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BIOLOGICAL PARAMETERS FOR ICEFISH (*CHIONOBATHYSCUS DEWITTI*) IN THE ROSS SEA, ANTARCTICA

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Abstract

Icefish (Channichthyidae) specimens were randomly collected by observers during the 2005/06 fishing season. These observers were placed on board three longline vessels targeting Antarctic toothfish (*Dissostichus mawsoni*) in the Ross Sea (CCAMLR Subareas 88.1 and 88.2). Biological data from 303 specimens were collected. These data included species identification, fish length, weight, sex, meristics, reproductive biology, diet and age estimation. All of the icefish sampled were identified as *Chionobathyscus dewitti*, and showed no significant difference in sex ratio. Meristic, diet and age data were consistent with previous research.

Regression equations for converting standard length to total length and for defining length–weight relationships were calculated and presented for both male and female fish. Gonad maturity stage data showed that most fish were either immature or resting (mature). Gonadosomatic indices (GSIs) were calculated and plotted against sample month. There was a weak positive trend in GSI between December and February, but this was limited, probably due to the short temporal distribution of the data. Length-at-maturity and age-at-maturity ogives indicated that 50% of the fish sampled were mature at about 340–360 mm total length (TL) and about 3–4 years of age, and that 95% were mature at about 370–400 mm TL and 6–8 years of age.

Counts of growth zones in sectioned otoliths were used to determine ages and von Bertalanffy growth parameters. Fish growth was rapid for both sexes, and females approached a significantly larger mean asymptotic maximum size than males. Maximum ages of 8 and 11 years were obtained for male and female fish respectively.

Diet analysis showed most icefish stomachs were empty and the few prey items recovered were generally in advanced stages of digestion. This may be due to regurgitation of prey during capture.

Résumé

Pendant la saison de pêche 2005/06, les observateurs ont collecté au hasard des spécimens de poisson des glaces (Channichthyidae). Ces observateurs avaient été placés à bord de trois palangriers visant la légine antarctique (*Dissostichus mawsoni*) dans la mer de Ross (sous-zones 88.1 et 88.2 de la CCAMLR). Des données biologiques de 303 spécimens ont été recueillies, entre autres, l'identification de l'espèce, la longueur, le poids, le sexe, la méristique, la biologie reproductive, le régime alimentaire et l'estimation de l'âge des poissons. Tous les poissons échantillonnés ont été identifiés comme étant des *Chionobathyscus dewitti*, et n'ont montré aucune différence significative de sex ratio. Les données méristiques, de régime alimentaire et d'âge correspondent aux recherches précédentes.

On a calculé et présenté, pour les poissons tant mâles que femelles, des équations de régression pour convertir la longueur standard en longueur totale et pour définir la relation longueur–poids. Les données sur le stade de maturité des gonades indiquent que la plupart des poissons étaient soit immatures soit en récupération (matures). Les indices gonado-somatiques (GSI) ont été calculés et représentés graphiquement en fonction du mois d'échantillonnage. Une tendance légèrement positive apparaît dans les GSI entre décembre et février, mais elle est limitée, probablement en raison de la courte distribution temporelle des données. Les ogives de maturité par longueur et par âge indiquent que 50% des poissons échantillonnés étaient matures à environ 340–360 mm de longueur totale (LT) et à environ 3–4 ans d'âge, et que 95% l'étaient à environ 370–400 mm de LT et à 6–8 ans d'âge.

Le comptage des zones de croissance des otolithes sectionnées a permis de déterminer l'âge et les paramètres de croissance de von Bertalanffy. La croissance a été rapide pour les deux sexes ; la taille des femelles était proche d'une taille asymptotique maximale moyenne nettement plus importante que celle des mâles. L'âge maximal de 8 ans pour les mâles et de 11 ans pour les femelles a été obtenu.

L'analyse du régime alimentaire a indiqué que l'estomac de la plupart des poissons était vide et que les quelques éléments de proie récupérés étaient généralement en état de digestion avancé. Ceci peut s'expliquer par une régurgitation des proies lors de la capture.

Резюме

Особи ледяной рыбы (Channichthyidae) случайным образом отбирались наблюдателями в промысловом сезоне 2005/06 г. Эти наблюдатели находились на борту трех ярусоловов, ведущих направленный промысел антарктического клыкача (*Dissostichus mawsoni*) в море Росса (подрайоны АНТКОМа 88.1 и 88.2). По 303 особям были собраны биологические данные, такие как вид, длина, вес, пол, меристические признаки, репродуктивная биология, рацион и оценка возраста особей. Вся отобранная ледяная рыба была идентифицирована как *Chionobathyscus dewitti* и не имела большой разницы в соотношении полов. Меристические данные, рацион и оценка возраста соответствовали предыдущим исследованиям.

Уравнение регрессии для пересчета стандартной длины в общую длину и определения зависимостей длина–вес было рассчитано и представлено и для самцов, и для самок. Данные о стадиях зрелости гонад показали, что большинство особей рыбы были неполовозрелыми или в состоянии покоя (половозрелыми). Были рассчитаны гонадосоматические индексы (ГСИ) и построен их график по месяцам проведения выборки. Наблюдалась слабая положительная тенденция в ГСИ с декабря по февраль, но она была ограничена, возможно, из-за недостаточно продолжительного распределения данных по времени. Огивы длины при половозрелости и возраста при половозрелости свидетельствуют о том, что 50% отобранной рыбы были половозрелыми при общей длине (ОД) около 340–360 мм и в возрасте примерно 3–4 года, и что 95% были половозрелыми при ОД около 370–400 мм и в возрасте 6–8 лет.

Подсчет зон роста по шлифам отолитов использовался для определения возраста и параметров роста Берталанфи. Рост рыбы был быстрым у обоих полов, и самки достигали значительно бóльшего асимптотического среднего значения максимального размера, чем самцы. Максимальный возраст, полученный для самцов и самок рыбы, составил соответственно 8 и 11 лет.

Анализ рациона показал, что в большинстве случаев желудки ледяной рыбы были пустыми и та немногочисленная добыча, что была найдена, была в значительной степени переварена. Это может быть связано с отрыгиванием добычи во время поимки.

Resumen

Ejemplares de dracos (Channichthyidae) fueron recogidos aleatoriamente por los observadores durante la temporada de pesca de 2005/06. Estos observadores fueron asignados a bordo de tres barcos palangreros dedicados a la pesca de austromerluza antártica (*Dissostichus mawsoni*) en el Mar de Ross (Subáreas 88.1 y 88.2 de la CCRVMA). Se recopilaron datos biológicos de 303 ejemplares. Estos datos incluyeron: identificación de especies, talla, peso, sexo, caracteres merísticos, biología reproductiva, dieta y estimación de la edad. Todos los dracos muestreados fueron identificados como *Chionobathyscus dewitti*, y no hubo diferencias significativas en la proporción de sexos. Los datos merísticos, de la dieta y de la edad fueron congruentes con los estudios previos.

Se calcularon las ecuaciones de regresión para la conversión de la longitud estándar a longitud total y para la definición de la relación talla-peso, para los peces macho y hembra. Los datos sobre el estado de madurez gonadal mostraron que la mayoría de los peces se encontraban en estado inmaduro o descansando (maduros). Se calcularon los índices gonadosomáticos (GSI) y se graficaron en función del mes en que se efectuó el muestreo. Se detectó una ligera tendencia positiva en el GSI de diciembre a febrero, aunque limitada, debido probablemente a la corta distribución temporal de los datos. Las ojivas de talla de madurez y edad de madurez indicaron que el 50% de los peces muestreados maduraron alrededor de 340–360 mm de longitud total (TL) y a los 3–4 años de edad, y un 95% había madurado alrededor de los 370–400 mm TL y a los 6–8 años de edad.

El número de anillos de crecimiento en secciones de otolitos fue utilizado para determinar la edad y los parámetros de crecimiento de von Bertalanffy. Los peces de ambos sexos crecieron rápidamente, y las hembras alcanzaron una talla promedio máxima asintótica significativamente mayor que la de los machos. Las edades máximas obtenidas para los peces macho fue de 8 años, y 11 años para los peces hembra.

El análisis de la dieta de los dracos mostró que la mayoría de los estómagos estaba vacío y los pocos pedazos de presas recuperados por lo general se encontraron en avanzado estado de digestión. Esto puede deberse a la regurgitación de la presa durante la captura.

Keywords: Antarctic toothfish, biology, *Chionobathyscus dewitti*, Ross Sea, CCAMLR

Introduction

There are about 15 species of icefish (Channichthyidae), all but one of which are found in the Southern Ocean (Kock, 2005a, 2005b). They possess adaptations suited to the extreme environmental conditions of this region, including little or no haemoglobin in their blood (Ruud, 1954). This has enabled them to evolve compensatory adaptations that reduce oxygen demand, maintain metabolic function and enhance oxygen delivery (Kock, 2005b). Some icefish, in particular mackerel icefish (*Champsocephalus gunnari*), are either the target of commercial fishing operations or a by-catch of fisheries targeting species such as krill (Everson et al., 1992). Other species, including *Chionobathyscus dewitti* (Figure 1), are caught as by-catch of fisheries targeting Antarctic toothfish (*Dissostichus mawsoni*).

Limited previous work has been undertaken on *C. dewitti*. Iwami and Kock (1990) presented meristic and morphometric data on the species. Balushkin (1997) investigated the taxonomic relationships between Antarctic icefish (Channichthyidae), including *C. dewitti*, by measuring the relative positions of dorsal and anal fins in relation to vertebrae. Takahashi and Iwami (1997) investigated the diet of demersal fish (including icefish) sampled from around the South Shetland Islands. However, they only examined stomachs from eight *C. dewitti* specimens. Pshenichnov (2004) provided preliminary data on *C. dewitti* biology (based on fish sampled from the Ross Sea toothfish longline fishery). Kock (2005a, 2005b) reviewed Antarctic icefish (Channichthyidae), but presented little information on *C. dewitti*. Balushkin and Prutko (2006) presented morphological characters along with general biological information on the species, including data on length and reproduction. Kock et al. (2006) documented evidence for egg brooding and parental care in icefish and other notothenioids.

Ross Sea toothfish fishery

Toothfish (*Dissostichus* spp., Notothenidae) are the major finfish resource exploited in Antarctic waters, with 16 843 tonnes being caught during the 2005/06 fishing season (CCAMLR, 2008). They are managed by CCAMLR and the New Zealand Government approves permits for New Zealand companies to fish in the Ross Sea region (CCAMLR Subareas 88.1 and 88.2) (Figure 2). The fishery (in Subarea 88.1 and Subarea 88.2 small-scale research units (SSRUs) A and B) has increased significantly from <1 tonne in 1996/97 to 2 963 tonnes in 2005/06 (Hanchet et al., 2006). A characterisation of the fishery from 1997/98 to 2005/06 is provided by Hanchet et al. (2006).

CCAMLR has recommended that a number of research activities be undertaken by Member countries to support the sustainable development and management of toothfish fisheries within its jurisdiction. These activities focus on the provision of accurate catch and effort data, target and non-target species biology, fishery–ecosystem interactions and estimation of the productivity and abundance of target and by-catch species.

Aim of this study

Although icefish by-catch in the Ross Sea toothfish fishery is limited (<1% of the total catch during the 2005/06 season) (Hanchet et al., 2006), very little is known about their species composition or biology. Eight species of icefish have been reported caught in the fishery in the CCAMLR vessel logbook (C2) data (Hanchet et al., 2005), but it is likely that many of these are cases of misidentification. This view is supported by the fact that most of these data were recorded using a generic icefish species code. Prutko and Lisovenko (2004) believed that the main species caught is *C. dewitti*, but this needed confirmation. The aim of this study was to test this view by collecting a random sample of two icefish from each New Zealand longline set during the 2005/06 fishing season. An additional aim was to provide further information on icefish biology.

The findings in this study are compared with previous research (Pshenichnov, 2004; Kock, 2005a, 2005b; Balushkin and Prutko, 2006; Kock et al., 2006).

Methods

Data collection

During the 2005/06 toothfish season, observers on board three New Zealand-flagged longline vessels operating in the Ross Sea were requested to randomly collect the first two icefish specimens (Channichthyidae) from each set. A summary of vessel fishing effort and the amount of icefish by-catch is provided in Table 1.

Approximately 350 icefish specimens were collected and returned to NIWA, Wellington, for identification, data collection and analysis. This number represented less than two per set as icefish were not caught on every line. Based on instruction from the New Zealand Ministry of Fisheries, 303 fish were then randomly sub-sampled. This involved thawing the specimens and identifying them to species level. The taxonomic key and species descriptions in Iwami and Kock (1990) were the main resources used for identification.

Biological data (including total length (TL), standard length (SL), sex and weight) were recorded. These data were used to calculate selected biological parameters, including length-at-weight and length-at-maturity. Meristic data were also collected to assist with identification, and included: first and second dorsal fin ray counts, anal fin ray counts, the distance between the first and second dorsal fin bases, pelvic fin length and head length. A macroscopic gonad maturity score (Table 2) and gonad weight were recorded to investigate the onset of spawning and sexual maturity. Stomachs were ligated and removed intact for diet analysis. Stomach weight and fullness were also recorded. The sagittal otoliths were extracted from each specimen, cleaned and stored dry in paper envelopes for further analysis.

Five voucher specimens were lodged in the Museum of New Zealand Te Papa Tongarewa fish collection (NMNZ P.41205 and NMNZ P.42294). Muscle biopsies were collected from each specimen for DNA sequencing as part of the Fish Barcode of Life (FISH-BOL) initiative (www.fishbol.org).

Length and weight data

Standard length to total length conversion

Where possible both SL and TL were recorded. Total length (measured to the nearest whole millimetre below actual length) was used in the analysis as this measurement more readily enables comparison with other icefish research (Pshenichnov, 2004; Kock, 2005a, 2005b). Total length could not be directly recorded for some fish due to loss or damage of the caudal fin. A linear regression model relating standard to total length was fitted. The regression model was:

$$L_{j,x,\mathrm{TL}} = \beta_x L_{j,x,\mathrm{SL}} + \alpha_x + \varepsilon_{j,x} \qquad (1)$$

where

$L_{j,x,\mathrm{TL}}$ = the total length of the *j*th fish of sex *x*

$L_{j,x,\mathrm{SL}}$ = standard length of the *j*th fish of sex *x*

α_x and β_x = the regression model parameters for sex *x*

$\varepsilon_{j,x}$ = independent, identically-distributed normal errors with mean zero and variance, σ^2.

The model was fitted separately for male and female fish and then for both sexes combined. This was achieved using the linear regression model-fitting algorithm, lm, in the R statistical programming language (R Development Core Team, 2006). Relative goodness of fit to the data was compared using Analysis of Variance (ANOVA) and two information criterion statistics, i.e. Akaike's

Information Criterion (AIC) (Akaike, 1973) and the Bayesian Information Criterion (BIC) (Schwarz, 1978). These criterion statistics are similar in that a penalty term is applied to each model's maximum log-likelihood, i.e. [$\mathrm{AIC} = -2\ln(L) + 2k$ and $\mathrm{BIC} = -2\ln(L) + k\ln(n)$],

where

L = the maximum likelihood
k = the number of parameters
n = the sample size.

Note: The derivations and the penalties applied differ for each criterion statistic. The BIC imposes a larger penalty than the AIC when n is greater than exp(2) and tends to favour more parsimonious models than the AIC for most datasets, i.e. those where $n > \exp(2)$.

Length-at-weight

Length-at-weight relationships were calculated using the equation $W = \alpha L^{\beta}$, assuming lognormal errors. Under these assumptions, $W_{j,x}$ the weight of the jth fish of sex x at length $L_{j,x}$ is

$$W_{j,x} = \alpha_x L_{j,x}^{\beta_x} e^{e_{j,x}} \qquad (2).$$

A geometric regression was fitted to the data using a linear regression of the logged fish lengths and weights, and applying the equation: $\ln W_{j,x} = \ln \alpha_x + \beta_x \ln L_{j,x} + \varepsilon_{j,x}$. This process assumes the same (α, β) parameters for all fish in the dataset, before refitting separate parameters for each sex. The linear regression model-fitting algorithm, lm, in the R statistical programming language was used to fit both models (R Development Core Team, 2006). The relative goodness of fit of the models was compared using ANOVA, AIC and BIC comparisons.

Reproductive biology

Reproductive stage and gonadosomatic indices

Gonads were examined macroscopically and a generalised five-point maturity score was assigned (Table 2).

The purpose of this work was to assess the reproductive stage of sampled fish. Icefish species are reported to spawn during late summer–autumn (Kock and Kellermann, 1991; Kock, 2005a, 2005b; Kock et al., 2006), so fish were considered to be mature if the gonad maturity stage was 2 or greater.

Gonadosomatic indices (GSIs) were derived by dividing gonad weight (in grams) by fish weight (in grams). This calculation is more accurately obtained by using gutted fish weight, however, this proved to be unnecessary due to the high proportion of fish with empty stomachs. The GSI was plotted against time to assess the degree of gonad development throughout the sampling period.

Length- and age-at-maturity

Length-at-maturity and age-at-maturity ogives were fitted to the data using logistic probit models (Pearson and Hartley, 1962). These models were fitted using a generalised linear model (GLM) (McCullagh and Nelder, 1989). This was achieved by fitting an algorithm in the R statistical programming language (R Development Core Team, 2006). The logistic regression model was fitted assuming independent, identically distributed binomial errors with a logit link function to the linear predictor. The probit model was fitted assuming binomial errors and a probit link to the linear predictor. The models were fitted separately for male and female fish and for both sexes combined. The relative goodness of fit of the models was compared using ANOVA, AIC and BIC comparisons.

$L_{50,x}$, $L_{95,x}$, $a_{50,x}$, and $a_{95,x}$, the length and age at which 50% and 95% of icefish of sex x are estimated to be mature, were obtained from the model fits as described in Venables and Ripley (2002).

Diet analysis

The stomachs of 281 icefish were removed and graded according to fullness and digestive state (Hanchet et al., 2006). Stomach fullness was graded using a four-point scale: empty, trace, part full and full. Digestive state was graded using a five-point scale: fresh, slightly digested, advanced digestion, digested and mixed stages. Individual food items were counted, weighed and identified to their lowest possible taxonomic level. Parasites (nematodes and trematodes) and bait were excluded from the dataset.

Additional analysis was not undertaken, due to the small number of prey items present.

Age and growth

Otolith preparation and interpretation

Icefish otoliths were collected from 138 males, 145 females and 13 unsexed fish. Seven otoliths were badly decalcified and deemed unsuitable for preparation. Investigation showed that the bake and embed method (Horn, 2002; Marriott et al., 2003) was inappropriate for this species. This was because reflected light is required when examining otoliths prepared using this method, and this form of lighting did not adequately illuminate the zones. Therefore, otoliths were prepared for reading using a thin-sectioning technique. They were transversely aligned in rows of four before being embedded in clear epoxy resin (Araldite K142) and left to cure at 50°C for 24 hours. Once cured, the blocks were transversely cut along the nuclear plane using a diamond-edged saw. One half of the sectioned block was mounted (otolith section down) onto a microscope slide using clear epoxy resin. Preparations were left to cure at 50°C for 24 hours. A 1 200 µm diamond-coated disc was used to grind the upper surface of each mounted, sectioned block to a thickness of about 300 µm.

Otolith sections were examined under a stereo microscope (x32) illuminated by transmitted light. A pattern of translucent and opaque zones was evident with the number of complete opaque zones interpreted as annuli. A three-point ‘margin-state’ score and a five-point ‘readability’ score were recorded for each otolith reading (Table 3).

Age estimation

Zone counts were converted to age estimates using an algorithm that sums three time components. The equation used to estimate the age of the ith fish, $\hat{a}_i$ is:

$$\hat{a}_i = t_{i,1} + t_{i,2} + t_{i,3} \tag{3}$$

where

$t_{i,1}$ = the time elapsed from spawning to completion of the first opaque zone;

$t_{i,2}$ = the time elapsed from completion of the first opaque zone to completion of the outermost opaque zone;

$t_{i,3}$ = the time elapsed from completion of the outermost opaque zone to the date when the ith fish was captured.

Hence,

$$\begin{aligned} t_{i,1} &= t_{i,\text{ end first opaque zone}} - t_{i,\text{ spawning date}} \\ t_{i,2} &= (n_i + w) - 1 \\ t_{i,3} &= t_{i,\text{ capture}} - t_{i,\text{ end last opaque zone}} \end{aligned} \tag{4}$$

where

n_i = the total number of opaque zones present for fish i;

w = an edge interpretation correction after Francis et al. (1992) applied to n_i.

Note: $w = 1$ if the recorded margin state = ‘wide’ and fish i was collected *after* the date when opaque zones are assumed to be completed; $w = -1$ if the recorded margin state = ‘narrow’ and fish i was collected *before* the date when opaque zones are assumed to be completed; $w = 0$ for all other cases.

An opaque zone completion date of 1 December and a spawning date of 1 February were used for all fish. This spawning date coincides roughly with the midpoint of the range given in Kock (2005a) (January–April). All of the fish examined in this study were collected between December 2005 and February 2006, with the majority (83%) being collected in January 2006. Otoliths collected from most of the calendar year were therefore lacking, so it was not possible to investigate the timing of opaque and translucent zone formation with precision. The date of capture was recorded as the start date of each longline set.

Mean length-at-age

The re-parameterised von Bertalanffy submodel obtained from the generalised Schnute (1981) mean length-at-age model was fitted to the data. This assumes the Schnute model parameter, γ, in the first of the four solutions, to be equal to one. This parameterisation of the von Bertalanffy model lacks an explicitly parameterised asymptote and therefore, arguably, has better statistical properties than von Bertalanffy’s (1938) original parameterisation. Under this model, the mean length, L_j, of the jth fish in a group of fish is:

$$L_j = \left\{ L_1 + (L_2 - L_1) \frac{1-\exp\left[-\kappa\left(t_j - \tau_1\right)\right]}{1-\exp\left[-\kappa\left(\tau_2 - \tau_1\right)\right]} \right\};\ \kappa \neq 0 \tag{5}$$

where

L_1 and L_2 = mean lengths at two reference ages
τ_1 and τ_2 = reference ages
κ = rate parameter
t_j = fish age.

Maximum-likelihood methods were used to fit the model. Four different models with different error types and structural assumptions were fitted. Initially, the model was fitted assuming independent, identically distributed, normal errors parameterised with a constant variance, σ^2. The same model parameters (L_1, L_2 and κ) and a single variance parameter were assumed for all fish in the dataset, and reference ages of $\tau_1 = 2$ and $\tau_2 = 8$ were used. The model was then refitted assuming lognormal errors, the same model parameters and reference ages, and a single variance parameter (of the logs). Following this, the model was refitted assuming normal errors parameterised with a constant coefficient of variation (CV), *c*, as well as the same model parameters, reference ages, and *c* for all fish. The optim function minimiser implemented in the R language (R Development Core Team, 2006) was used to fit the models by directly minimising the negative of each joint log-likelihood function. The likelihood functions are given in Manning and Sutton (2007).

One model was selected (from the four tested) based on the appearance of diagnostic residual plots, AIC values and BIC values. This model was refitted assuming separate parameters for each sex. The relative goodness of fit of this model and the corresponding model with the same error structure (that did not assume separate parameters by sex) were then compared using the likelihood-ratio test and the model AIC and BIC statistic values. This tested whether there is any difference in growth (mean length-at-age) between the sexes. The null hypothesis for the likelihood ratio test was that the full and reduced models obeyed a set of constraints such that their parameters were equivalent. The alternative hypothesis was that they did not obey these constraints.

Reader error

Reader error was investigated using a between-reader comparison test after Campaña et al. (1995). A sample of 114 otoliths was selected from the set of all prepared otoliths and read by a second reader. These results were then compared with the readings of the primary reader. Between-reader bias was examined using reader bias plots. Reader precision was quantified by calculating the index of average percentage error (IAPE) (Beamish and Fournier, 1981), and mean CV (Chang, 1982). The equations used to make these calculations are:

$$\mathrm{IAPE} = 100 \times \frac{1}{N} \sum_{j=1}^{N} \left[\frac{1}{R} \sum_{i=1}^{R} \frac{\left| X_{ij} - X_j \right|}{X_j} \right] \qquad (6)$$

and

$$\text{mean CV} = 100 \times \frac{1}{N} \sum_{j=1}^{N} \left[\frac{\sqrt{\sum_{i=1}^{R} \frac{\left(X_{ij} - X_j \right)^2}{R-1}}}{X_j} \right] \qquad (7)$$

where

X_{ij} = the *i*th count of the *j*th otolith
R = the number of times each otolith is read
N = the number of otoliths read or re-read.

Results

Fish identification

The 303 icefish (138 males; 147 females; 18 unsexed) examined by NIWA staff were all identified as *C. dewitti*, and showed no significant difference in sex ratio. A summary of meristic and morphometric data gathered during species identification is provided in Table 4. These data are consistent with those presented by Iwami and Kock (1990).

Length and weight data

Standard length to total length conversion

A total of 250 fish were retained for this analysis. Unsexed fish and fish missing either SL or TL were omitted from the analysis. Three outlier values were also removed from the final dataset. Two models were fitted to the data and parameter estimates for these are presented in Table 5. Both the AIC and BIC statistics suggest that the full model (assuming separate parameters for each sex) provides a greater degree of relative fit, despite additional parameters. The results of an analysis of variance comparing the two models are consistent with this view: ($f_{\mathrm{df}=2} = 14.597$; $P(F_{\mathrm{DF}=2} > f_{\mathrm{DF}=2} \mid H_0) = 1.0220 \times 10^{-6}$). The data are plotted in Figure 3, with the fitted curves from the full model overlayed. The fitted curves from both the full and reduced models are similar.

Length-at-weight relationship

A total of 280 fish were retained for this analysis. Unsexed fish and fish missing either TL and SL or weight were omitted from the analysis. The relationship between length and weight produced *b* estimates of 3.85 for males and 3.27 for females respectively. This is consistent with Artigues et al. (2003) who calculated *b* estimates of 3.80 and 3.37

for males and females respectively. In all cases the differences between sexes are not statistically significant.

Parameter estimates from the two models fitted are given in Table 6. Both the AIC and BIC statistics show that the model which assumes the same parameters for all fish has the greatest relative fit to the data, despite having fewer parameters. The results of an analysis of variance comparing the two models are also consistent with these results: ($f_{\mathrm{df}=2} = 1.5551$; $\mathrm{P}(F_{\mathrm{DF}=2} > f_{\mathrm{DF}=2} \mid H_0) = 0.2130$). The data are plotted in Figure 4 with the fitted curves from the full model overlayed. The fitted curves from both the full and reduced models are very similar.

Reproductive biology

Reproductive stage and gonadosomatic indices

Macroscopic gonad maturity stages and gonad weights were collected for 295 and 293 fish respectively. Table 7 displays the numbers and proportions of fish at each maturity stage (standardised by month of collection). Most fish (58%) were either immature (stage 1), or in the early stages of gonad development (stage 2 = 26%). GSIs were calculated and ranged between 0.01–22.2%, averaging 1.53%. There is a very weak positive trend in GSI over time (Figure 5). This is supported by the following simple linear regression results: ($\hat{\alpha}_x = -2.34,\ \hat{\beta} = 0.09,\ R^2 = 0.05$). Balushkin and Prutko (2006) found similar results with most fish in pre-spawning condition. They calculated similar GSI values, which ranged from 7.0–23.9%.

Length and age-at-maturity

Unsexed fish and fish missing either TL and SL, or gonad maturity stage observations were omitted from the analysis. A total of 283 fish were retained for analysis. Parameter estimates from the maturity-at-length model fits are given in Table 8. Both the AIC and BIC statistics show that the combined sexes model has the best fit to the data, although the difference between models is negligable. Separate analyses of variance comparing the two logistic ($\mathrm{P}(\mathrm{X}_{\mathrm{DF}=2} > \chi_{\mathrm{DF}=2} \mid H_0) = 0.171$) and probit ($\mathrm{P}(\mathrm{X}_{\mathrm{DF}=2} > \chi_{\mathrm{DF}=2} \mid H_0) = 0.196$) models are consistent with this result. The predicted length-at-maturity (using probit analysis with separate sex parameters) is plotted in Figure 6.

The four age model fits provide conflicting results (Table 9). The AIC statistics suggest that the probit model which assumes separate parameters for males and females is the best fit, as it has the lowest AIC value. However, the BIC statistics suggest the logistic model (which assumes parameters for both sexes combined) has the best fit to the data, although the difference between AIC and BIC statistics is minor. This inconsistency is due to the different way that each statistic penalises the number of parameters in each model. Separately comparing the AIC and the BIC statistics across the models suggests that a probit curve is a better description of icefish maturity ogives, but the differences are small (differences in AIC for models 2–4 compared with model 1 range between <1% to 3%; differences in BIC range between <1% to about 1%). The results of analyses of variance comparing the two logistic ($\mathrm{P}(\mathrm{X}_{\mathrm{DF}=2} > \chi_{\mathrm{DF}=2} \mid H_0) = 0.015$) and probit ($\mathrm{P}(\mathrm{X}_{\mathrm{DF}=2} > \chi_{\mathrm{DF}=2} \mid H_0) = 0.007$) models suggest that significant differences exist between age-at-maturity for male and female fish.

The predicted age-at-maturity (using probit analysis with separate sex parameters) is plotted in Figure 7. The results show that 50% of *C. dewitti* mature at about 340–360 mm TL and 3–4 years of age, while 95% are mature at 370–400 mm TL and 6–8 years of age. Females appear to mature at a similar size but younger age than males.

Diet

A total of 270 (95%) of the stomachs examined were empty. The rest contained the remains of crustaceans, fish and squid (Table 10). All of the possible prey items were in advanced stages of digestion, except for two fish eggs.

One stomach contained a single eroded fish otolith, which was identified using the descriptions of Williams and McEldowney (1990), and is likely to be from a Whitson's grenadier (*Macrourus whitsoni*). The single fish eggs contained in four stomachs were relatively large (~4 mm) consistent in size and colour with those produced by *C. dewitti*. It is possible that they may have been accidentally ingested by the fish. Crustacean remains were in advanced stages of digestion and were difficult to positively identify. One upper squid beak (upper rostral length = 17.4 mm) was compared with reference material and is probably from *Kondakovia longimana*. A scavenging lysianassid amphipod, which is likely to have entered the icefish stomach after death, was omitted from the dataset. It is probable that water pressure created during longline retrieval forced this amphipod into the stomach.

Three stomachs containing bait (arrow squid and jack mackerel) were also excluded from the dataset.

Age and growth

Otolith interpretation

Figure 8 shows a prepared otolith that has been transversely sectioned.

Age estimation and mean length-at-age

A total of 296 icefish otoliths were read. Unsexed fish and fish missing TL were omitted from the analysis, which left 283 individuals. Four models were fitted to the age and length data and the results are given in Table 11. Three models were fitted to the data assuming the same von Bertalanffy parameters (L_1, L_2 and κ) for the two sexes in the dataset. These models differed in assuming either normal (constant σ^2), lognormal, or normal (constant c) errors (models 1, 2 and 3 respectively). The AIC and BIC statistics and diagnostic residual plots suggested that model 2 (i.e. the model assuming lognormal errors) had the best relative fit to the data. This model was then refitted to the data, assuming separate parameters by sex (model 4), to test for differences in mean length-at-age between the sexes. Comparing AIC and BIC statistics suggested that model 4 has the best relative fit, despite its extra parameters (Table 11).

This model showed that the fitted growth curves are very steep, with asymptote estimates about 1.5 times longer than the longest fish. Growth appears to be extremely rapid throughout the timeframe observed. This trend is evident for both sexes, but females approach a significantly larger mean asymptotic maximum size than males ($L_{\infty,M}$ = 420 mm; $L_{\infty,F}$ = 608 mm) (Figure 9). Differences in growth rate (k) were significant ($\kappa_M = 0.21$; $\kappa_F = 0.09$), with male fish growing more rapidly than females. Maximum ages of 8 and 11 years were obtained for male and female fish respectively.

Reader error

Both readers found *C. dewitti* otoliths difficult to interpret as sections were characterised by a high frequency of diffuse and/or 'false' opaque zones. Despite this, there was a high level of consistency between readers, which is shown by the symmetry in Figure 10(a); the clustering of points about the zero-line in Figure 10(b); the one-to-one line in Figure 10(c); and the relative stability of the CV and APE profiles in Figure 10(d). The slight negative weighting in Figures 10(a) and (b) suggests that there may be a slight tendency for the second reader to over-count relative to the first reader. Despite this finding, there was no significant systematic difference (bias) in annuli interpretation.

The mean CV and IAPE calculated for the between-reader comparison were 3.92% and 2.76% respectively.

Discussion

This study confirms that *C. dewitti* is the most common icefish species taken as by-catch in the Ross Sea longline fishery for toothfish. The meristic and morphometric data collected in the study are consistent with those presented by Iwami and Kock (1990) and Balushkin and Prutko (2006). The relationship between weight and length agrees with Artigues et al. (2003). Fish TL (260–460 mm) is similar to that reported in Pshenichnov (2004) (300–460 mm). There was no obvious difference in sex ratio, which contrasts with Pshenichnov (2004), where 80% of fish sampled were male. This is likely to be the result of differences in sampling area and/or depth and suggests that the species may at times be segregated by sex. A more detailed investigation of spatial trends in fish size and sex composition would be useful in the future when more data are available.

Macroscopic assessment of gonad maturity stages showed that most fish are either immature (stage 1) or resting (mature) (stage 2). Differentiating between these two stages was difficult, due to the small size and lack of observable features in the gonads. It is therefore probable that some gonads were classified incorrectly. This is likely to bias the length-at-maturity and age-at-maturity estimates, however, this bias could be reduced by microscopically examining the gonad samples. GSIs plotted against time showed a very weak positive (or increasing) trend from December to February as the austral summer progressed.

The gonad maturity stages observed in this study agree with Balushkin and Prutko (2006), but contrast with those outlined by Pshenichnov (2004) and Kock et al. (2006). These researchers reported that *C. dewitti* sampled from the Ross Sea spawn during the summer months. They observed spent females in early January and no females with maturing gonads after mid-February. It is unclear why this difference exists, although it could be due to geographical differences. It is also possible that the spawning season may change between successive years. This situation has been reported for *C. gunnari* occurring at South Georgia and Shag Rocks (Kock, 2005a).

Kock (2005a) reported that at least four icefish species are known to exhibit parental care, and that three species (*Chaenodraco wilsoni*, *Pagetopsis macropterus* and *Chaenocephalus aceratus*) deposit their eggs on the seabed, where they are guarded by the males (Kock and Kellermann, 1991). Pshenichnov (2004) and Kock et al. (2006) documented that *C. dewitti* females carry their eggs in a cylindrical bundle (of 500–600 eggs) on their pelvic fins and aggregate for spawning and brooding. They also mentioned that less than 50% of the spawned eggs are brooded in this manner, however, it is unclear why this is. Egg bundles were not observed on specimens examined during the current study. It is possible that brooding fish did not occur in the sampling area/depth or that egg bundles were dislodged prior to landing.

Length-at-maturity and age-at-maturity ogives indicated that both male and female *C. dewitti* are sexually mature at about 370–400 mm TL and 6–8 years of age. This finding is consistent with the data presented for other icefish species in Kock (2005a).

There is little information on the diet of *C. dewitti* (Kock, 2005a). Takahashi and Iwami (1997) examined eight stomachs from *C. dewitti* captured off the South Shetland Islands. They reported that one species of Myctophidae (*Gymnoscopelus nicholsi*) was abundant in the diet (87.7%). The remainder of the prey items comprised other fish species and Antarctic krill (*Euphausia superba*). Pshenichnov (2004) examined 380 fish captured at depths of 450–1 600 m in the Ross Sea. He reported a single squid beak from one stomach and bait from others, but did not specify the number of stomachs containing bait. Kock (2005a) reported that older icefish (of all species) could be categorised into one of three dietary groups. He included *C. dewitti* in a group which feeds primarily on notothenioids and occasionally on mesopelagic fish. He also reported that young icefish occurring in the Southern Ocean are pelagic or migrate regularly into the water column, where they feed largely on euphausiids

In the current study, a high proportion of stomachs were empty and the few prey items recovered were generally in advanced stages of digestion. This may be due to regurgitation of prey during capture.

All otoliths were read by a single reader, and 30% were then read by a second reader. The between-reader comparison showed that both otolith readers interpreted opaque zones in *C. dewitti* consistently. However, without validating the ageing methodology it is not possible to determine the degree of accuracy. Kock (2005a) reported that age determination of icefish is unreliable, with only a few stocks of *C. gunnari* having been validated. He also noted that mark and recapture experiments, including the use of tetracycline, are unlikely to be successful due to the fragility of icefish. Assessing daily growth increments may assist with validation, but to date only the larvae of *C. gunnari* (Townsend, 1980) and *Pseudochaenichthys georgianus* (Kellermann et al., 2002) have been investigated.

Growth parameters for *C. dewitti* show that growth is very rapid, which is consistent with the findings reported for other icefish species (Kock, 2005a). Female fish approach a significantly larger mean asymptotic maximum length (L_∞) than males. Differences in growth rate (k) were significantly higher for males than females, and t_0 values were large. However, there is a lack of small fish (≤30 cm; age ≤ 1), and so the von Bertalanffy growth curve parameters are considered to be uncertain.

This poor representation of small fish may be because these size classes are inadequately sampled by the longline gear or are absent from the area. This will also affect the mean length-at-age values and bias the estimates of k. However, the extent of this bias cannot be determined currently. Efforts to address this concern will be made during subsequent seasons when observers on board longline vessels targeting Antarctic toothfish in the Ross Sea will be requested to collect small icefish (≤28 cm TL).

The current work produced ages ranging between 1 and 11 years, with maximum ages of 8 years for males and 11 years for females. Pshenichnov (2004) obtained ages ranging between 5 and 11 years. The greater age range observed in the current study is likely to be a function of the different areas sampled.

Conclusions

1. This study confirmed that *C. dewitti* is the predominant icefish species taken as by-catch in the Ross Sea longline fishery for toothfish.

2. Biological parameters (including length–weight, length- and age-at-maturity, age and growth) were consistent with previous research.

3. Gonad maturity stage data showed that most fish were either immature or resting (mature). GSIs plotted against sample month showed a weak positive trend between December and February, but this was limited by the short temporal distribution of the data.

4. Length-at-maturity and age-at-maturity ogives were presented along with von Bertalanffy growth parameters. These values were

consistent with previous research, but are considered to be unreliable due to the poor representation of small fish (≤30 cm). There is a need to sample these small fish.

5. Diet analyses showed most icefish stomachs were empty and the few prey items recovered were generally in advanced stages of digestion. This may be due to regurgitation of prey during capture.

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References

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. In: Petran, B.N. and F. Csaaki (Eds). *Second International Symposium on Information Theory*. Akademia Kiado, Budepest, Hungary: 267–281.

Artigues, B., B. Morales-Nin and E. Balguerías. 2003. Fish length–weight relationships in the Weddell Sea and Bransfield Strait. *Polar Biol.*, 26 (7): 463–467.

Balushkin, A.V. 1997. Topography of unpaired fins with respect to the vertebrae and similarities among icefishes of the family Channichthyidae. *Comp. Biochem. Physiol.*, 118A (4): 1079–1081.

Balushkin, A.V. and V.G. Prutko. 2006. On occurrences of *Chionobathyscus dewitti* (Notothenioidei Channichthyidae) in the Ross Sea. *J. Ichthyol.*, 46 (3): 271–273.

Beamish, R.J. and D.A. Fournier. 1981. A method for comparing the precision of a set of age determinations. *Can. J. Fish. Aquat. Sci.*, 38: 982–983.

von Bertalanffy, L. 1938. A quantitative theory of organic growth (inquiries on growth laws II). *Human Biol.*, 10: 181–213.

Campaña, S.E., M.C. Annand and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. *Trans. Am. Fish. Soc.*, 124: 131–138.

CCAMLR. 2008. *Statistical Bulletin*, Vol. 20 (1998–2007). CCAMLR, Hobart, Australia: www.ccamlr.org/pu/e/e_pubs/sb/vol20.htm.

Chang, W.Y.B. 1982. A statistical method for evaluating the reproducibility of age determination. *Can. J. Fish. Aquat. Sci.*, 39: 1208–1210.

Everson, I., A. Neyelov and Y.E. Permitin. 1992. Bycatch of fish in the South Atlantic krill fishery. *Ant. Sci.*, 4 (4): 389–392.

Francis, R.I.C.C., L.J. Paul and K.P. Mulligan. 1992. Ageing of adult snapper (*Pagrus auratus*) from otolith annual ring counts: validation by tagging and oxytetracycline injection. *Aust. J. Mar. Freshw. Res.*, 43 (5): 1069–1089.

Hanchet, S.M., M.L. Stevenson, N.L. Phillips and A. Dunn. 2005. A characterisation of the toothfish fishery in Subareas 88.1 and 88.2 from 1997/98 to 2004/05. Document *WG-FSA-05/29*. CCAMLR, Hobart, Australia.

Hanchet, S.M., M.L. Stevenson and A. Dunn. 2006. A characterisation of the toothfish fishery in Subareas 88.1 and 88.2 from 1997/98 to 2005/06. Document *WG-FSA-06/29*. CCAMLR, Hobart, Australia.

Horn, P.L. 2002. Age and growth of Patagonian toothfish (*Dissostichus eleginoides*) and Antarctic toothfish (*D. mawsoni*) in waters from the sub-Antarctic to the Ross Sea, Antarctica. *Fish. Res.*, 56 (3): 275–287.

Iwami, T. and K.-H. Kock. 1990. Channichthyidae. In: *Fishes of the Southern Ocean*. Gon, O. and P.C. Heemstra (Eds). J.L.B Smith Institute of Ichthyology, Grahamstown, South Africa: 381–399.

Kellermann, A.K., R. Gauldie and J. Ruzicka. 2002. Otolith microincrements in the Antarctic fishes *Notothenia coriiceps* and *Pseudochaenichthys georgianus*. *Polar Biol.*, 25 (11): 799–877.

Kock, K.-H. 2005a. Antarctic icefishes (Channichthyidae): a unique family of fishes. A review, Part I. *Polar Biol.*, 28 (11): 862–895.

Kock, K.-H. 2005b. Antarctic icefishes (Channichthyidae): a unique family of fishes. A review, Part II. *Polar Biol.*, 28 (12): 897–909.

Kock, K.-H. and A. Kellermann. 1991. Review. Reproduction in Antarctic notothenioid fish. *Ant. Sci.*, 3 (2): 125–150.

Kock, K.-H., L.K. Pshenichnov and A.L. Devries. 2006. Evidence for egg brooding and parental care in icefish and other notothenioids in the Southern Ocean. *Ant. Sci.*, 18 (2): 223–227.

McCullagh, P. and J.A. Nelder. 1989. Generalized linear models. 2nd Edition. *Monogr. Stat. Appl. Prob.*, 37. Chapman and Hall, London: 511 pp.

Manning, M.J. and C.P. Sutton. 2007. Further studies on the age and growth of giant stargazer, *Kathetostoma giganteum*, from the West Coast of the South Island (STA 7). *New Zealand Fisheries Assessment Report*, 2007/12: 68 pp.

Marriott, P., P.L. Horn and P. McMillan. 2003. Species identification and age estimation for the ridge-scaled Macrourid (*Macrourus whitsoni*) from the Ross Sea. *CCAMLR Science*, 10: 37–51.

Pearson, H.S. and H.O. Hartley. 1962. *Biometrika Tables for Statisticans*. Vol 1. Cambridge University Press, Cambridge: 240 pp.

Prutko, V.G. and L.A. Lisovenko. 2004. New data on Antarctic toothfish and some other by-catch fishes fecundity with gonads histological pictures from Ross Sea region and data on Patagonian toothfish from the Argentina Sea. Document *WG-FSA-05/28*. CCAMLR, Hobart, Australia.

Pshenichnov, L.K. 2004. Some peculiarities of *Chionobathyscus dewitti* biology in the Ross Sea. Document *WG-FSA-04/90*. CCAMLR, Hobart, Australia.

R Development Core Team. 2006. *R: A Language and Environment for Statistical Computing*. Version 2.4.0. R Foundation for Statistical Computing, Vienna, Austria: www.R-project.org.

Ruud, J.T. 1954. Vertebrates without erythrocytes and blood pigment. *Nature*, 173: 848–850.

Schnute, I. 1981. A versatile growth model with statistically stable parameters. *Can. J. Fish. Aquat. Sci.*, 38 (9): 1128–1140.

Schwarz, G. 1978. Estimating the dimensions of a model. *The Annals of Statistics*, 6 (2): 461–464.

Takahashi, M and T. Iwami. 1997. The summer diet of demersal fish at the South Shetland Islands. *Ant. Sci.*, 9 (4): 407–413.

Townsend, D.W. 1980. Microstructural growth increments in some Antarctic fish otoliths. *Cybium*, 3 (8): 17–22.

Venables, W.N. and B.D. Ripley. 2002. *Modern Applied Statistics with S*. Fourth edition. Springer, New York: 495 pp.

Williams, R. and A. McEldowney. 1990. A guide to the fish otoliths from waters off the Australian Antarctic Territory, Heard and Macquarie Islands. *ANARE Res. Notes*, 75: 1–173.

Table 1: Summary of fishing effort and amount of icefish caught (in tonnes) during the three fishing trips during which specimens were collected.

Vessel	Trip duration		Fishing effort		Icefish by-catch (tonnes)
	Start	End	Sets	Hooks	
FV *Janas*	8 Dec 2005	23 Feb 2006	117	564 480	1.029
FV *San Aotea II*	7 Dec 2005	22 Feb 2006	125	672 370	0.182
FV *San Aspiring*	23 Nov 2005	24 Feb 2006	93	637 800	0.271

Table 2: Generalised five-point macroscopic gonad maturity scale.

Stage	Description
1	Immature
2	Resting (mature)
3	Ripe
4	Running ripe
5	Spent

Table 3: Otolith scores used in readings.

(a) Three-point margin scores	Description
Narrow	Last opaque zone considered to be fully formed; a thin layer of translucent material may be present outside the last opaque zone.
Medium	Last opaque zone considered to be fully formed; a thicker layer of translucent material is present outside the last opaque zone.
Wide	Last opaque zone considered to be fully formed; a thick layer of translucent material is deposited outside the last fully formed opaque zone.
(b) Five-point readability scores	**Description**
1	Otolith very easy to read; excellent contrast between successive opaque and translucent zones.
2	Otolith easy to read; good contrast between successive opaque and translucent zones, but not as marked as in 1; potential error ± 1 opaque zone.
3	Otolith readable; less contrast between successive opaque and translucent zones than in 2, but alternating zones still apparent; potential error ± 2 opaque zones.
4	Otolith readable with difficulty; poor contrast between successive opaque and translucent zones; potential error ± 3 opaque zones.
5	Otolith unreadable.

Table 4: Summary of meristic and morphometric data for *Chionobathyscus dewitti* ranging from 249 to 400 mm standard length. (A – anal fin; D1 – first dorsal fin; D2 – second dorsal fin; D2–D1 – distance between first and second dorsal fin bases; HL – head length; PL – pelvic length; SL – standard length; *n* – number of fish examined). Summary values from Iwami and Kock (1990) and Balushkin and Prutko (2006) are provided for comparison.

	Number of fin rays			Lengths		
	A	D1	D2	D2–D1 (mm)	(HL/SL) (%)	(PL/SL) (%)
Minimum	32	3	39	0.0	32.6	18.8
Maximum	35	7	44	24.0	37.8	28.5
Mean	-	-	-	5.6	35.8	24.8
Mode	34	5	41	-	-	-
n	50	52	50	49	43	44
Iwami and Kock (1990)	33–34	5–6	39–40	-	33.3–36.9	25.9–30.5
Balushkin and Prutko (2006)	34–35	5–6	41–42	-	33.8–35.5	24.4–28.2

Table 5: Results of total length ~ standard length regressions. Number of parameters (*p*), proportion of residual variance explained (R^2), AIC and BIC values, parameter estimates, and standard errors (SE) for each fitted model are provided. The regressions relate standard length (mm) to total length (mm).

Model	Description	*p*	R^2	AIC	BIC	Parameter	Estimate	SE
1	Same parameters for all fish	2	0.996	1259.3	1275.5	α_{All}	15.34	1.38
						β_{All}	1.08	0.00
2	Separate parameters for males and females	4	0.999	1235.4	1247.4	α_M	22.10	2.70
						α_F	16.99	1.71
						β_M	1.05	0.01
						β_F	1.08	0.01

Table 6: Results of log(weight) ~ log(length) regressions. Number of parameters (*p*), proportion of residual variance explained (R^2), AIC and BIC values, parameter estimates, and standard errors (SE) for each fitted model are provided. The regressions relate weight (g) to total length (mm).

Model	Description	*p*	R^2	AIC	BIC	Parameter	Estimate	SE
1	Same parameters for all fish	2	0.928	–350.1	–344.8	α_{All}	1.01×10^{-7}	3.05×10^{-8}
						β_{All}	3.72	0.06
2	Separate parameters for males and females	4	0.999	–349.2	–336.7	α_M	4.80×10^{-8}	2.46×10^{-8}
						α_F	9.85×10^{-8}	3.66×10^{-8}
						β_M	3.85	0.12
						β_F	3.73	0.08

Table 7: Numbers and proportions of fish categorised by gonad stage and month of collection. Proportions are standardised by month of collection.

Numbers of fish				
Stage	Month			
	December 2005	January 2006	February 2006	Total
1	30	140	3	173
2	7	66	4	77
3	0	8	0	8
4	2	31	2	35
5	1	1	0	2
Total	40	246	9	295
Proportions of fish				
Stage	Month			
	December 2005	January 2006	February 2006	Total
1	0.75	0.57	0.33	0.59
2	0.18	0.27	0.44	0.26
3	-	0.03	-	0.03
4	0.05	0.13	0.22	0.12
5	0.03	-	-	0.01
Total	1.00	1.00	1.00	1.00

Table 8: Maturity-at-length model fits. Number of parameters (p), AIC and BIC values, parameter estimates (α_x, β_x), and standard errors (SE) for the linear predictor for each model fit are provided. The derived lengths at which 50% and 95% of fish are mature ($L_{50,x}$, $L_{95,x}$) are shown.

Model	Description	p	AIC	BIC	Parameter	Estimate	SE
Logistic model fits							
1	Same parameters for all fish combined	2	174.69	181.98	α_{All}	–26.15	2.97
					β_{All}	0.08	0.01
					$L_{50,\text{All}}$	346.88	2.73
					$L_{95,\text{All}}$	385.94	5.92
2	Separate parameters for males and females	4	175.16	189.74	α_{M}	–26.89	4.42
					α_{F}	–26.63	4.52
					β_{M}	0.08	0.01
					β_{F}	0.08	0.01
					$L_{50,\text{M}}$	351.18	3.74
					$L_{50,\text{F}}$	341.30	3.91
					$L_{95,\text{M}}$	389.64	8.44
					$L_{95,\text{F}}$	379.03	8.60
Probit model fits							
3	Same parameters for all fish combined	2	175.05	182.35	α_{All}	–14.82	1.51
					β_{All}	0.04	0.00
					$L_{50,\text{All}}$	346.40	2.66
					$L_{95,\text{All}}$	384.85	5.47
4	Separate parameters for males and females	4	175.79	190.37	α_{M}	–14.91	2.18
					α_{F}	–15.21	2.33
					β_{M}	0.04	0.01
					β_{F}	0.04	0.01
					$L_{50,\text{M}}$	350.67	3.80
					$L_{50,\text{F}}$	341.21	3.75
					$L_{95,\text{M}}$	389.37	8.09
					$L_{95,\text{F}}$	378.11	7.79

Table 9: Maturity-at-age model fits. Number of parameters (p), AIC and BIC values, parameter estimates (α_x, β_x), and standard errors (SE) for the linear predictor for each model fit are provided. The derived ages at which 50% and 95% of fish are mature ($a_{50,x}$, $a_{95,x}$) are shown.

Model	Description	p	AIC	BIC	Parameter	Estimate	SE
Logistic model fits							
1	Same parameters for all fish combined	2	223.22	230.52	α_{All}	–5.28	0.58
					β_{All}	1.36	0.16
					$a_{50,\mathrm{All}}$	3.89	0.13
					$a_{95,\mathrm{All}}$	6.06	0.29
2	Separate parameters for males and females	4	218.79	233.37	α_{M}	–5.11	0.80
					α_{F}	–5.33	0.88
					β_{M}	1.17	0.21
					β_{F}	1.51	0.25
					$a_{50,\mathrm{M}}$	4.35	0.25
					$a_{50,\mathrm{F}}$	3.54	0.16
					$a_{95,\mathrm{M}}$	6.86	0.63
					$a_{95,\mathrm{F}}$	5.50	0.38
Probit model fits							
3	Same parameters for all fish combined	2	222.62	229.91	α_{All}	–3.07	0.30
					β_{All}	0.78	0.08
					$a_{50,\mathrm{All}}$	3.93	0.13
					$a_{95,\mathrm{All}}$	6.03	0.29
4	Separate parameters for males and females	4	216.82	231.40	α_{M}	–3.04	0.42
					α_{F}	–3.11	0.47
					β_{M}	0.69	0.11
					β_{F}	0.88	0.13
					$a_{50,\mathrm{M}}$	4.39	0.25
					$a_{50,\mathrm{F}}$	3.55	0.16
					$a_{95,\mathrm{M}}$	6.76	0.58
					$a_{95,\mathrm{F}}$	5.42	0.34

Table 10: Number of icefish stomachs containing prey and prey descriptions. In two instances individual stomachs contained multiple prey items.

Prey description	Number of stomachs
Crustacean	
Eye	2
Mixed remains	2
Fish	
Egg	4
Eye	1
Otolith	1
Scales	3
Vertebrae	1
Squid	
Upper beak	1

Table 11: Results of von Bertalanffy models assuming the same model parameters for all fish and either normal (constant σ^2), lognormal, or normal (constant c) errors. p – number of parameters. $L_{1,x}$, $L_{2,x}$, and κ_x are model parameters; $L_{\infty,x}$ and $t_{0,x}$ are derived from estimates of the model parameters using equations in Schnute (1981).

Model	Error structure	p	AIC	BIC	Parameter	Estimate	SE
1	Normal (constant σ^2)	4	2591.5	2606.1	$L_{1,\mathrm{All}}$	305.85	2.18
					$L_{2,\mathrm{All}}$	427.72	4.13
					κ_{All}	0.10	0.03
					$L_{\infty,\mathrm{All}}$	576.87	-
					$t_{0,\mathrm{All}}$	–5.59	-
					σ^2	539.82	45.38
2	Lognormal	4	2555.2	2569.8	$L_{1,\mathrm{All}}$	306.17	1.83
					$L_{2,\mathrm{All}}$	428.05	4.82
					κ_{All}	0.07	0.03
					$L_{\infty,\mathrm{All}}$	643.05	-
					$t_{0,\mathrm{All}}$	–6.64	-
					σ^2	0.00	0.00
3	Normal (constant c)	4	2560.2	2574.8	$L_{1,\mathrm{All}}$	305.74	1.83
					$L_{2,\mathrm{All}}$	430.19	4.98
					κ_{All}	0.08	0.04
					$L_{\infty,\mathrm{All}}$	619.90	-
					$t_{0,\mathrm{All}}$	–6.08	-
					c	0.06	0.00
4	Lognormal	7	2523.3	2548.9	$L_{1,\mathrm{M}}$	304.55	2.19
					$L_{2,\mathrm{M}}$	399.69	1.40
					κ_{M}	0.22	0.09
					$L_{\infty,\mathrm{M}}$	420.34	-
					$t_{0,\mathrm{M}}$	–3.98	-
					$L_{1,\mathrm{F}}$	309.02	2.75
					$L_{2,\mathrm{F}}$	466.33	9.70
					κ_{F}	0.09	0.04
					$L_{\infty,\mathrm{F}}$	608.19	-
					$t_{0,\mathrm{F}}$	–5.61	-
					σ^2	0.00	0.00

Figure 1: *Chionobathyscus dewitti* specimen caught in the Ross Sea toothfish longline fishery during 2005/06. This specimen is 316 mm in total length.

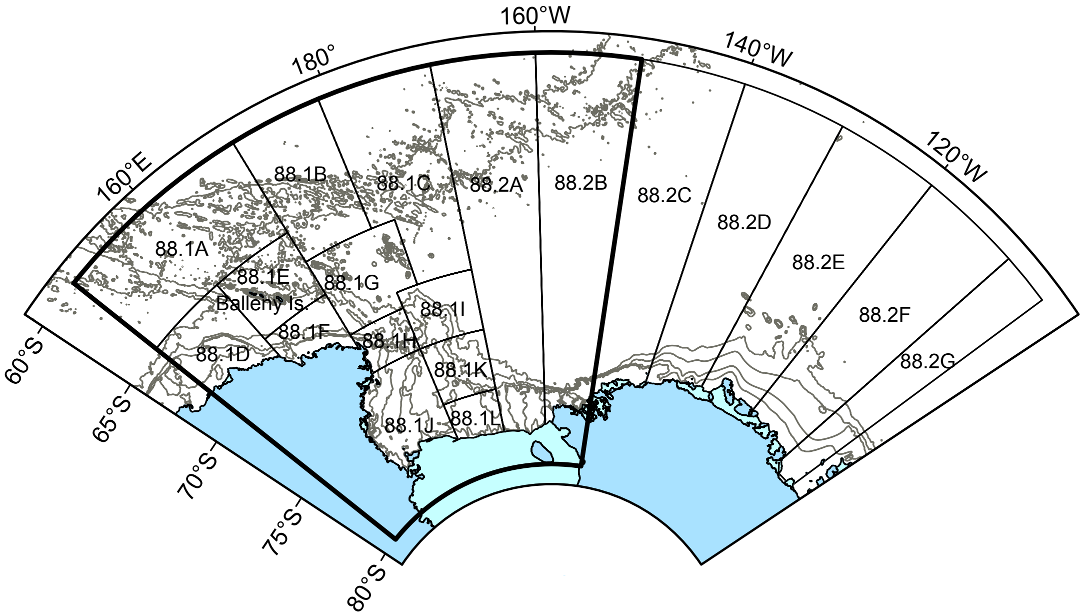
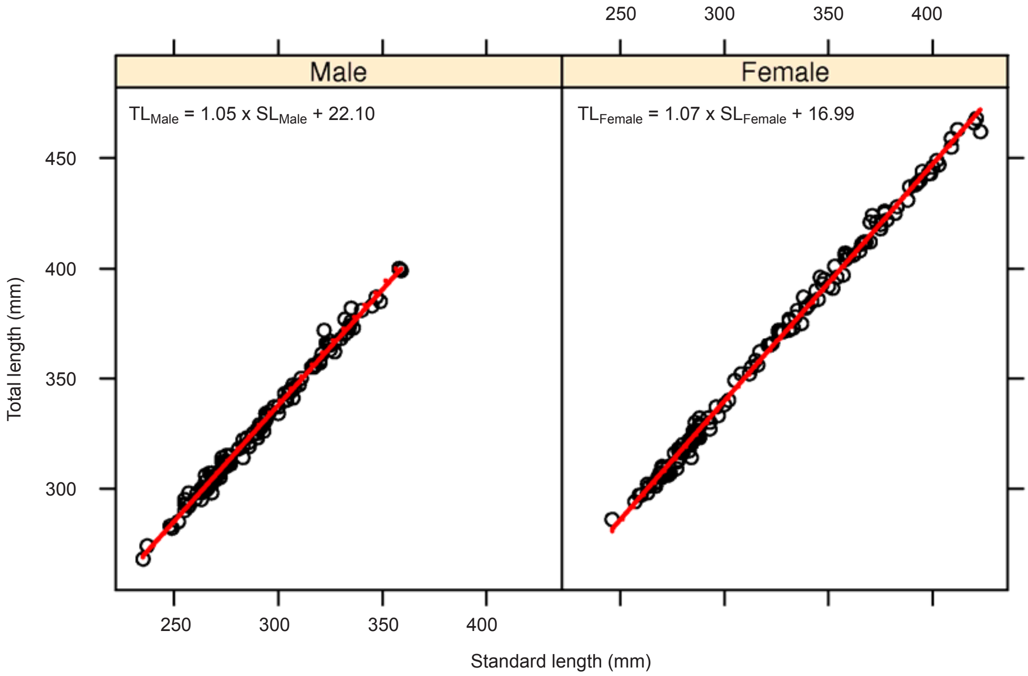


Figure 2: CCAMLR Subareas 88.1 and 88.2, small-scale research units (SSRUs), and the Ross Sea (bounded region). Depth contours are plotted at 500, 1 000, 2 000 and 3 000 m.



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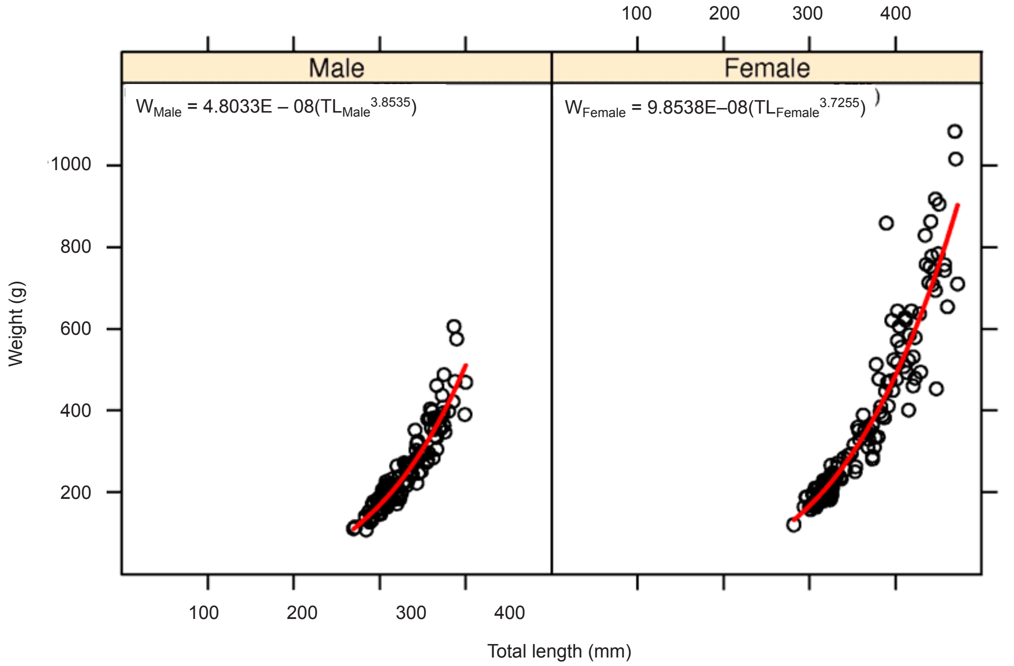

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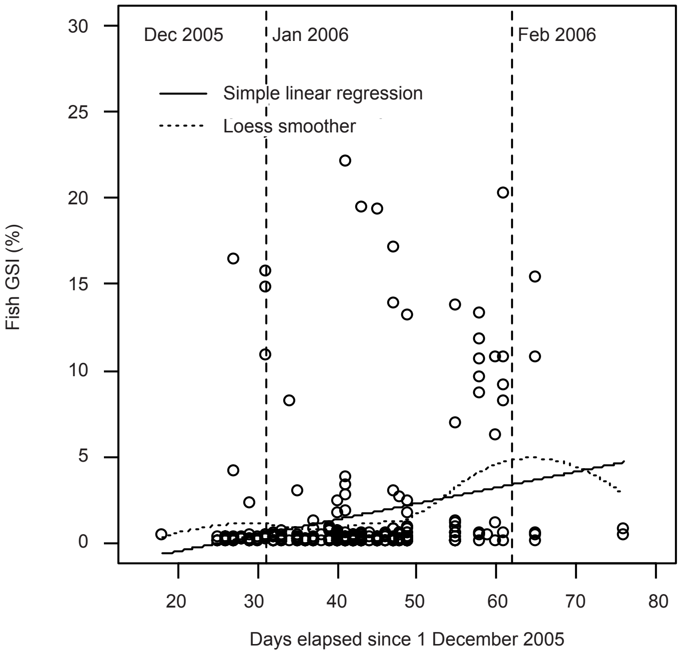

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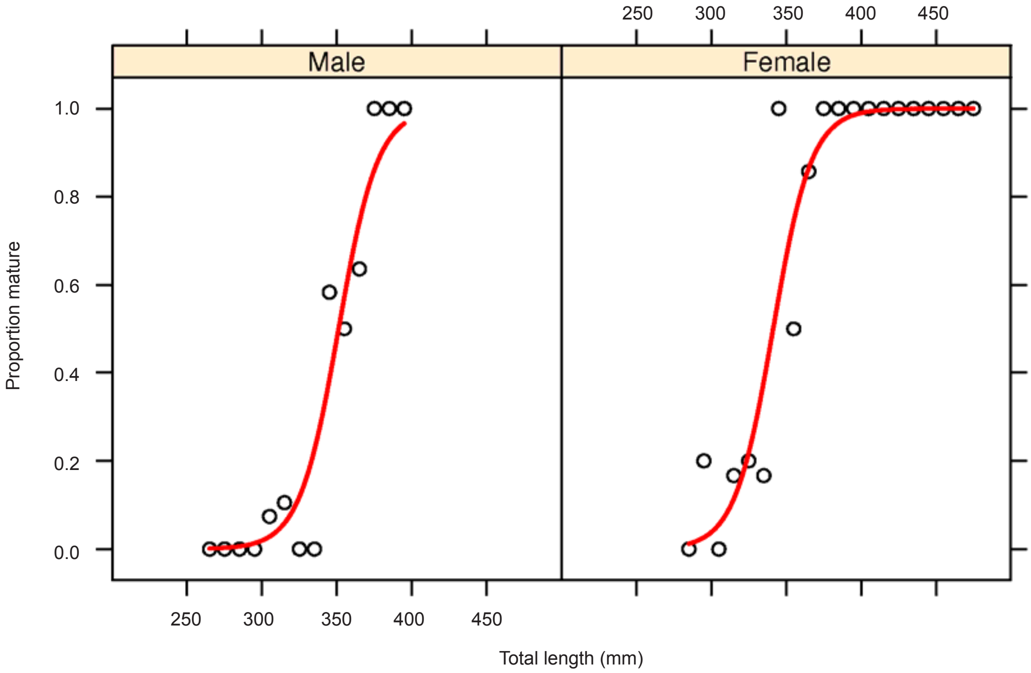

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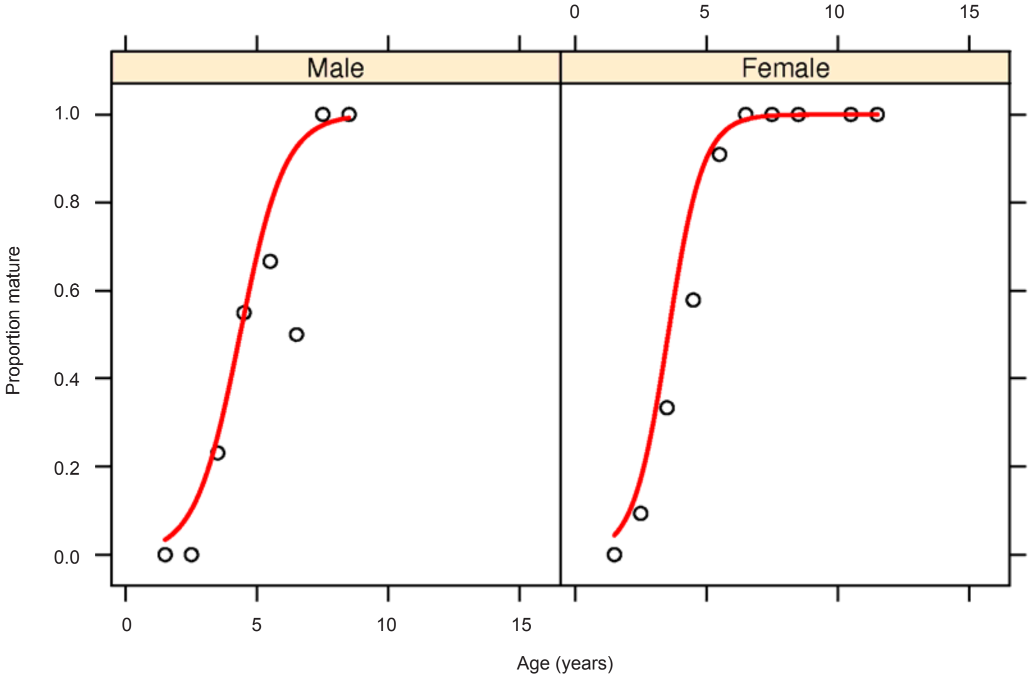

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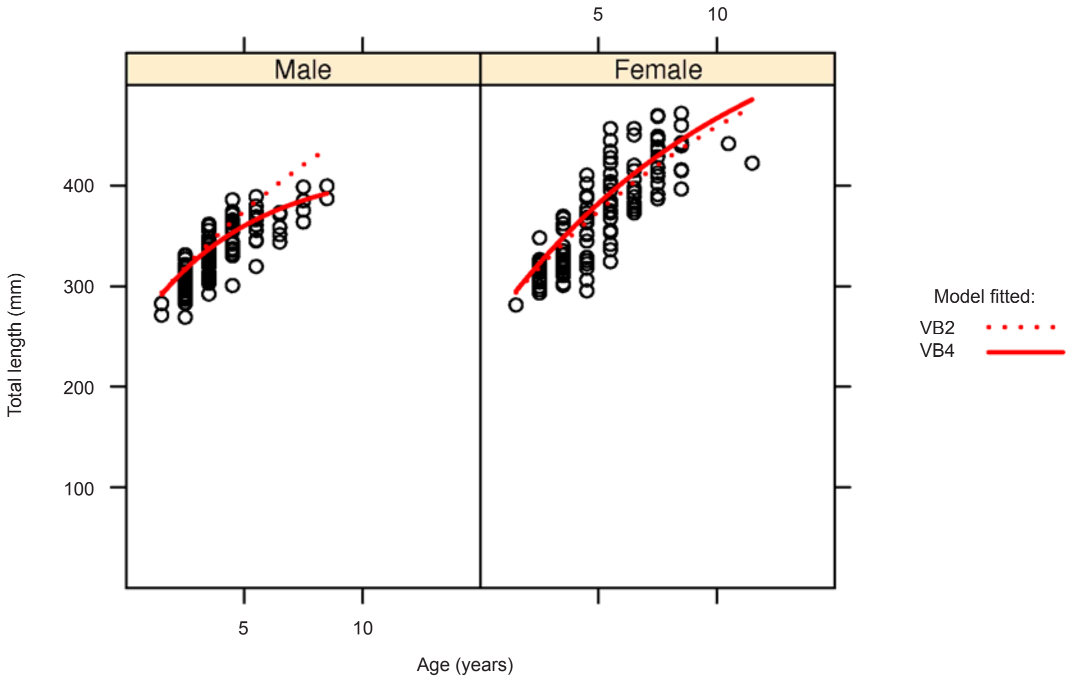

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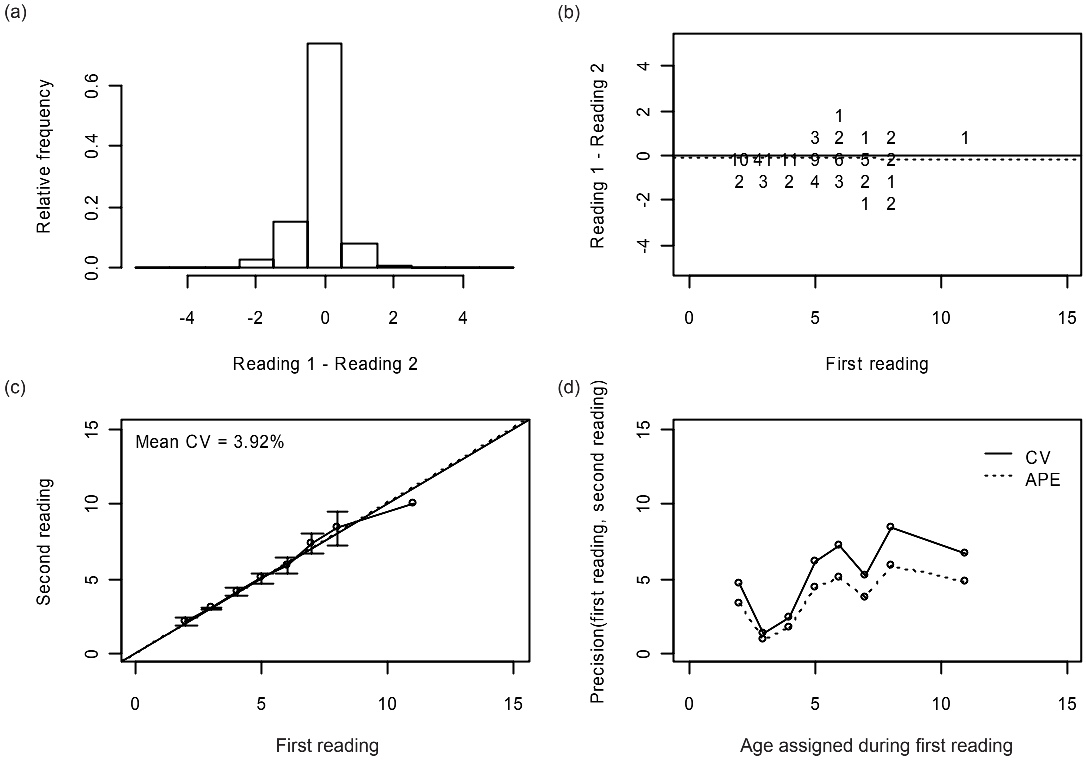

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Figura 4: Datos de la relación talla-peso de *Chionobathyscus dewitti*. Superposición de las curvas de ajuste del modelo de regresión (suponiendo parámetros separados para cada sexo).

Figura 5: Índices gonadosomáticos (GSI) para *Chionobathyscus dewitti* muestreado entre diciembre de 2005 y febrero de 2006, con dos líneas de tendencia ajustadas a los datos.

Figura 6: Talla de madurez; ajuste de curvas con el método de los probit, con parámetros separados para cada sexo.

Figura 7: Edad de madurez; ajuste de curvas con el método de los probit, con parámetros separados para cada sexo.

Figura 8: Corte transversal de un otolito sagital de *Chionobathyscus dewitti*. Las líneas negras muestran las zonas opacas que se interpretan como anillos anuales; los números representan cada banda 'anual'.

Figura 9: Datos de talla por edad de *Chionobathyscus dewitti*. Superposición de las curvas de ajuste del modelo 2 de von Bertalanffy (parámetros de von Bertalanffy iguales para todos los peces) y del modelo 4 (parámetros de von Bertalanffy separados para cada sexo).

Figura 10: Resultados de la comparación de lecturas: (a) histogramas de la diferencia entre las lecturas para un mismo otolito; (b) diferencias entre la primera y la segunda lectura para una edad determinada durante la primera lectura; (c) gráfico de las diferencias; y (d) perfiles de CV y APE con relación a las edades determinadas durante el primer conjunto de lecturas. Superposición estimada de la relación uno a uno (línea continua) y de la relación verdadera (línea entrecortada) entre la primera y segunda edad en (b) y (c).