocean (Iwamoto, 1990). They are commonly caught as by-catch in longline fisheries for Patagonian toothfish (*Dissostichus eleginoides*), which are regulated under the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). In some areas the macrourid by-catch comprises up to 17% of the total catch (SC-CAMLR, 1998). One of the objectives of CCAMLR is to manage the sustainable harvesting of target species from Southern Ocean waters without adversely affecting the long-term viability of interdependent species and predators. For this reason, increased attention is now being focused on taxa that are most commonly caught as by-catch (e.g. macrourids and rajids). In order to determine appropriate levels of by-catch, it is imperative to have information on the life history and abundance of these species. In particular, age, growth and reproductive parameters are essential for calculating estimates of yield, which can be used to set appropriate by-catch limits to ensure that these species are managed sustainably.

This paper provides estimates of age and growth for *Macrourus carinatus* from Heard and McDonald Islands using annual increments from otoliths. In addition, length at maturity, sex ratios, otolith and body size and length–weight relationships are also presented.

METHODS

Length–weight Relationships

Length–weight data for 633 *M. carinatus* specimens were obtained during two commercial trawl fishing trips to Macquarie Island in January 1999 and June 2000, three research cruises to Heard and McDonald Islands in June 1990, January/February 1992 and September 1993, and a commercial trawl fishing trip to Heard and McDonald Islands in September/October 2000. On each voyage, observers measured total length (to the nearest millimetre) and weight (to the nearest 10 grams) of a random subsample of fish. Only fish with undamaged tails were measured. Tail damage of macrourids can be a substantial problem in longline fisheries, which led to the adoption by CCAMLR in 2002 of anal length as the standard length measurement for macrourids. In accordance with this, anal length will be used as the standard for this species in all future work.

Maturity and Sex Ratios

A total of 162 *M. carinatus* specimens were collected by observers during a commercial trawl fishing trip to Heard and McDonald Islands in September/October 2000. The fish were measured for total length, weighed, sexed and a maturity stage assigned to the gonads according to the standard maturity scale for Antarctic fish derived from Kock and Kellerman (1991) and adopted by CCAMLR (Table 1).

Table 1: The five-point scale used to assign maturity stage by sex (Kock and Kellerman, 1991).

Maturity Stage	Female	Male
1	Immature	Immature
2	Maturing virgin or resting	Developing or resting
3	Developing	Developed
4	Gravid	Ripe
5	Spent	Spent

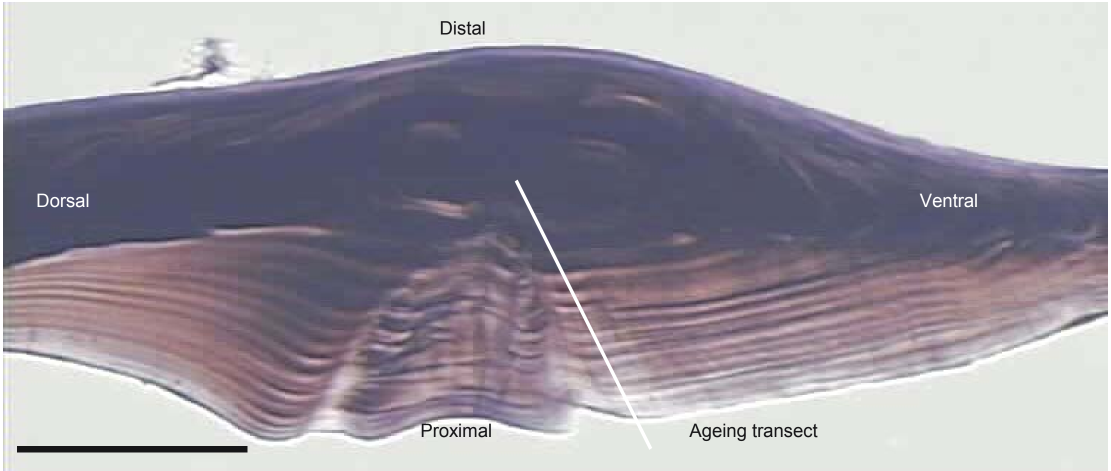

Figure 1: A transverse section of a *Macrourus carinatus* otolith (estimated age: 14 years) viewed using transmitted light. The ageing transect illustrates the position where annual increments were marked. Scale bar = 1 mm. Image provided by CAF.

Specimens were binned into 50 mm size classes and the proportion of fish with maturity stages 2–5 and 3–5 in each length bin calculated. A logistic curve, according to the method of Ni and Sandeman (1984) was fitted to the resultant data and values of L_{50} and L_{m50} estimated. L_{50} is defined as the length at which 50% of the fish population reaches sexual maturity and L_{m50} as the length at which 50% of the fish population spawn for the first time (Kock, 1989).

Age and Growth

Otoliths were extracted from 176 randomly selected *M. carinatus* during two research voyages to Heard and McDonald Islands during January/February 1992 and September 1993. Samples were collected from the Heard Island Plateau in an area from 50° to 54°S and 71.5° to 75.5°E.

Otoliths were analysed by the Central Ageing Facility (CAF) in Queenscliff, Victoria, Australia, using a standard resin embedding technique. One randomly selected otolith from each pair was weighed to the nearest milligram, embedded in clear polyester casting resin and cured at room temperature for 24 hours. Four otolith sections, each approximately 350 µm in thickness, were cut transversely from each resin block using a diamond-edged blade, ensuring that the otolith primordium was included. Sections were cleaned with alcohol, immersed in resin on a glass slide, and cured at room temperature for at least 3 hours. Prepared otoliths were viewed with a dissecting microscope under transmitted light at 25× magnification.

The growth zone structure was most clearly discernable on the ventral side of the otolith sections. Figure 1 shows the position of the ageing transect consistently adopted for all samples.

Otoliths were read 'blind' to avoid potential bias from prior knowledge of the length or weight of the fish. Ages were estimated by counting the number of complete opaque growth increments (increments were assumed to be laid down annually). A readability score was assigned to each age count to give some indication of the uncertainty of each estimate.

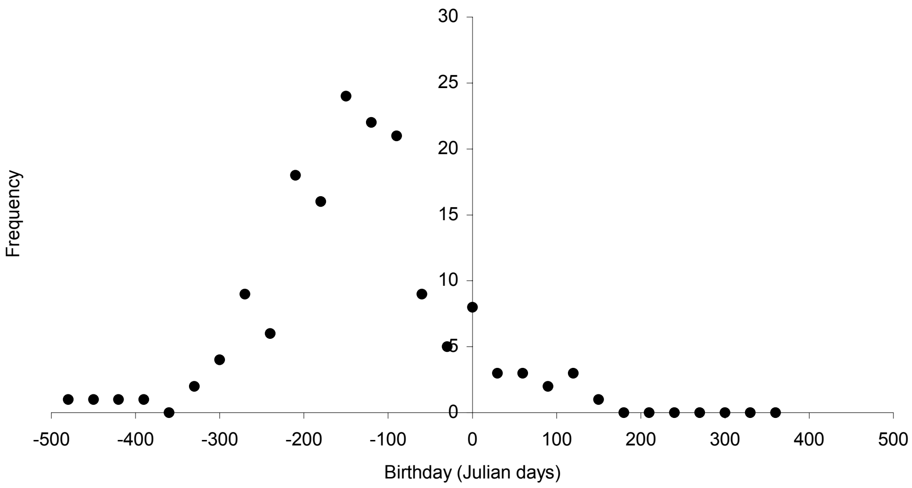

Figure 2: Frequency of fish with a birthday in each 30-day period.

Age estimates were subsequently adjusted by taking into account the difference between the birthday and the capture date of each fish. The birthday was calculated using the equation:

$$B = D - (E/L \times 365)$$

where B = birthday of the fish (in Julian days), D = date of capture (in Julian days), E = edge width (distance from outer edge of otolith to last ring) and L = last increment width (distance from last ring to second last ring).

The number of fish with a birthday in each 30-day period is shown in Figure 2. The peak occurs at -150 Julian days, corresponding to a birthday in July for this species.

Estimates of von Bertalanffy growth parameters were generated from the length-at-age data using a non-linear ordinary least-squares fitting procedure. Otolith weight and body size relationships were also determined.

Reader Validation of Otolith Age

The intra-reader and inter-reader variability in otolith interpretation was quantified by the index of average percent error (IAPE) developed by Beamish and Fournier (1981). Confidence intervals to these estimates of precision were calculated using a bias-corrected bootstrap technique modified from Efron and Tibshirani (1993).

A subset of 49 otoliths were re-read by the primary reader to determine the intra-reader variability. The distribution of differences approximated a normal distribution. Fifty-four percent of secondary age estimates by the primary reader agreed with the first estimates, and 88% were within one year. This relatively high level of precision was also indicated by a bias corrected bootstrap mean IAPE = 2.6% (CI = 1.5–3.6%).

To determine the inter-reader variability, a second reader aged a subsample of 45 otoliths. The inter-reader age differences approximated a normal distribution around zero, indicating that there was no significant bias between readers. Twenty-nine percent of otoliths were assigned to the same year, 69% were within one year of each other and 92% were aged within two years of each other. The bias corrected bootstrap mean IAPE = 4.6% (CI = 3.2–6.0%), indicating a greater discrepancy between readers.

RESULTS AND DISCUSSION

Length–weight Relationships

Length–weight relationships for *M. carinatus* from Macquarie Island and Heard and McDonald Islands were determined from the data according to the model:

$$W = a.L^b$$

where W = weight of the fish (kg), L = total length (mm) and a and b are parameters to be estimated.

The length–weight relationships derived for *M. carinatus* are shown by region in Table 2 and Figures 3 and 4.

Table 2: Parameters of the length–weight relationship by region (N = number of samples). *Parameters for *Macrourus holotrachys* from South Georgia from Morley and Belchier (2002).

Region	a	b	R^2	N
Heard and McDonald Island	2.4589×10^{-9}	3.1159	0.9721	474
Macquarie Island	1.4676×10^{-9}	3.1804	0.9624	159
Pooled data from Heard/McDonald Islands and Macquarie Island	4.0417×10^{-9}	3.0313	0.9839	633
South Georgia*	8×10^{-9}	2.9297	0.8221	227

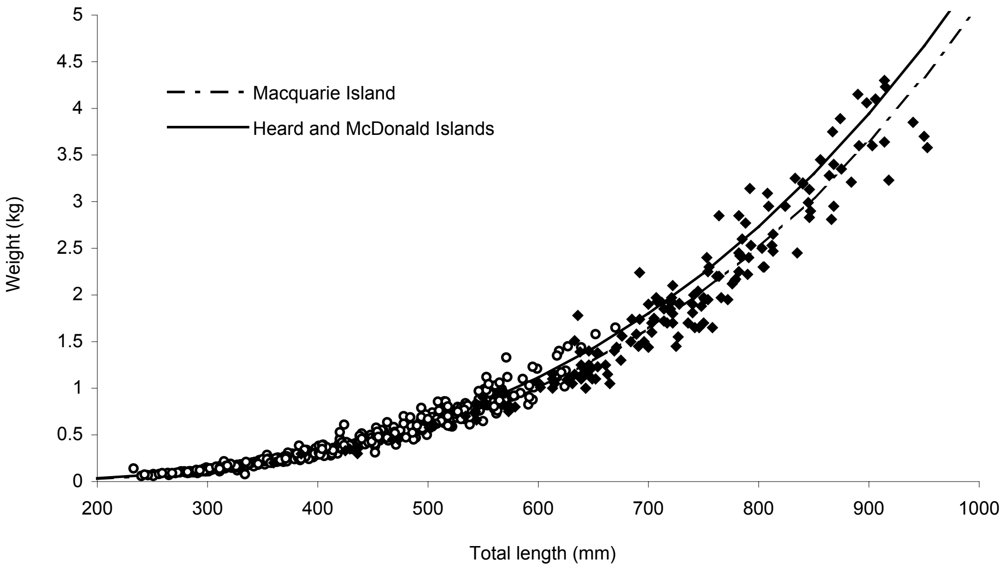

Figure 3: Length–weight relationship for *Macrourus carinatus* from Heard and McDonald Islands (o) and Macquarie Island (♦). The equations for the fitted lines are given in Table 2.

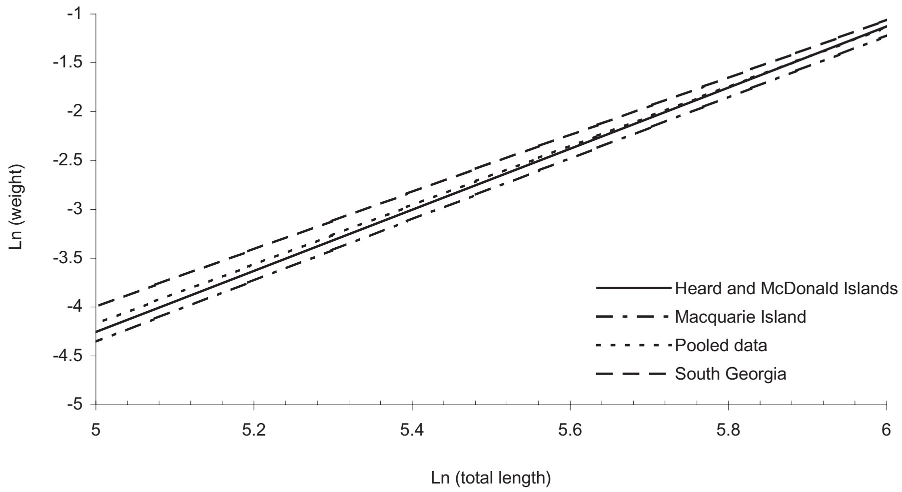

Figure 4: Log-transformed length–weight relationships for *Macrourus carinatus* from Macquarie Island, Heard and McDonald Islands and a pooled dataset combining Macquarie and Heard and McDonald Islands. Data for *Macrourus holotrachys* from South Georgia from Morley and Belchier (2002).

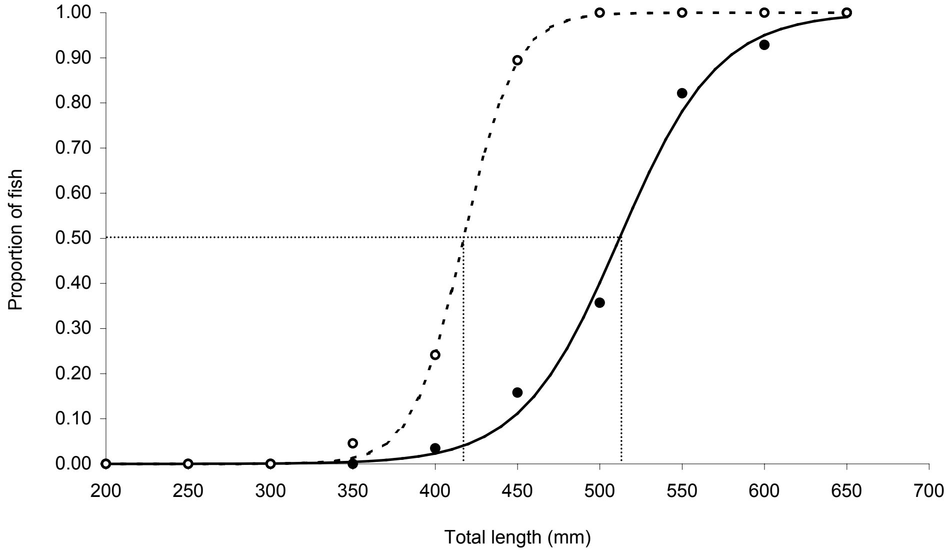

Figure 5: The proportion of *Macrourus carinatus* at maturity stages 2–5 (o) and 3–5 (•) for both sexes combined from Heard and McDonald Islands. The values of L_{50} and L_{m50} are indicated by the dashed lines.

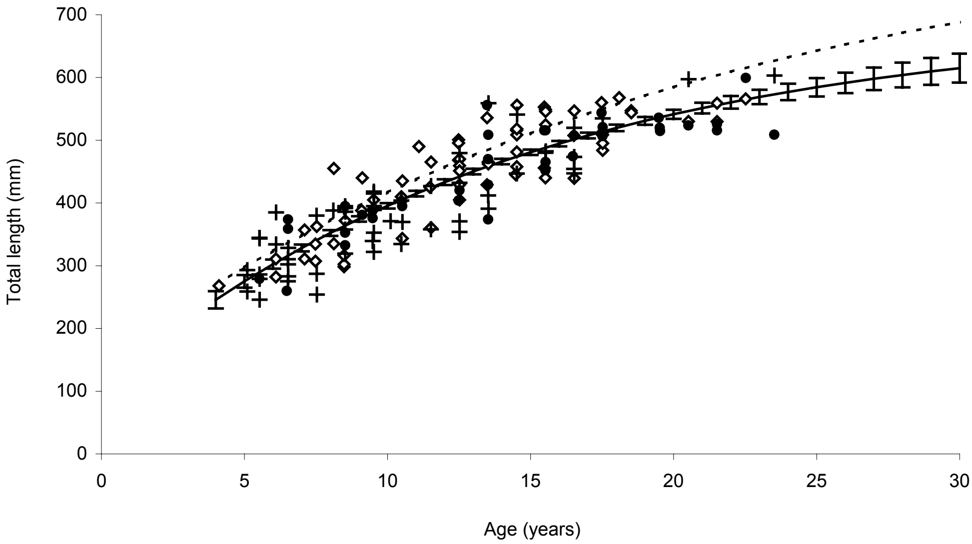

Figure 6: Age data for *Macrourus carinatus*: ◊ = females, • = males, + = juveniles and indeterminate sexes. The von Bertalanffy growth curve for all sexes combined is denoted by the solid line. Error bars represent the standard error. The dashed line represents the von Bertalanffy growth curve from Marriott and Horn (2001) for *Macrourus whitsoni* from the Ross Sea.

The length and weight data were log-transformed to stabilise the variances across the length range of the data. An *F*-test determined that the length–weight relationships were statistically different between Macquarie, and Heard and McDonald Islands; however this may not be of practical significance. The slopes of the data from the two regions were the same ($F_{1, 629} = 1.22$, $P = 0.271$), but the intercepts were significantly different ($F_{1, 630} = 36.57$, $P < 0.001$) (Figures 3 and 4). Apart from differences caused by geographical separation of the two sites, seasonal variations in reproductive condition linked to the different sampling times in the two areas may also influence results.

A comparison of the pooled data from Macquarie and Heard and McDonald Islands with that derived by Morley and Belchier (2002) for *M. holotrachys* from South Georgia shows that the length–weight relationships are significantly different ($F_{3, 631} = 88.58$, $P < 0.001$) (Figure 4).

Maturity and Sex Ratios

The proportion of fish from Heard and McDonald Islands at maturity stages 2–5 and 3–5 were calculated for males, females and for both sexes combined to estimate length at sexual maturity (L_{50}) and length at first spawning (L_{m50}). As there was no significant difference in the values of L_{50} and L_{m50} calculated for females and males ($P > 0.01$), only the plot for all sexes combined is shown here (Figure 5).

Logistic curves were fitted as a generalised linear model to the data using a maximum likelihood method (McCullagh and Nelder, 1989):

$$p = 1/(1+ e^{-(\alpha + \beta L)})$$

where p = proportion of fish, L = total length and α and β are coefficients. For maturity stages 2–5 (standard errors in parentheses) $\alpha = -29.43 \pm (6.86)$ and $\beta = 0.0704 \pm (0.0164)$ and for maturity stages 3–5 $\alpha = -16.14 \pm (2.73)$ and $\beta = 0.0316 \pm (0.0053)$.

The value of $L_{50} \pm$ (95% CI) is 418 ± 12 mm, corresponding to an approximate age of 11 years, and the value of $L_{m50} \pm$ (95% CI) is 511 ± 17 mm, corresponding to an approximate age of 17 years. The 95% confidence intervals were determined using Fieller's Theorem (Finney, 1971). The large difference between L_{50} and L_{m50} noted in this study has also been observed for *M. holotrachys* at South Georgia (Mulvey et al., 2002). These estimates of length at maturity are similar to those obtained in previous studies. Alekseyeva et al. (1993) estimated a value of 580–590 mm for L_{m50} and a value of 700–710 mm for L_{m100} for *M. carinatus* in the Falkland/Malvinas Islands and Patagonian Shelf region. Estimates of length at maturity for *M. carinatus* were 500 mm for males and 550–600 mm for females from the South Atlantic (Zakharov et al., 1988; Cousseau, 1993).

Of the 162 *M. carinatus* specimens, 97 were female, 38 were male and a further 27 were either juveniles or of undetermined sex. The sample has a skewed sex ratio of 2.6:1 in favour of females, the reasons for which are unknown. Studies on macrourid species in the northern hemisphere have noted similarly skewed sex ratios. D'Onghia et al. (2000) found that females of three species of macrourid were more abundant than males at all depths in the Ionian Sea. Similarly, Massuti et al. (1995) found a higher proportion of females present in the larger size classes when studying sex composition by size for four species of macrourid from the Mediterranean Sea. There are many possible reasons for skewed sex ratios, including differences in gear selectivity, behaviour, growth rate, longevity and ecology between sexes. Further work is required to clarify which of these factors are important, and whether the skewed sex ratio reflects the actual sex composition of the population or simply differences in catch rates between sexes or size classes.

Age and Growth

Twenty of the 176 *M. carinatus* otolith samples were excluded from the age analysis because they were either unreadable, had a ratio of edge width/last increment width of more than 1.4, or the accompanying length–weight data were unreliable. Estimates of age were generated from the remaining 156 otoliths. The range of estimated ages for the sample was 4 to 25 years (Figure 6). As there was no significant difference between the fitted growth curves for males and females ($F_{3, 96} = 1.1364$, $P = 0.33$), all data were pooled, including juveniles and those of indeterminate sex. Von Bertalanffy growth parameters for the pooled data, with standard errors given in parentheses, were: $L_\infty = 690$ (±67) mm, $K = 0.069$ (±0.018) and $t_0 = -2.4$ (±1.35)[1]. The test for lack of fit (using pure error $F_{40, 113} = 1.1647$, $P = 0.26$, Draper and Smith, 1981) showed no significant departure of the mean lengths at age from the fitted von Bertalanffy curve.

[1] Please note these parameters have been revised since the first edition of this manuscript submitted to the CCAMLR Working Group on Fish Stock Assessment (Document WG-FSA-02/48).

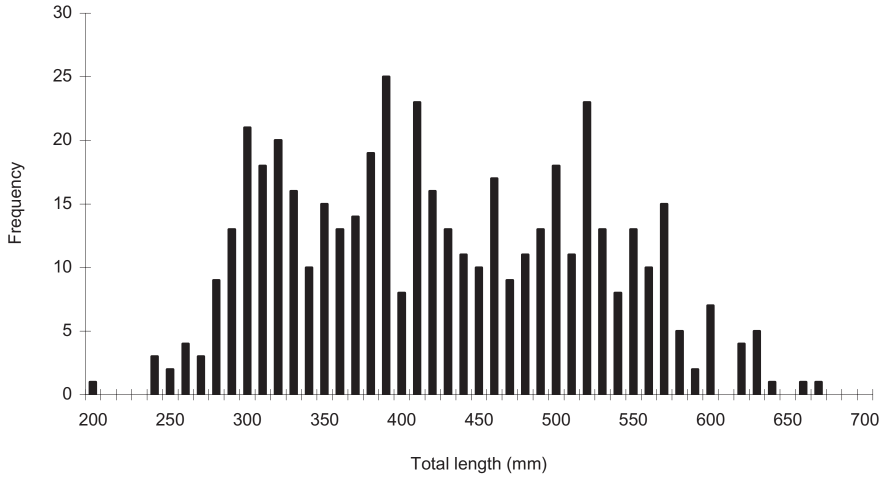

Figure 7: Length-frequency diagram of all specimens of *Macrourus carinatus* sampled from Heard and McDonald Islands. Data is binned into 10 mm length bins with the length label corresponding to the upper end of each bin.

The data for *M. carinatus* were compared to the growth curve derived by Marriott and Horn (2001) for *M. whitsoni* from the Ross Sea (Figure 6). These were significantly different when compared with a lack-of-fit test using pure error, $F_{43,\,113} = 2.928$, $P < 0.01$. This is especially evident at the upper end of the size spectrum, with *M. whitsoni* growing faster and attaining a larger maximum size than *M. carinatus*. While there are many possible reasons for the different growth parameters, including the geographical separation of sites and the distinction between species, it should be noted that the under-representation of large fish in this study may be causing a downward bias in the growth parameters, particularly at the upper end of the size spectrum.

Marriott and Horn (2001) also found differences in growth rate between the sexes in *M. whitsoni*. This is common in macrourid species from other parts of the world, where females generally grow faster and attain a larger maximum size than males (Kelly et al., 1997; Andrews et al., 1999). No such difference could be discerned between male and female *M. carinatus* in our study (Figure 6). However this would need to be validated by future studies which include more data from larger fish.

The observations made in determining the birthday indicate that the laying down of rings could be annual, although the ages determined from otoliths have not been validated using other techniques. The distribution of lengths at age (Figure 6) and the low proportions of mature fish in the samples described above indicate that older fish are likely to be under-represented in this study. This is due to the relatively shallow depths at which the trawl fishery operates. Larger fish are more frequently caught by longliners, which can fish in deeper waters than the current trawl fishery. Coggan et al. (1996) found that *M. carinatus* around the Falkland/Malvinas Islands increased in size with depth. This has also been noted for other grenadier species in other parts of the world (Massuti et al., 1995; D'Onghia et al., 2000). The estimation of von Bertalanffy growth parameters would be improved by the addition of larger, older fish to future ageing samples.

The lengths of *M. carinatus* in our ageing sample ranged from 246 to 603 mm. The smallest specimen of *M. carinatus* caught in the commercial fishery in Division 58.5.2 was 195 mm total length (Figure 7), corresponding to between 2 and 3 years of age. The largest specimen of *M. carinatus* caught at Heard and McDonald Islands was 670 mm long which corresponds to an age of 50 years or more.

The von Bertalanffy growth curve indicates that *M. carinatus* is a relatively long-lived and slow-growing species. This is similar to results obtained in other studies on macrourids. Marriott and Horn (2001) produced estimates of unvalidated age for *M. whitsoni* from the Ross Sea of 9 to 55 years. Bergstad (1995) estimated that *Coryphaenoides rupestris* in the North Atlantic reached a maximum age of approximately 70 years, while Kelly et al. (1997) estimated a maximum age for males of 50 years, and 60 years for females. A related species, *Coryphaenoides acrolepis*, was aged by Andrews et al. (1999) to a maximum range of 56 to 73 years.

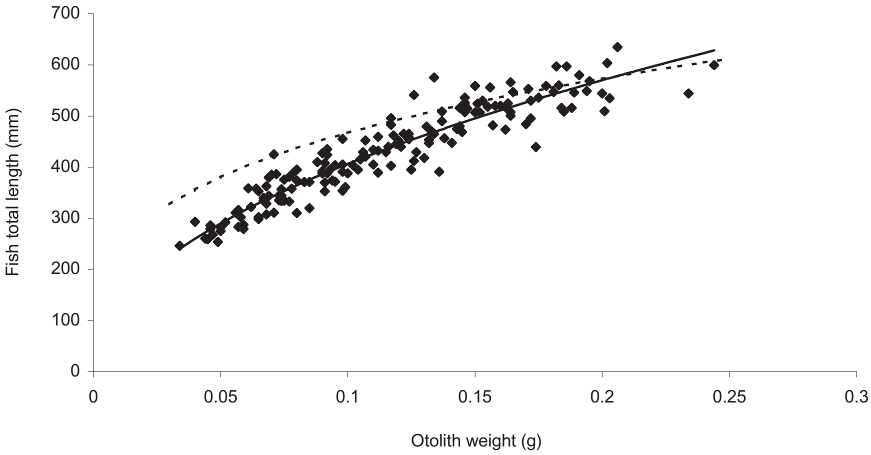

Figure 8: Relationship between total length (mm) of fish and otolith weight (g) for *Macrourus carinatus* from Heard and McDonald Islands. The equation of the line of best fit to the data (solid line) is given in the text. The dashed line is the relationship derived by Morley and Belchier (2002) for *Macrourus holotrachys* from Subarea 48.3.

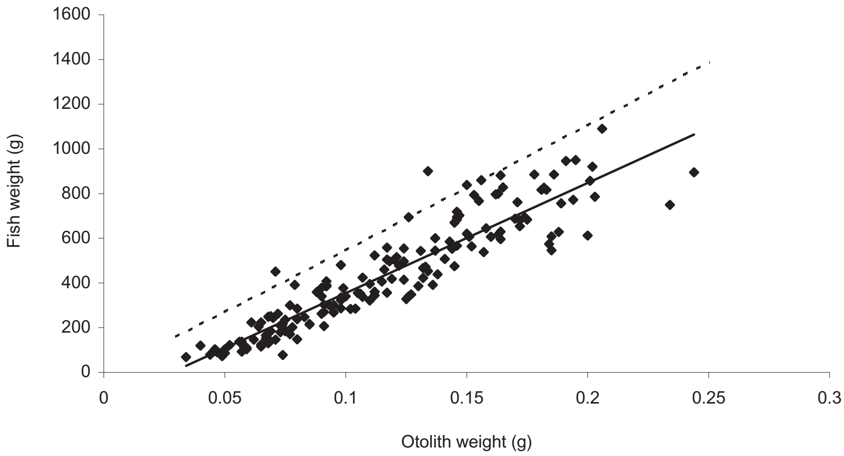

Figure 9: Relationship between fish weight (g) and otolith weight (g) for *Macrourus carinatus* from Heard and McDonald Islands. The equation of the line of best fit to the data (solid line) is given in the text. The dashed line is the relationship derived by Morley and Belchier (2002) for *Macrourus holotrachys* from Subarea 48.3.

Otolith and Body Size Relationships

Studies examining the interrelationships of predators and prey often use fish otoliths and hard parts extracted from a predator's stomach contents or scats to determine diet. It is useful to be able to determine fish biomass or size from these otoliths in order to calculate estimates of prey consumption rates. Morley and Belchier (2002) determined that otolith weight was a more useful predictor of fish size than otolith length in *M. holotrachys*. The relationships between otolith weight and body size for *M. carinatus* have been determined in the present study and are shown in Figures 8 and 9. Significant relationships exist between total length (L_t) of fish and otolith weight ($W_{otolith}$) and fish weight (W_t) and otolith weight:

$$L_t \text{ (mm)} = 1249.7 \times W_{otolith} \text{ (g)}^{0.4879} \quad (R^2 = 0.89)$$
$$W_t \text{ (g)} = 4927.9 \times W_{otolith} \text{ (g)} - 137.37 \ (R^2 = 0.85).$$

The relationships derived in this study are significantly different from those obtained by Morley and Belchier (2002) for *M. holotrachys* from South Georgia. It is important to consider that estimates of fish weight derived directly from otolith weight are likely to be influenced by variations in condition and reproductive status (Everson et al., 1999; Morley and Belchier, 2002). Future analyses of otolith and body size relationships would benefit from the analysis of data collected over different seasons.

CONCLUSIONS

Length–weight relationships for *M. carinatus* were statistically different between Macquarie Island and Heard and McDonald Islands. Future studies should analyse data collected from the two regions simultaneously to reduce the influence of seasonal variations. Otolith weight can be used to predict both fish length and fish weight in diet studies of predators, but seasonal variations in fish condition and reproductive status need to be taken into account. There were no significant differences in the estimates of L_{50} and L_{m50} between sexes, and the estimates derived here are similar to those reported for *M. carinatus* from other areas. Age and growth estimates calculated for *M. carinatus* from Heard and McDonald Islands showed no significant differences between sexes. Studies of macrourids in other regions have shown sexual dimorphism, with females growing faster and attaining a larger maximum size than males. In order to validate this and improve the accuracy of age estimates in future studies, it is important to increase the representation of older fish in ageing samples. The ages estimated in this study were similar to those published for macrourids from other regions. The results presented here indicate that *M. carinatus* is likely to be a slow-growing and long-lived species and as such, may be potentially vulnerable to impacts from high levels of fishing. The estimates of life history parameters for *M. carinatus* presented here, combined with the information contained in van Wijk et al. (1999 and 2000) could be used to calculate a precautionary estimate of yield for this species.

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