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SPECIES IDENTIFICATION AND AGE ESTIMATION FOR THE RIDGE-SCALED MACROURID (*MACROURUS WHITSONI*) FROM THE ROSS SEA

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Abstract

Samples of macrourid rattail by-catch from the toothfish fishery in the Ross Sea dependency in 2002 were identified by observers and returned to New Zealand for subsequent confirmation of their identity by researchers from the National Institute of Water and Atmospheric Research (NIWA). Two species were found, *Macrourus whitsoni* and *M. holotrachys*. A previously aged sample from 1999 was confirmed as being solely *M. whitsoni*, based on otolith comparisons and the geographic source of the aged sample.

Counts of translucent zones were made from baked and cross-sectioned otoliths of the ridge-scaled macrourid (*M. whitsoni)* sampled from the commercial longline fishery in the Ross Sea (CCAMLR Subarea 88.1). The zones are assumed to form annually as this ageing methodology has yet to be validated for this species. Von Bertalanffy growth parameters were calculated from the readings, separately by sex. *M. whitsoni* appears to be a slow-growing and long-lived species, living to at least 50 years. Females grow at a faster rate, and reach a larger size, than males, but both sexes exhibit comparable maximum ages. Regression relationships were calculated, by sex, between total and snout–vent lengths, snout–vent length and weight, and total length and weight. The species exhibited a degree of sexual dimorphism. The age at which 50% of fish are sexually mature was estimated to be from 12 to 14 years.

Résumé

Des échantillons de grenadiers macrouridés prélevés dans la capture accessoire de la pêche à la légine menée en 2002 dans les eaux territoriales de la mer de Ross ont été identifiés par les observateurs puis renvoyés en Nouvelle-Zélande pour confirmation ultérieure de leur identité par des chercheurs du National Institute of Water and Atmospheric Research (NIWA). Deux espèces ont été identifiées, *Macrourus whitsoni* et *M. holotrachys*. En 1999, il avait été déclaré, sur la base des comparaisons d'otolithes et de la source géographique d'un échantillon utilisé pour des lectures d'âge que celui-ci était constitué uniquement de *M. whitsoni*.

Les zones translucides ont été comptées sur des otolithes cuits au four et sur des coupes transversales d'otolithes de macrouridés à écailles en écusson (*M. whitsoni)* d'un échantillon prélevé au cours de la pêche commerciale à la palangre dans la mer de Ross (sous-zone 88.1 de la CCAMLR). Il est présumé que la formation de ces zones est annuelle, ce qui reste à valider pour cette espèce. Les paramètres de croissance de von Bertalanffy sont calculés à partir des lectures, en séparant les sexes. *M. whitsoni* semble se caractériser par sa croissance lente et sa durée de vie atteignant au moins 50 ans. Les femelles ont une croissance plus rapide que les mâles et elles atteignent une plus grande taille, mais les deux atteignent des âges comparables. Des rapports de régression sont calculés, par sexe, entre la longueur totale et la longueur museau–anus, entre cette dernière et le poids et entre la longueur totale et le poids. Cette espèce présente un certain dimorphisme sexuel. L'âge auquel 50% des poissons atteignent la maturité sexuelle est estimé entre 12 et 14 ans.

Резюме

Образцы прилова макрурусового долгохвоста при промысле клыкача в водах, относящихся к морю Росса, в 2002 г. были идентифицированы наблюдателями и возвращены в Новую Зеландию для последующего подтверждения их видовой принадлежности учеными из Национального института водных и атмосферных исследований (NIWA). Было обнаружено два вида – *Macrourus whitsoni* и *M. holotrachys*. На основании сравнений отолитов и географического происхождения образца 1999 г., возраст которого был определен ранее, было подтверждено, что он относится исключительно к *M. whitsoni*.

Были произведены подсчеты полупрозрачных зон по обожженным и разрезанным отолитам гребенчаточешуйного макруруса (*M. whitsoni)*, образцы которого были получены в ходе коммерческого ярусного промысла в море Росса (Подрайон АНТКОМа 88.1). Поскольку такая методология определения возраста для данных видов еще нуждается в проверке, принимается допущение, что эти зоны формируются ежегодно. На основе этих данных были рассчитаны параметры роста по Берталанфи отдельно для каждого пола. *M. whitsoni*, по-видимому, является медленно растущим видом с большой продолжительностью жизни – минимум 50 лет. Самки растут быстрее и достигают бóльших размеров, чем самцы, однако оба пола демонстрируют сопоставимый максимальный возраст. Были рассчитаны регрессионные соотношения для каждого пола, между общей длиной и длиной от носа до анального отверстия, длиной от носа до анального отверстия и весом, общей длиной и весом. Данный вид продемонстрировал некоторую степень полового диморфизма. Возраст, при котором 50% рыбы является половозрелой, был определен в 12–14 лет.

Resumen

Las muestras de granaderos presentes en la captura secundaria de la pesquería de austromerluza efectuada en la dependencia del mar de Ross en 2002 fueron identificadas por los observadores y enviadas a Nueva Zelandia para la confirmación posterior de su identidad por investigadores del Instituto Nacional de Investigaciones Hidrológicas y Atmosféricas (NIWA). Se encontraron dos especies, *Macrourus whitsoni* y *M. holotrachys*. Se confirmó que una muestra recolectada en 1999, y a la cual se le había determinado la edad mediante una comparación de sus otolitos y del lugar de procedencia, estuvo compuesta en su totalidad de *M. whitsoni*.

Los otolitos del granadero de escamas escutiformes (*M. whitsoni)* capturado durante las operaciones de la pesquería de palangre comercial realizada en el mar de Ross (Subárea 88.1 de la CCRVMA) fueron secados al horno y cortados en secciones para el recuento de las zonas translúcidas. Se ha supuesto la formación de zonas anuales dado que este método aún no ha sido convalidado para esta especie. De las lecturas de cada sexo por separado se calcularon los parámetros de crecimiento de von Bertalanffy. Parece ser que *M. whitsoni* es una especie longeva, de crecimiento lento, que alcanza a llegar, por lo menos, hasta los 50 años. Las hembras crecen más rápidamente que los machos y alcanzan un tamaño mayor, pero las edades máximas son comparables para ambos sexos. Se calcularon las relaciones de regresión por sexo entre la longitud total y la longitud preanal, la longitud preanal y el peso y la longitud total y el peso. La especie exhibió cierto dimorfismo sexual. La edad a la cual el 50% de los peces alcanzó la madurez sexual fue estimada en 12 a 14 años.

Keywords: *Macrourus whitsoni*, identification, otoliths, ageing, maturity, CCAMLR

INTRODUCTION

A target longline fishery for *Dissostichus* spp. in waters in and near the Ross Sea has operated each year since 1998 (Hanchet et al., 2002). Toothfish landings increased steadily from 41 tonnes in 1998 to 1 370 tonnes in 2002. The Antarctic toothfish (*D. mawsoni*) accounted for about 85% of total landings, and the Patagonian toothfish (*D. eleginoides*) made up less than 1% of the catch. Macrourids, almost exclusively *Macrourus whitsoni*, comprised a substantial by-catch of the fishery and accounted for about 10% of total landed weight (Hanchet et al., 2002). In the 2002 season, about 158 tonnes of *M. whitsoni* were reported as having been caught. Although a by-catch, the species is clearly of commercial importance, and is in need of monitoring and management. However, little is known about its biology.

In the past, identification of Ross Sea macrourids by observers has been uncertain. In 1999 and 2002 CCAMLR observers recorded *M. whitsoni, M. carinatus*, *M. holotrachys* and *Coryphaenoides armatus* in observations and collections from longline catches in the Ross Sea. A large number of randomly selected specimens collected from the same fishery in 2002 were returned whole to New Zealand for accurate taxonomic identification.

Growth parameters have been developed for numerous macrourid species distributed throughout the world's oceans (see review by Swan and Gordon, 2001) and a wide variety of longevities were reported, but many species appear to have a moderate lifespan (i.e. a maximum age in excess of 15 years), and a few species are slow growing and very long lived (e.g. Bergstad, 1995; Andrews et al., 1999). The growth rate and longevity of a species markedly influence its sustainable exploitation rate. Such information is required for *M. whitsoni* in the Ross Sea.

The aim of the current study is to provide estimates of a number of productivity parameters for *M. whitsoni*, i.e. von Bertalanffy growth parameters, instantaneous natural mortality, and age at maturity. These parameters are essential inputs in any fishery yield models. It should be noted that the results presented below are preliminary, as the ageing technique used has yet to be validated for this species. Macrourids have a long, tapering tail and the terminal segment of the tail is often missing from sampled specimens. Consequently, comparative regressions for snout–vent length, total length, and weight have also been generated for *M. whitsoni*.

METHODS

Species Identification

In 1999, CCAMLR observers collected macrourid otoliths, for subsequent ageing, on two commercial longline trips to the Ross Sea (CCAMLR Subarea 88.1), from an area with bounds of 71–76°S and 170°E–170°W. Considerable doubt was expressed as to the identity of specimens sampled by the observers. The majority of specimens were labelled as *M. carinatus*, a species common in southern New Zealand. A few specimens were labelled as *M. whitsoni*, a known Antarctic macrourid. Examination of otolith morphometrics and meristics showed the otolith structure was either highly polymorphic or that there was more than one species in the collection (Marriott and Horn, 2001). It was assumed that the majority of macrourids sampled were *M. whitsoni* but were misidentified by the observers.

In 2002, CCAMLR observers were requested to collect macrourid specimens for identification. The requirements were 'Two fish at random are to be collected from each of 50 sets, frozen and stored. These samples should be labelled with vessel, observer name, set number, observer identification of the fish, "random" and date'.

These specimens were thawed and identified by fish taxonomists before biological and otolith samples were taken. Subsamples of the specimens were retained and passed to the National Museum of New Zealand Te Papa Tongarewa. Iwamoto (1990), the main reference used for identification, outlines the key differences between *M. carinatus*, *M. whitsoni* and *M. holotrachys* (Table 1), and provides information for identification of other rattails from the area. The sex, gonad stage, weight, total length and snout–vent length were also recorded for each fish.

Otoliths from positively identified macrourids of the 2002 sample were visually compared to the range of morphs exhibited in the 1999 macrourid sample. Otolith morphometrics of *M. holotrachys* were also compared with the morphometrics of the 1999 sample.

The start positions of all sets that caught macrourids were analysed for the 1999 and 2002 seasons, to see if species of macrourid caught could be separated by their geographical range.

Otolith Preparation and Interpretation

A random sample of 300 *M. whitsoni* otoliths was selected, ensuring coverage of the full range of available fish lengths. Where possible the left

Table 1: Summary of key characters used to identify specimens of *Macrourus carinatus*, *M. holotrachys* and *M. whitsoni*, from Iwamoto (1990), from this study, and unpublished data.

M. carinatus	*M. holotrachys*	*M. whitsoni*
Underside of head		
scaled posterior to snout	naked except for a few scales	mostly scaled
Scales in oblique row between anal fin origin and lateral line (mean in parentheses)		
<27	22–31 (26)	25–59 (36)
Pyloric caeca (mean in parentheses)		
13–21	9–17 (13)	17–38 (27)
Scales in oblique row between second dorsal fin and lateral line		
5–6	6–7	7–9
Distribution		
temperate to sub-Antarctic	temperate to sub-Antarctic	Antarctic, mostly inside Antarctic Convergence

otolith was used for morphometrics and preparation, but if it was damaged, absent or displayed calcium resorption, the right otolith was used.

A sample of 300 otoliths was prepared using a standardised resin embedding technique. The otoliths were baked at 285°C for 8 minutes, then embedded in epoxy resin (Araldite K142) and cured at 50°C for 24 hours. The resin blocks were sectioned transversely through the otolith primordia using a diamond-edged wafering blade, and polished on the cut surfaces. The prepared otolith surfaces were coated with paraffin and observed through a stereomicroscope at approximately ×50 magnification, with illumination by reflected light. The sections generally exhibited a regular pattern of translucent and opaque zones; counts were made of the translucent zones.

Age estimates were generated on the assumption that one opaque and one hyaline zone represent one year's growth in the otolith. A readability value was attributed to each age estimate, as follows:

1. certain count
2. uncertainty of ±1 year
3. uncertainty of ±2 years
4. uncertain count of more than ±2 years
5. unreadable.

All otoliths were read without prior knowledge of the length or sex of the individual. A subset of 60 otoliths were also read by another worker familiar with otolith interpretation, to obtain an estimate of the between-reader variability in attributed ages.

Estimation of Growth Parameters

Von Bertalanffy curves were fitted to the resultant length-at-age data, and growth between sexes was compared, using the likelihood method of Kimura (1980). An estimate of instantaneous natural mortality (M) was derived using the equation

$$M = -\log_e(p)/A$$

where p is the proportion of the population that reaches age A or older (Hoenig, 1983). A p of 0.01 was used here as the stock is presumed to have experienced a relatively low level of exploitation so far. Only fish with readability grades of 1–3 were used in the analysis of von Bertalanffy parameters and natural mortality.

Regression Equations

Observers measured the following parameters on fresh macrourids:

- total length (cm) – tip of snout to tip of tail;
- snout–vent length (cm) – tip of snout to the vent; and
- whole weight (to 0.1 kg).

Regression equations relating total length to snout–vent length, total length to weight, and snout–vent length to weight were generated. Regression slopes were tested using a heterogeneity-of-slopes model, and if that test was non-significant, the intercepts (elevations) of the two regression lines were tested by analysis of covariance.

Analysis of Size and Age at Maturity

Observers determined gonad stage macroscopically, using the following five-stage scale for both males and females:

1. immature
2. maturing
3. ripe
4. running ripe
5. spent.

Data were collated by centimetre size class, and mean snout–vent length at maturity was designated as the size class at which more than 50% of the fish sampled were at maturity stage 2 or greater. The regression equations derived above were used to convert mean vent length at maturity into mean total length at maturity and mean age at maturity.

RESULTS

Species Identification

Of the 361 individually recorded observer specimens from the Ross Sea in 2002, 348 were labelled *M. whitsoni*, 11 were labelled *M. carinatus* and two were labelled *C. armatus*. The specimens the observers labelled as *C. armatus* were identified as *M. holotrachys*. The total of identified specimens consisted of 364 *M. whitsoni* and 11 *M. holotrachys* individuals.

A summary of some of the meristic and morphometric character values are given in Table 2. *M. whitsoni* was readily distinguished from *M. holotrachys* using the following characters (details for *M. holotrachys* in parentheses):

- underside of the head mostly covered with small scales, especially posteriorly (naked on underside of head except for a few scales opposite the angles of the mouth);
- smaller scales with 25–59 (22–31) in an oblique row between the anal fin origin and the lateral line; and
- more pyloric caeca, i.e. 17–38 (9–17).

The two species were similar in maximum size and weight but there were very few smaller sized *M. holotrachys* specimens in the samples. Detailed taxonomic examination would be required to document other differences.

Otolith morphology for both *M. whitsoni* and *M. holotrachys* appeared to be polymorphic and encompassed a similar range of forms. The dorsal margin of *M. holotrachys* otoliths tended to show more exaggerated sculpting and processes than similar sized *M. whitsoni* otoliths. Meristics of *M. holotrachys* showed reasonably distinct but partially overlapping ranges when plotted with the meristic data from the aged specimens collected in 1999.

Analysis of the start positions of longline sets for the 2002 data and the 1999 data showed that *M. holotrachys* was only found in the most northerly stations (north of 65ºS). The fish from the 1999 season ageing study all came from stations far to the south of any stations where *M. holotrachys* occurred (all south of 70ºS).

Otolith Interpretation

The otolith sections generally exhibited a regular pattern of translucent and opaque zones, most clearly apparent in the region extending from the ventral margin to the ventral side of the sulcus (Figure 1).

There was a change in the growth pattern in most otoliths at about the tenth zone, i.e. the otolith growth changed from rapid anterior–posterior and dorso–ventral growth to a more even deposition of material over the whole surface of the otolith, resulting in a thickening of the otolith laterally. The location of the transition zone was variable, but usually lay within the range of zone 8 to zone 13 inclusive. Microscopically, wide zones with many checks were observed up to the transition zone, followed by regular, narrow, and generally clear zones from the transition zone to the otolith margin.

The primary reader interpreted the 300 prepared otoliths with readability grades as follows:

Readability	1	2	3	4	5
Number	7	62	144	71	16

The two readers achieved a good correlation in attributed ages in the subset of 60 otoliths. All otoliths to which both readers attributed a readability of 3 or better were compared, resulting in 73% of counts being within 3 of each other and 93% within 5. The between-reader age differences approximated a normal distribution around zero, which indicated the lack of between-reader bias.

Growth Parameters

Calculated von Bertalanffy growth parameters together with sample details are listed for all

Table 2: Summary meristic and morphometric data collected for specimens of *Macrourus whitsoni* and *M. holotrachys* from the region of the Ross Sea, 2002.

	Range	Mean	*N*
Macrourus whitsoni			
Weight (g)	215–5125	1128	362
Total length (cm)	33–94	58	353
Snout–vent length (mm)	121–348	206	363
Scale row count – lateral line to anal fin origin	25–59	36	59
Scale row count – second dorsal fin origin to lateral line	7–9	8	62
Pyloric caeca	17–38	27	58
Macrourus holotrachys			
Weight (g)	1067–5134	3153	11
Total length (cm)	59–92	77	11
Snout–vent length (mm)	235–411	322	11
Scale row count – lateral line to vent	22–31	26	11
Scale row count – second dorsal fin origin to lateral line	6–7	6	11
Pyloric caeca	9–17	13	11

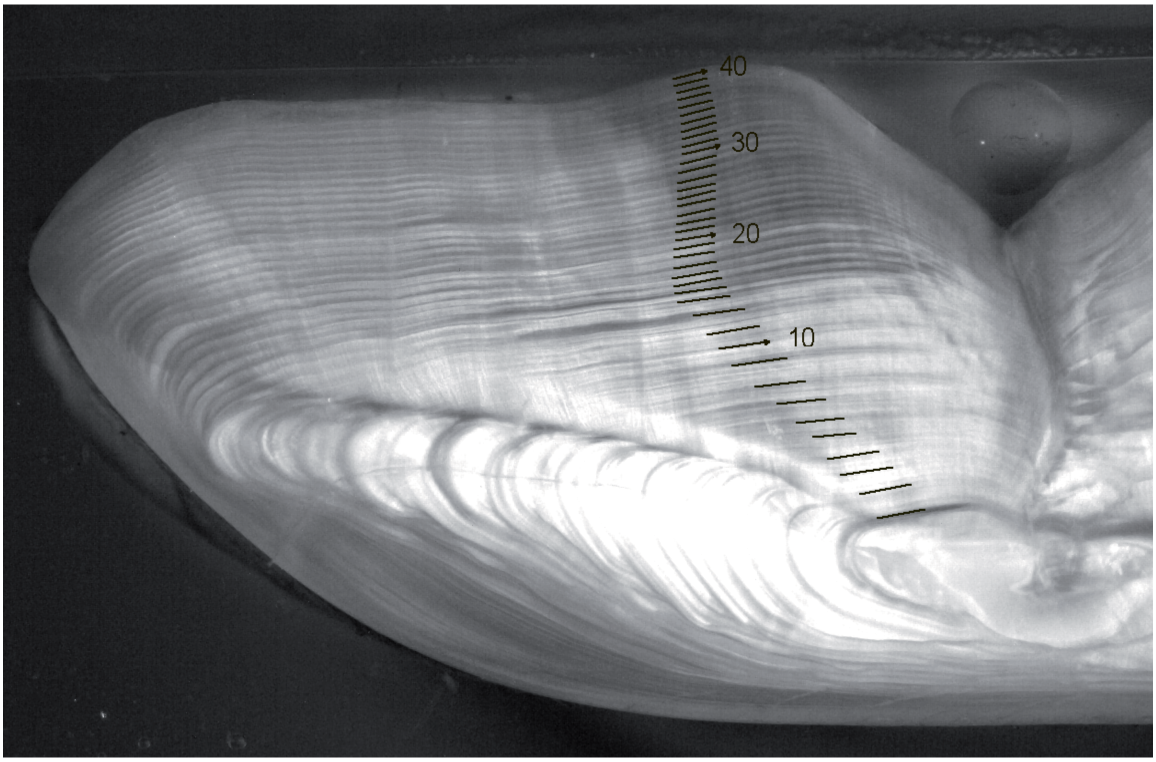

Figure 1: Sectioned otolith displaying the zone structure and region utilised for zone counts. This section contains 40 complete zones or years of growth.

available age data (Table 3). Raw age data and fitted von Bertalanffy growth curves are plotted (Figure 2) separately by sex.

Females appear to attain a larger size at age than males (Figure 2). The von Bertalanffy curves fitted separately to data from the two sexes were significantly different (χ^2 = 61.7, $P < 0.0001$). Between-sex differences are apparent for all three parameters (Table 3). However, the lack of fish aged younger than 9 years has resulted in unrealistic estimates of the t_0 values.

Natural Mortality

In all the available age data, 1% of males were at least 55 years old, and 1% of females had lived 51 years. The subsequent estimates of M from these ages are 0.08 and 0.09. However, the longline fishery is unlikely to provide an unbiased estimate of population numbers at age, so these estimates must be considered to be very uncertain. Therefore a range of ±0.03 around these values is recommended, i.e. M = 0.05–0.12.

Regressions relating Length and Weight

Observers collected nearly 4 200 measurements of total length and snout–vent length, and 337 measurements of snout–vent length and weight. Females comprised nearly two-thirds of the samples. The few obvious outliers in the data were removed from the subsequent analysis.

The linear regressions fitted to the plots of total length versus snout–vent length and total length versus weight were tested for significant differences between the two sexes. Regression slopes were tested using a heterogeneity-of-slopes model, and if that test was non-significant, the intercepts (elevations) of the two regression lines were tested by analysis of covariance.

There was a significant difference in the slopes of the male and female regression lines for both snout–vent length versus total length (for both males and females, $p < 0.0001$) and log weight versus log total length ($p = 0.013$ and $p < 0.0001$ for males and females respectively). Consequently, data should not be pooled across sexes. Regression equations for the three parameters, separated by sex, are given in Figure 3.

Size and Age at Maturity

As the von Bertalanffy curves generated for this study are significantly different between sexes, separate length and age-at-maturity estimates were produced for males and females. The analysis was performed on data pooled across a calendar year to produce a robust length-at-maturity estimate. The length classes at which the fish were maturing occurred at the lower end of the size range of fish sampled in this study, where sample sizes per length class were low.

Little of the gonad stage data recorded by observers contained information on total lengths (n = 1 470), so the analysis was run using snout–vent lengths for which there was a much larger set of data (n = 4 239). The proportions of each size class at each maturity stage are shown for females (Figure 4) and males (Figure 5).

Total length at maturity was estimated using the regression function for males and females from the observer data, derived from fresh specimens. Mean total lengths at maturity were estimated to be 46 cm (15 cm snout–vent length) for males, and 50 cm (17 cm snout–vent length) for females.

Using the von Bertalanffy regression equations, the mean age at maturity was estimated to be 12 years for males and 14 years for females.

DISCUSSION

In 2002 observers had difficulty identifying the macrourids of the Ross Sea region. Most of the *M. holotrachys* specimens were labelled *M. whitsoni* by the observers; the two remaining specimens of *M. holotrachys* which observers had identified as being distinct from *M. whitsoni* had been labelled as *C. armatus*. Some of the *M. whitsoni* specimens were miss-identified as *M. carinatus* by observers. Production of an accurate identification guide should alleviate this problem.

M. whitsoni and *M. holotrachys* are readily separable by their external features. *M. holotrachys* lacks scales on the underside of the head (there may be a few scales near the angles of the mouth), whereas in *M. whitsoni* the underside of the head is scaled. *M. holotrachys* also has larger, heavier scales with more prominent ridging. Counts of scale rows from anal fin origin to lateral line (oblique) and below second dorsal fin origin are lower for *M. holotrachys* than *M. whitsoni*. Pyloric caeca counts are also lower for *M. holotrachys* (from Iwamoto 1990, this study, and unpublished data).

The predominant macrourid by-catch species of the Ross Sea toothfish fishery is *M. whitsoni,* which is found throughout the fished areas of the greater Ross Sea. In our observed specimens *M. holotrachys*

Table 3: Von Bertalanffy growth parameters and sample details for *Macrourus whitsoni*. Standard errors are presented for the male and female von Bertalanffy parameters.

	Males	Females	Combined
L_∞	78.4 ± 3.6	87.0 ± 4.4	85.7
K	0.050 ± 0.011	0.068 ± 0.018	0.048
t_0	-5.36 ± 2.87	1.37 ± 2.74	-3.89
Age range (years)	9–55	11–51	9–55
N	117	96	213

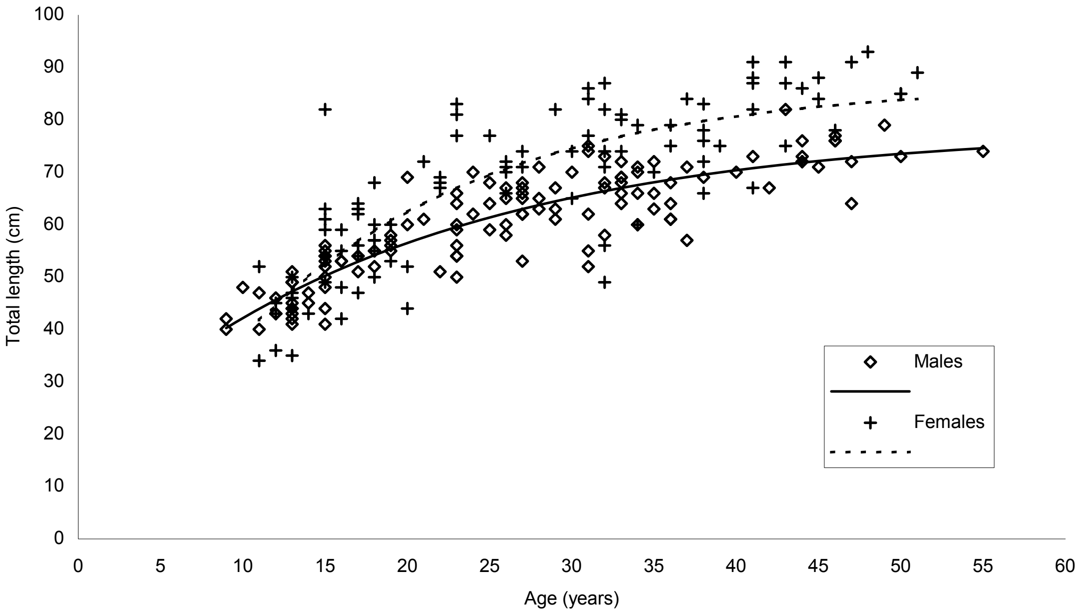

Figure 2: Raw age data and von Bertalanffy curves, separately by sex, for *Macrourus whitsoni*.

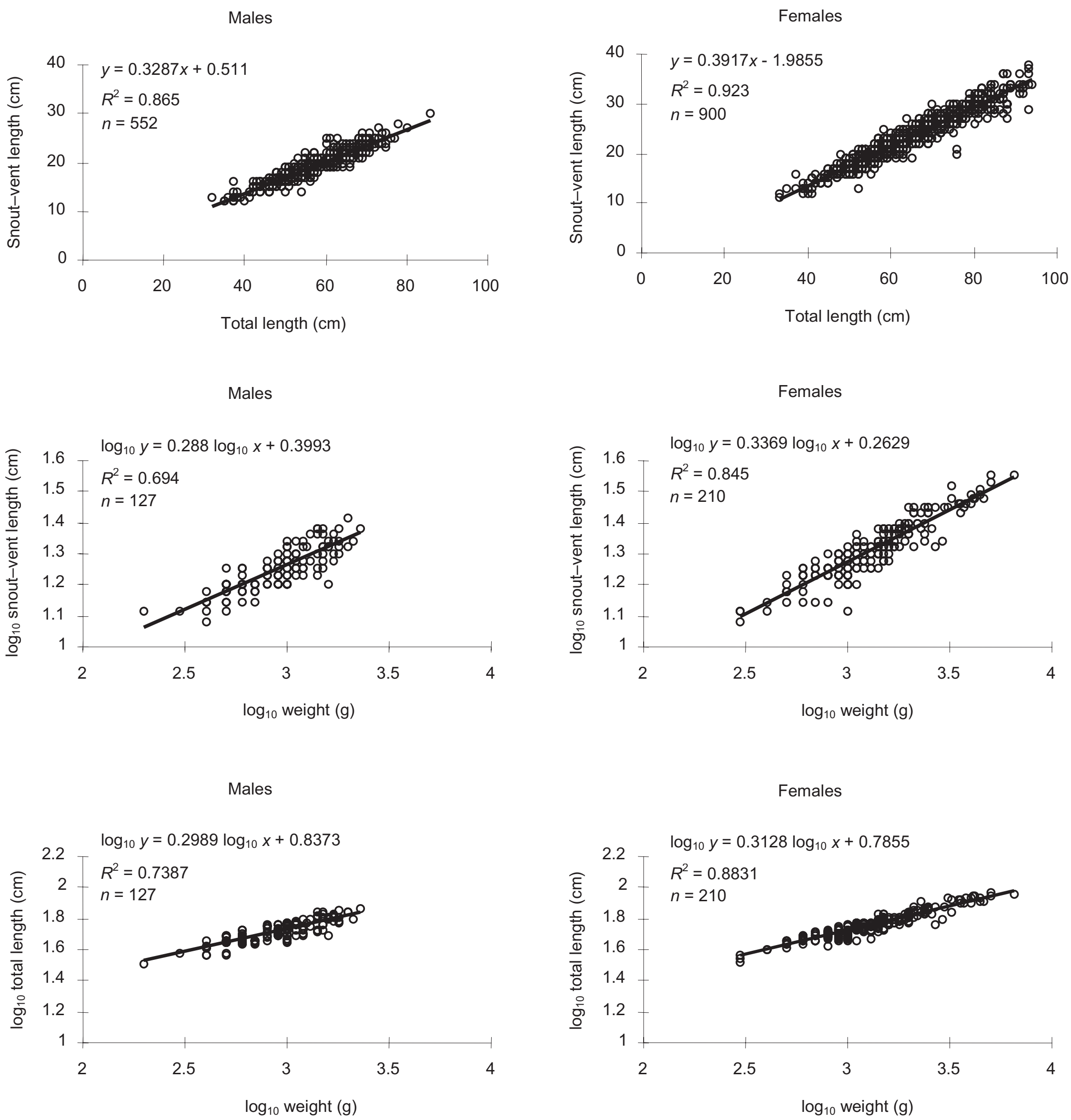

Figure 3: Snout–vent length, total length and weight relationships for male and female *Macrourus whitsoni*, with fitted linear regressions.

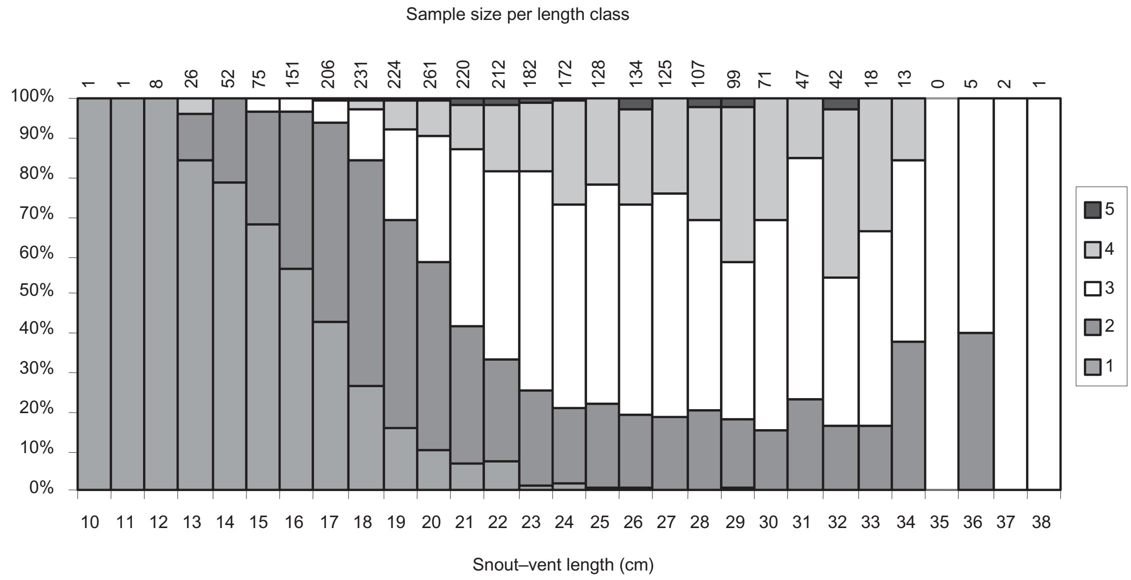

Figure 4: Females – plot of gonad stage of maturity versus snout–vent length. Stage 1 is immature, stage 2 is maturing.

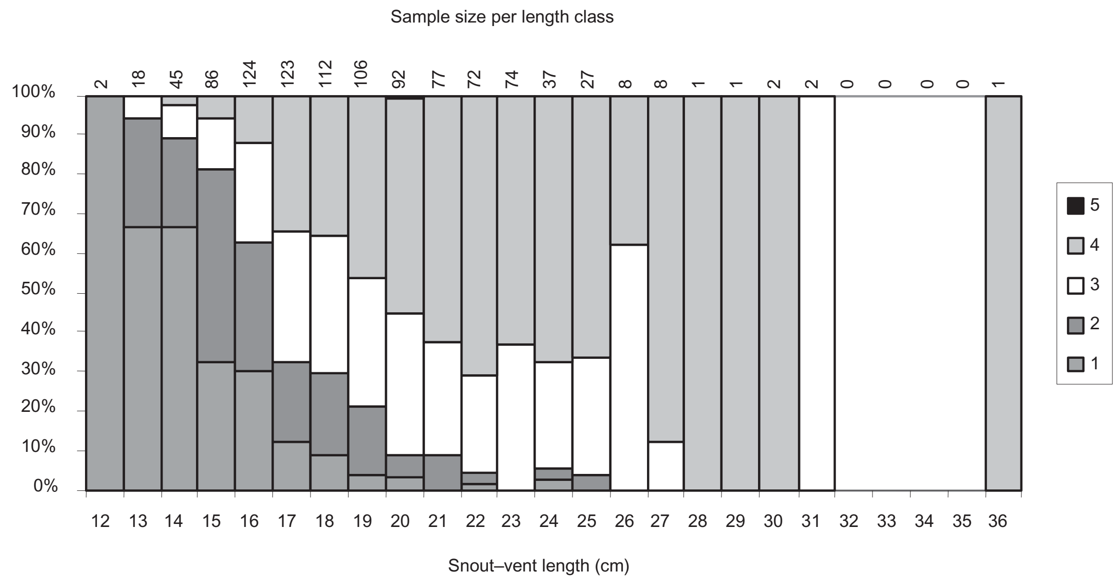

Figure 5: Males – plot of gonad stage of maturity versus snout–vent length. Stage 1 is immature, stage 2 is maturing.

only occurred north of 65ºS, and comprised only about 2.5% of the samples returned. The fish aged in the 1999 sample were all from south of 71ºS. At 71.28ºS, Cape Adare is the northwestern limit of the Ross Sea proper. Within the confining landmasses of the Ross Sea, only *M. whitsoni* were found in our samples. This is 6º of latitude further south than any known *M. holotrachys* specimens.

Visually, the known *M. whitsoni* otoliths from the 2002 samples were indistinguishable from the 1999 samples that had been assumed to be *M. whitsoni*. Both samples displayed a reasonably high degree of polymorphism in their otolith structure. The *M. holotrachys* otoliths from the 2002 samples appeared to be subtly different from the *M. whitsoni* otoliths in their general form and in their edge morphology, which tends to be more irregular and have larger and more numerous projections. Separating the two species solely on visual inspection of the otoliths was not reliable. Plots of the otolith morphometrics of the two macrourid species displayed overlapping ranges (Marriott and McMillan, 2002), so it was not possible to separate the two species on the basis of their otolith morphology.

Given the geographical location of the samples provided, it seems highly probable that all of the specimens aged from the 1999 sample were *M. whitsoni*. Therefore the provisional age estimates generated from the 1999 sample should be considered as valid for *M. whitsoni*.

For ageing, the use of baked cross-sectioned otoliths appeared to produce acceptable results with ages being confidently (±2 years) attributed by the primary reader to 213 of the 300 otoliths prepared. Ages estimated for this sample ranged from 9 to 55 years. *M. whitsoni* otoliths can, on occasion, exhibit mineral resorption and regions of irregular growth: this accounted for a substantial proportion of the unreadable otoliths. A recent review on age determination of deep-water fishes (Bergstad, 1995) concluded that for long-lived species, techniques using sectioned otoliths were the most reliable.

The first zone proved to be quite variable in width. This is most likely due to an extended spawning period. This has been exhibited in *M. whitsoni* and other macrourids such as *M. carinatus* and *Caelorinchus fasciatus* (Alekseyeva et al., 1993). This added to the difficulties in interpreting the juvenile regions of the otolith.

A change in the zone pattern (i.e. a transition zone) was observed in most otoliths at approximately zone 10. Similar transition zones have been reported (Morales-Nin, 2001) in *Coryphaenoides rupestris* at around zones 10 to 12 (Bergstad, 1995) and at around zone 20 (Kelly et al., 1997). This transition zone is probably indicative of some change in life history. For *M. whitsoni*, it could signify the initial onset of maturity; age at 50% maturity for this species was estimated as 12 and 14 years for males and females respectively. However, it could also be associated with some change in habitat or feeding. The reason for the transition zone is therefore currently uncertain.

Related macrourid species from the Northern Hemisphere have been studied and zone-count age estimates similar to those produced here for *M. whitsoni* were obtained. *C. rupestris* off the coast of Norway were aged to about 70 years (Bergstad, 1995), to 60 years (Kelly et al., 1997) and to 46 years by Lorance et al. (2001). Two smaller species, *Nezumia sclerorhynchus* (maximum snout–vent length 7.3 cm) and *Caelorinchus caelorinchus* (maximum snout–vent length 10.6 cm), were aged to a maximum of 10 and 11 years respectively (Labropoulou and Papaconstantinou, 2000). Small otoliths were read whole and larger specimens were hand polished to the primordium.

It was not possible to validate the ageing technique developed during this study, due in part to the absence of fish less than 9 years old and the fact that the samples were not representative of the whole of the year. Consequently, the data and von Bertalanffy growth parameters presented in this work must be considered preliminary.

Samples of young fish will need to be obtained for accurate future validation of the reading technique, either as large annual samples for tracking length–modal progression of strong year classes or smaller intra-annual samples for marginal increment analysis. Length–modal progression is not practical, as the required representative juvenile samples are unlikely to be obtained with current fishing practices. Marginal increment analysis has been used to validate ages in other species of the Macrouridae (Bergstad, 1995; Gordon and Swan, 1996; Labropoulou and Papaconstantinou, 2000; Merrett and Haedrich, 1997; Morales-Nin, 2001; Swan and Gordon, 2001), with some researchers noting that the marginal state of an otolith can only be accurately assessed in juvenile fish (Bergstad, 1995; Swan and Gordon, 2001; Morales-Nin, 2001). Due to sea-ice formation, the Ross Sea is inaccessible for much of the year, which would effectively preclude the collection of samples throughout a year for marginal increment analysis. It may be possible to obtain *M. whitsoni* specimens from north of the Ross Sea and its winter sea-ice for a series of intra-year samples.

Validation of the reading technique could be performed on the extant specimen sets by employing radiometric ion disequilibria techniques (Andrews et al., 1999; Bergstad, 1995; Campana, 1999) or bomb radiation techniques (Kalish, 1995; Campana, 1997) to attribute an age range to individual fish. The ion disequilibria technique can be used to generally validate an interpretation protocol, the bomb radiation technique can validate the age of a fish to within three years given the right circumstances. Due to the imprecise nature of the techniques (Swan and Gordon, 2001), it cannot accurately validate the protocols employed to interpret key localised regions of an otolith such as the inner juvenile zones.

The Pacific grenadier (*Coryphaenoides acrolepis*) from the northern Pacific has been aged to 73 years (Andrews et al., 1999) from thin otolith sections of fish approximately 70 cm in total length. Radioactive disequilibria of ^{210}Pb and ^{226}Ra from the otolith cores was used to validate their age estimates and good correlation up to the 46–56 age group was achieved. There were insufficient specimens to extend their validation work to older age classes.

The longline fishery catches few fish younger than 10 years old. Geographic segregation of a fish stock has been noted in other macrourids (Merrett and Marshall, 1981; Merrett and Haedrich, 1997), commonly referred to as a bigger–deeper trend, so poorly represented size classes in our samples may not be present in the commercially fished areas. However evidence suggests that *C. rupestris* adopts a benthopelagic lifestyle after its first year in the Skagerrak Sea and juveniles are most abundant in the Rockall Trough at around 1 000 m (Gordon and Swan, 1996), so it is more likely in the Ross Sea toothfish fishery that hook selectivity precludes the capture of small fish.

M. whitsoni appears to be a relatively slow-growing species, as are many of the deep demersal fishes (Haedrich, 1997). It is apparent that females reach a greater length and have a faster growth rate than males, as is the case for many teleost species. All otoliths were derived from the longline fishery, which catches few small fish. Consequently, fish 10 years or younger were largely missing from the length-at-age data, so the von Bertalanffy curves will be poorly defined for these ages. This accounts for the generally unsatisfactory t_0 values.

The regression lines relating total and snout–vent length, and weight to length, fitted the raw data well. The significant differences between the male and female lines imply that a degree of sexual dimorphism exists. The use of separate sex regression functions should therefore be maintained in any future conversions.

The long whip-like tails of many macrourids are prone to truncation either prior to, or at, capture, so an alternative standardised measurement system is necessary for accurate length measurements. The snout–vent length was used as this is unambiguous and measures a larger proportion of the total length than methods utilised by other researchers, such as head length (Merrett and Marshall, 1981), to increase the accuracy of extrapolated total lengths.

The estimated mean lengths at maturity were 46 cm total length (15 cm snout–vent length) for males and 50 cm total length (17 cm snout–vent length) for females. The mean ages at maturity were 12 years for males and 14 years for females. These are comparable to the 11.5 cm mean pre-anal length and 14 years mean age at maturity as derived by Allain (2001) in his studies on *C. rupestris* west of the British Isles. In *C. rupestris*, a pre-anal length of 13 cm ≈ 50 cm total length (Gordon and Hunter, 1994, in Allain, 2001). Kelly et al. (1997) estimated 10 cm (males) and 12 cm (females) pre-anal length at maturity for *C. rupestris* in the Rockall Trough.

The estimated mean lengths at maturity show that *M. whitsoni* is vulnerable to the commercial longline fishery prior to their becoming sexually mature. Approximately 3.3% of males and 7.5% of females were sexually immature. The age of maturity indicates that males start to become vulnerable to commercial longlining practices for about three years prior to reaching the mean age at maturity; females are vulnerable for about five years. The high ages at maturity suggest that stocks would take a significant time to recover naturally from large biomass reductions. The stock structure and biomass for this species in the Ross Sea is unknown so it is not possible to comment on the potential impact of the current fishing practices in this region.

CONCLUSIONS

Uncertainty in the identification of species of the genus *Macrourus* from the Ross Sea has now been resolved. In the Ross Sea south of the 65ºS latitude, only *M. whitsoni* were found in the samples studied here. All otoliths used for ageing were from south of 70ºS and this, along with the otolith morphology, confirms that the previously aged sample from 1999 was *M. whitsoni.*

Age and growth analysis of *M. whitsoni* was successfully completed. Unvalidated age estimates were generated from counts of translucent zones in cross-sectioned otoliths. The species appears to be long lived and slow growing, living to at least 50 years. Females grow at a faster rate, and reach a larger size, than males, but both sexes exhibit comparable maximum ages. Mean total lengths at maturity were estimated to be 46 cm (15 cm snout–vent length) for males, and 50 cm (17 cm snout–vent length) for females. This indicates that *M. whitsoni* is vulnerable to current commercial fishing practices prior to maturation. The age and growth estimates must be considered preliminary in nature as the ageing methodology has yet to be validated.

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