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GEOGRAPHICAL DIFFERENCES IN THE CONDITION, REPRODUCTIVE DEVELOPMENT, SEX RATIO AND LENGTH DISTRIBUTION OF ANTARCTIC TOOTHFISH (*DISSOSTICHUS MAWSONI*) FROM THE ROSS SEA, ANTARCTICA (CCAMLR SUBAREA 88.1)

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Abstract

A number of morphological and reproductive measurements made seasonally on Antarctic toothfish (*Dissostichus mawsoni*) from mid-December to early April during the 2000/01 to 2004/05 fishing seasons on board the autoliner *San Aotea II* have been analysed. Results of this study indicate measurable differences in a number of indices from toothfish found on the Ross shelf proper, as distinct from those sampled on the more isolated seamounts and features to the north. These are modal length distribution, sex ratio, fish body condition factor and reproductive development. *Dissostichus mawsoni* samples from the northern part of the Ross Sea showed that this component of the population had a unimodal length distribution at a consistent peak over all sampling seasons in comparison with the southern group (in which the distribution was multimodal), showed a consistent and significantly higher ratio of males to females, poorer condition and more advanced reproductive development.

Résumé

Un certain nombre de mesures morphologiques et sur la reproduction effectuées chaque saison sur la légine antarctique (*Dissostichus mawsoni*) de mi-décembre à début avril pendant les saisons de pêche 2000/01 à 2004/05 à bord du palangrier automatique *San Aotea II* ont été analysées. Les résultats de cette étude indiquent des différences mesurables d'indices entre les légines provenant du plateau de Ross même et celles prélevées sur les bancs et les caractéristiques topographiques plus isolés du nord. Il s'agit de la distribution des longueurs modales, du sex ratio, du facteur de condition corporelle des poissons et du développement reproductif. Les échantillons de *D. mawsoni* prélevés dans la partie nord de la mer de Ross montrent que cette composante de la population, contrairement au groupe du sud dont la distribution est multimodale, a une distribution de longueurs unimodale d'une valeur maximale constante quelle que soit la saison d'échantillonnage, son sex ratio est régulièrement nettement en faveur des mâles, sa condition est moins bonne et son développement reproductif plus avancé.

Резюме

Был проанализирован ряд морфологических и репродуктивных показателей антарктического клыкача (*Dissostichus mawsoni*), измерявшихся с середины декабря по начало апреля в течение промысловых сезонов 2000/01–2004/05 гг. на борту автолайнера *San Aotea II*. Результаты этого исследования свидетельствуют об измеримых различиях в нескольких показателях для клыкача, обнаруженного на самом шельфе Росса, в отличие от особей, пойманных на более изолированных подводных возвышенностях и особенностях рельефа, расположенных севернее. К этим показателям относятся распределение модальных длин, соотношение полов, коэффициент упитанности рыбы и репродуктивное развитие. Образцы *D. mawsoni* из северной части моря Росса показали, что эта часть популяции имела одномодальное распределение длин со сходным максимумом для всех сезонов сбора данных, в отличие от южной группы (в которой распределение было мультимодальным), и характеризовалась устойчивым и значительным превышением доли самцов над самками, более плохим физиологическим состоянием и более высокой стадией репродуктивного развития.

Resumen

Se analizaron varios parámetros morfológicos y reproductivos de la austromerluza antártica (*Dissostichus mawsoni*) medidos desde mediados de diciembre hasta principios de abril durante las temporadas de pesca de 2000/01 a 2004/05 a bordo del palangrero de calado automático *San Aotea II*. Los resultados de este estudio indican diferencias mensurables en varios de estos índices entre la población de austromerluza de la plataforma de Ross y las que habitan en los montes submarinos y accidentes topográficos más aislados de la zona norte. Estos índices son: la distribución de la talla modal, la proporción de sexos, el factor de la condición corporal de los peces y el desarrollo gonadal. Las muestras de *D. mawsoni* del sector norte del mar de Ross mostraron que la distribución de tallas de este componente de la población es unimodal con un valor máximo constante en las muestras de todas las temporadas – en comparación con el grupo del sector sur que mostró una distribución multimodal – una proporción constante y significativamente mayor de machos que de hembras, una peor condición y un estadio de desarrollo gonadal más avanzado.

Keywords: Antarctic toothfish, *Dissostichus mawsoni*, reproductive development, sex ratio, coefficient of condition, length distribution, length–weight relationship, Ross Sea, CCAMLR

Introduction

The Antarctic toothfish (*Dissostichus mawsoni*) is a large nototheniid species found on the Antarctic continental shelf (Goldsworthy et al., 2002) and on isolated features to the north of the shelf within the Ross Sea (CCAMLR Subareas 88.1 and 88.2).

The New Zealand autoliner *San Aotea II* was one of the original vessels pioneering the exploratory longline fishery for *D. mawsoni* in Subarea 88.1 and has consistently participated in that fishery since the 1999/2000 season. This initial descriptive review, based on the analysis of seasonal biological data collected on board the *San Aotea II*, shows geographical differences in a number of key indices between data collected north and south of the shelf break within Subarea 88.1 (the western and central Ross Sea). There were four main areas where these differences are significant. These are fish length-frequency distribution, sex ratio, fish condition and reproductive development. These differences between areas may influence future assessments, should be taken into account in planning future sampling, and are relevant to the current assessment using a tag and recapture program. A likely interpretation of the results suggests a movement of reproductively mature fish to and from the northern area from the south for spawning. This possibility should be considered in any stock model used to assess and manage this fishery. Serious consideration should be given to a more sophisticated analysis by modelling using the complete Ross Sea dataset from all participating vessels.

Materials and methods

Specimens of *D. mawsoni* caught in Subarea 88.1 over five seasons were randomly sampled. Data collected included total length, whole fish weight, gonad condition (using maturity stages of Antarctic fish as specified in the CCAMLR *Scientific Observers Manual*), otoliths, qualitative data for stomach contents and, from the 2002/03 season onward, gonad weight.

Visual observations indicate that *D. mawsoni* in poor condition, often referred to as 'axe handles' by vessel crew, are generally much thinner in the body directly behind the head than fish having 'normal' length-to-weight ratios (Figure 1). An additional measurement of *D. mawsoni* girth was made so as to quantify fish condition independently during the 2003/04 and 2004/05 seasons. The girth measurement was made by encircling the body immediately behind the pectoral fins with either a tape or a length of non-elastic snood firmly, but without constricting the body, and measuring the circumference.

Based on these data, a significant relationship between the girth and the weight of *D. mawsoni* was established; this can be defined as

$$W = aGb$$

where W is the wet body weight in grams, G is the girth in centimetres and where a and b are constants derived from fitting the equation

$$\ln(W) = \ln(a) + b\ln(G).$$

This was used to independently corroborate the results from Fulton's condition factor analysis.

The length and weight data were analysed and grouped by 1 cm total length bins. The length–weight parameters presented in Table 6 were derived by plotting the logarithms of the available mean weights for each length group for each season and area against the logarithms of the corresponding lengths, i.e.

$$\log(W) = \log(a) + b\log(L)$$

to derive parameters a and b to satisfy the relationship

$$W = aL^b$$

where W is the mean live body weight, a is a multiplicative factor, L the total length of the fish body, and b is an exponent.

To explore differences in the body condition of *D. mawsoni*, a Fulton's condition index (K) has been calculated for the five sampling seasons. This index assumes an isometric length–weight regression and is represented as:

$$K = W / L^3 \times 10^5$$

where W is the whole fish weight in grams and L is the total length in millimetres.

Most biological samples on *D. mawsoni* taken aboard the *San Aotea II* during the 2002/03, 2003/04 and 2004/05 seasons included the collection of gonad weight using motion-compensated scales (accuracy ±10 g). These measurements were made to provide an objective alternative to the visual staging that is currently used. These gonad weights have been used to calculate a gonadosomatic index (GSI). The GSI calculation for *D. mawsoni* was as follows:

$$\text{GSI} = (\text{gonad weight (kg)} / \text{wet body weight (kg)}) \times 100.$$

Separate analyses for all these indices have been made for Subarea 88.1 north and south of latitude 70°S (Figure 2). This latitude has been used as a delineator, as it effectively divides Subarea 88.1 into the contiguous Antarctic shelf and the area to the north containing isolated hills and ridges. The northern area, part of the Pacific-Antarctic Ridge, extends north of 60°S, and the southern area extends south to about 78°S near the Ross ice shelf. Data collected in the area between 71° and 73°S includes most of the northern shelf break and the area south of 73°S, the shallower shelf. The data used for each of the five seasons covered by this analysis have been restricted to the period between mid-December to early April. This was done to provide interannual comparability during the summer period.

Comparisons of the northern and southern data used in this paper were made using an unequal variances two-sample T-test.

Results

Length frequency

Figure 3 shows the catch-weighted length-frequency distribution separated into the northern and southern areas. Sample numbers and scaled sample numbers are shown in Table 1.

The modal distribution of the northern samples is very similar for the five seasons. The distribution is essentially unimodal with the average value for all years occurring at about 141 cm TL for males and 152 cm TL for females. Average and median values are shown for the five seasons in Table 2.

Most of the northern population was greater than 120 cm TL with very few fish recorded as being less than 100 cm. The southern sample differs from the northern in that the distribution is multimodal and includes a much higher ratio of sexually immature fish. The large number of small fish shown in the figure for the 2000/01 season was due to a higher proportion of sets made further south in shallow water on the Antarctic continental shelf. A greater number of samples were collected there due to extensive sea-ice cover encountered in other areas during that season. Fishing in the extreme south of the Ross Sea is possible early in the season, as the Ross polynya clears from the south to the north in spring. When the data for 2000/01 are restricted to fishing depths of 900 m or greater, the distribution is similar to the other four years.

The frequency distributions of the southern lengths show similar maximum values as those to the north but include considerably more values less than 110 cm TL. There is a more regular multimodal distribution between 110 and 165 cm TL.

Table 3 shows the mean depth of sampling for the length records used in the length-frequency analysis. The average annual depths for both areas are very similar, apart from a lower value in the south caused by a higher number of sets made in shallow water during the 2000/01 season and a higher value in the north in 2003/04 caused by intensive fishing in one area. Depth preference is unlikely to be the cause of the differences in frequency distribution between areas.

Sex ratio

There is still uncertainty regarding maturity and age- or length-at-maturity for *D. mawsoni*. As a consequence, much of the current stock modelling is based on the closely related Patagonian toothfish (*Dissostichus eleginoides*). Hanchet et al. (2003) noted values for *D. mawsoni* suggesting that 50% of the population of both sexes is mature at 100 cm TL with a 30 cm range over maturity (i.e. 85–115 cm TL). This equates to 50% maturity at about age 9. As the sex-ratio analysis is relevant only to the spawning population, the analysis was restricted to measurements of 100 cm TL and above. Typically, over the five annual sampling seasons covered in this paper, *D. mawsoni* of less than 100 cm TL represented less than 2% of the numbers in each annual sample.

Table 4 shows the overall ratio of females to the total catch-weighted sample for each year from each area. The proportion of females to males is variable in the north, the imbalance being most evident in the 2000/01 and 2003/04 seasons. Over all seasons, however, males dominated in the northern sample. The female-to-male ratio is much more constant in the south, averaging 60.7% of the catch-weighted sample over five seasons (standard deviation 1.4%).

Figure 4 shows the proportion of females, grouped by geographical area, for the sampling seasons from 2000/01 to 2004/05. The data were restricted to those sets where at least 10 fish were sampled, to reduce any bias caused by low sample numbers. Three areas are used: north (north of 70°S), south shelf break (70°–73°S), and the south shelf (73°S and greater) where data was available.

Figure 4 shows that there is generally a lower proportion of females to males in the population north of 70°S and a higher ratio of females to males from 70°S southwards. This difference is highest about the northern shelf break between 70° and 73°S, but is still apparent south of 73°S to a lesser degree. The figures are highly significant (two-tail $P < 0.001$) between the northern values and the southern shelf break for each season, and also between the northern and combined southern sample where present. Much of the population sampled south of 73°S has been found to consist of immature fish of less than 100 cm TL. These smaller fish show a more even sex ratio and account for the lower proportions in this area.

Due to the opportunistic nature of the data collection forced by operational, environmental and quota management considerations, no finer detail can currently be extracted from this information with any statistical confidence. However, indications are that the sex ratio differences in the north are highest in December, and that later in the season the sex ratio in that area becomes more balanced. The support for this comes from limited data collected during April and May of the 2000/01 and 2001/02 seasons.

Fish condition

The length–weight data for each season are plotted using the parameters shown in Table 6 and presented separately for values north and south of 70°S in Figure 5. Minimum and maximum lengths by sampling season used in the regressions are shown in Table 5. Table 6 lists the parameters and the associated R^2 values representing the 'goodness of fit'. Lower R^2 values for some of the northern samples are due to low sample numbers during some seasons.

Mean weight-for-length has been consistently lower in the northern area than for the south over all seasons. The biggest difference can be seen in male fish as shown in Table 6. These data quantify the poor body condition noted visually in that area.

It was impossible to sample both the northern and southern areas simultaneously, and data collection in the north has not consistently occurred at the same time each season – a potential for bias. Sampling in the north took place in March 2001, March and December 2002, February and December 2003, December 2004 and February 2005. Specific sampling dates by area are shown in Figure 7. Even with this spread of sampling over the December-to-March period, the results of the analysis are consistent for the summer period over all five sampling seasons.

Fulton's condition index (K) is plotted by latitude in Figure 6 for both sexes and all fish sizes sampled. The numbers of fish sampled in each area for each season are shown in Table 7, which lists the underlying data for the plots. The plots, which are presented by sex, show that the arithmetic mean is lower for values of K north of 70°S for both sexes. The average values for both sexes are highest between 70° and 73°S. South of 73°S, the mean values again tend to trend lower. These lower values in this southern area are chiefly the result of the predominance of smaller *D. mawsoni* in samples from this area. Overall, the average values of K are higher for female fish than for males, as shown in Table 7.

The area between 70° and 73°S is effectively the northern shelf break of the Ross shelf. Overall, the difference in values of K is highly significant (two-tail $P < 0.001$) for values calculated north and south of 70°S for both sexes.

The measurements of girth made during the 2003/04 and 2004/05 seasons corroborate the condition factor results. A significant relationship between the girth and the weight of *D. mawsoni* was established from the *San Aotea II* data. Applying the expected values of weight from this relationship, and comparing actual weights, confirms the poor condition of *D. mawsoni* of both sexes in the north when compared with the south.

Gonadosomatic indices (GSI)

Table 8 shows the mean GSI for all five sampling seasons by month.

Figure 7 shows GSI data for the three seasons (2002/03 onwards) during which gonad weights were collected. Values are separated by area (north or south) and sex, and grouped by two-day periods. The data are presented to show the median, the interquartile range and the range of values recorded for each interval.

Analyses show much higher values in the north and a trend of increasing GSI over the course of the season in that area. The median value for the southern samples remains consistently at a lower level than that of the northern ones until at least the end of February. The maximum values indicate that some of the fish sampled had GSI values similar to those in the north but these were uncommon, as shown by the interquartile range. These disparities between areas were common to both sexes. Differences between north and south were highly significant for each sex (two-tail $P < 0.001$).

Due to patterns of sampling forced by ice-clearance patterns and SSRU closures there is limited concurrence in observations. There were dates when there were samples collected in both areas in late December, early January and about the third week in February. In all cases the southern GSI indices are much lower than the northern.

Discussion

There are clear differences in four indices examined for the areas north and south of 70°S. These are length-frequency distribution, sex ratio, index of body condition and GSI.

There are a number of possible explanations for these differences. Regional differences in availability could be suggested, where availability is defined as the fraction of a fish population living in a region that is susceptible to fishing during a given fishing season. In this context, the argument would be that some proportion of the accessible population is unavailable to the fishing gear used. For example, the sex ratio imbalance could be due to a preference by one sex for the gear in use. This would appear unlikely given that there were a number of sets on which ratios were just about even. Furthermore, such an argument does not explain why female *D. mawsoni* in the south should prefer the same bait types that are taken predominantly by males in the north. A similar argument could be proposed for the length differences – smaller fish in the north are less vulnerable to the hooks and bait used. Again this seems improbable given the smaller fish caught in the south and the ability of the hooks in use to catch even small by-catch species of less than 300 g.

Assuming that the regional differences are real, there are a number of possible explanations. One possibility is two (or more) distinct recruited cohorts, spawning at different periods in the Ross Sea, in different geographical areas. The generally low GSI level in the southern samples is not consistent with this hypothesis. Alternatively there could be an interchange of fish between at least these two broadly defined areas. The predominance of sexually mature fish in the north and the general absence of fish smaller than 100 cm TL support this view. The consistently higher levels of females in the south combined with a more variable (but overall higher) proportion of males in the north may also reflect migration; one explanation could be that the males may stay longer over a spawning season or seasons in the northern grounds. A likely cause of the generally poorer condition of *D. mawsoni* in the northern area is deterioration of physical condition following, or during, spawning. This state could be aggravated by the effects of migration to the northern hills over areas of open ocean (waters deeper than 2 500 m). Additional factors could be the influence of the strong tidal influences characteristic of these northern geological features combined with lower productivity. Feeding data collected during trophic studies have shown a lower diversity and a smaller quantity of prey items in toothfish stomachs in the northern area.

This likelihood was reinforced when a clearly spawning *D. mawsoni* was caught during the 2004/05 season. This was a running-ripe female of 47 kg wet body weight caught in the northern area. This fish (Figure 8) had an ovarian mass of 14.2 kg, giving a GSI of 30.2. When the ovaries were removed the fish body had the classic 'axe handle' form seen in many of the northern samples over all seasons. The gut cavity was fully distended and entirely packed with eggs, making feeding an unlikely activity. An 83 kg female subsequently captured during the 2005/06 season showed similar characteristics. This fish had a gonad weight of 21.4 kg, a GSI of 25.8.

An appropriate interpretation of these differences based on information to date is that *D. mawsoni* builds up condition in the south over one or more seasons and then migrates north for spawning. This spawning season may extend over a protracted time period that may amount to a number of months. Such an extended spawning season has been noted for cod, *Gadus morhua* (Kjesbu, 1989; Chambers and Waiwood, 1996). The long season for cod is achieved in part by repeated spawning by individual females (Kjesbu, 1994; Hislop, 1984) and is thought to reduce the potential for mismatch between larval occurrence and favourable environmental conditions (Mertz and Myers, 1994). *Dissostichus mawsoni* may exhibit similar behaviour for a similar result.

Finding fish in poor condition prior to spawning is contrary to accepted knowledge of generalised fish spawning behaviour; however our observations support an asynchronous spawning over an extended season (or seasons). Poor physical condition is not universally consistent in the northern sample, possibly indicating different arrival times or spawning duration. The capture during this program of only two clearly identifiable spawning females may also indicate an extended and asynchronous event, with these two fish being at the extreme limits of the spawn. There is a general trend of increasing GSI recorded in the north over the period from December to February (Table 8 and Figure 7). Assuming, from the observations of two identifiable spawning fish, that spawning females have high GSI values (in the range of 20 and greater), most spawning would appear to take place at some time between the post-summer freeze through to the spring thaw.

Vitellogenesis in many species of Antarctic fish is reported to be a prolonged process (Everson, 1977; Kock, 1992). Everson et al. (1996) noted that this prolonged vitellogenesis means that sexually mature female fish will have ovaries with yolked oocytes at all times of the year. This is true of the sexual cycle of Notothenioids (Shandikov and Faleeva, 1992). Patchell (2002) reported that in ovarian sections of *D. mawsoni* taken in the Ross Sea during autumn 2001 at the onset of the spawning season there were often two size groups of vitellogenic oocytes present. This strategy would be consistent with an extended spawn.

A possible trigger for the onset of spawning may be firstly the end of the continuous daylight period and thence seasonal changes in day and night length. It was noted over the 2001/02 and 2002/03 seasons, that with the arrival of polar darkness for several hours a day in late February and early March, gonad development started to progress rapidly, particularly in male *D. mawsoni*. Average GSI by month, given in Table 8, clearly shows this pattern.

A rough estimate of the projected timing of spawning using CCAMLR gonad stage data, collected in 2000/01 and 2001/02 during sampling from April onwards, indicates the start of spawning occurring from about early June. This is about the mid-winter solstice when there are long nights at latitude 65°–70°S. This suggests photoperiod as a possible spawning switch. Photoperiod is well documented as a spawning trigger in many fish species including cod, haddock and various salmonids (McCormick and Naiman, 1984; Harmon et al., 2003; Trippel and Neil, 2003). The trend of increasing GSI in the northern area compared to a lower and static mean GSI in the south over the summer sampling season also supports the view that spawning occurs in the northern area.

Although recaptured tagged fish recorded on board the *San Aotea II*, from both the northern and southern areas, have generally shown only small distances between the release and recapture positions, it should be kept in mind that the tagging of larger fish only commenced in the 2004/05 season. Prior to this, the toothfish tagged were smaller than the observed population size distribution and were either sexually immature or at the smaller end of the spawning population. Some preliminary work carried out by the New Zealand National Institute of Water and Atmospheric Research (NIWA) indicated that large geographical movements may be limited to larger fish. If this is the case, major movements of tagged fish will not be apparent until increased numbers of larger toothfish are recaptured from the tagged pool over coming seasons.

In respect to the tagging program which now underpins the stock assessment for *Dissostichus* spp. in Subarea 88.1, the differences in fish condition between areas need to be quantified. This is particularly important as estimators such as the numbers of hooked fish observed or numbers of fish scanned for tags are related back to the proportion of the total tagged population. Effectively there are greater numbers of fish for a given unit of weight in the north than in the south. Differing figures should be applied to each area for this process.

Experience gained in working on *D. mawsoni* has shown that the standard CCAMLR gonad staging system used to index sexual maturity is too coarse to provide any sophisticated analysis of reproductive biology. If *D. mawsoni* gonads as reported by

Patchell (2002) contain more than one group of vitellogenic oocytes, the current staging definitions in use are unacceptable alone for detailed analysis. The collection of gonad weight for all toothfish sampled has proved a more useful tool to study the seasonal reproductive progression. GSI data could additionally be linked to the collection of samples to measure melatonin, vitellogenin and other enzymes associated with reproduction and spawning behaviour. There has been an increased sampling effort to obtain gonad tissue samples for microhistological study over the 2004/05 and 2005/06 season.

Conclusion

Analyses of data using four separate indices for the five summer seasons from 2000/01 to 2004/05 consistently support the hypothesis that there are differences in the structure of *D. mawsoni* populations between fish found on the hills and ridges of the Pacific-Antarctic Ridge to the north and the main Ross shelf to the south of Subarea 88.1 during the summer period. Genetic studies of *D. mawsoni* stock structure in the Ross Sea using mitochondrial DNA have so far shown few differences within the area and suggest that there is a single stock of *D. mawsoni* within Subarea 88.1. The differences between areas are as yet unexplained but, in particular given the differences in gonad development, suggest a spawning migration. An extended, asynchronous spawning in the northern area outside the polar summer season is suggested as the best explanation based on current results. The limited data from tagging returns do not generally show extensive fish movement, however the tagged pool at present represents smaller fish in the population, most of which are not part of the spawning population. More extensive movements may be seen as the tagging of more representative fish sizes that commenced in the 2004/05 season is continued, and the pool size of the larger size group increases.

These analyses were carried out using data collected over five seasons by the same vessel. The results are presented in order to highlight important elements, to tailor sampling requirements, and to provide a focus for future research on *D. mawsoni* in Subarea 88.1.

There is a more extensive set of data provided by all vessels participating in the fishery. These results suggest that serious consideration should be given to a more sophisticated analysis using modelling on the complete Ross Sea dataset and an increased focus on the collection of appropriate data at the appropriate time to describe the reproductive biology of *D. mawsoni*.

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Table 1: Numbers of fish sampled and numbers scaled by catch for Figure 3.

Fishing season	North				South			
	Males		Females		Males		Females	
	Scaled	Sampled	Scaled	Sampled	Scaled	Sampled	Scaled	Sampled
2000/01	1196	819	742	534	3851	1868	5695	2639
2001/02	1975	1119	1794	1124	5991	2287	9837	3596
2002/03	2548	1137	2497	1023	1953	1037	2952	1628
2003/04	810	378	304	171	1588	780	2625	1242
2004/05	2314	861	2236	682	4337	1994	6264	2843

Table 2: Comparison of mean and median total lengths from Antarctic toothfish samples in the northern area.

Season	Sex	Average length (cm)	Median length (cm)	Standard deviation from the mean	% less than 100 cm TL
2000/01	Male	139.9	140	12.54	0.52
2001/02	Male	140.8	142	12.91	0.37
2002/03	Male	143.0	143	11.63	0.14
2003/04	Male	141.2	141	12.23	0.36
2004/05	Male	141.3	141	12.24	0.45
2000/01	Female	150.5	151	15.00	0.44
2001/02	Female	151.4	151	12.51	0.16
2002/03	Female	153.7	153	11.66	0
2003/04	Female	152.3	152	11.37	0
2004/05	Female	153.8	154	12.99	0.57

Table 3: Antarctic toothfish, average depth for length samples by season for length-frequency analysis.

Season	Mean depth of sampling (m)	
	North	South
2000/01	1226.6	937.7
2001/02	1229.8	1212.9
2002/03	1365.7	1389.9
2003/04	1621.2	1223.8
Average	1354.5	1195.4

Table 4: Ratio of females to total catch-weighted sample for northern and southern areas.

Season	% females	
	North of 70°S	South of 70°S
2000/01	38.3	59.6
2001/02	47.5	62.1
2002/03	49.5	60.2
2003/04	27.3	62.3
2004/05	49.1	59.2

Table 5: Minimum and maximum lengths for length–weight data by season.

Season	Minimum	Maximum
2000/01	59	188
2001/02	62	197
2002/03	83	209
2003/04	50	197
2004/05	65	197

Table 6: Length–weight regression coefficients for samples taken north and south of 70°S over five seasons. The weight used is the average for each length class in grams and total length in centimetres. The standard equation is $W = aL^b$.

Sample	Area	Season	*a*	*b*	Number of observations	R^2
All	North	2000/01	0.0738	2.6133	202	0.91
		2001/02	0.0096	3.0104	947	0.96
		2002/03	0.0036	3.2165	2160	0.97
		2003/04	0.0138	2.9471	596	0.96
		2004/05	0.0104	2.9960	1560	0.74
	South	2000/01	0.0063	3.1479	4555	0.99
		2001/02	0.0062	3.1503	4396	0.99
		2002/03	0.0060	3.1563	1319	0.99
		2003/04	0.0054	3.1871	2440	0.99
		2004/05	0.0034	3.2656	4854	0.95
Males	North	2000/01	0.1288	2.4957	143	0.89
		2001/02	0.0426	2.6943	515	0.95
		2002/03	0.0212	2.8440	1137	0.97
		2003/04	0.1996	2.3920	390	0.84
		2004/05	0.0204	2.8578	872	0.66
	South	2000/01	0.0084	3.0860	1826	0.99
		2001/02	0.0056	3.1696	2119	0.99
		2002/03	0.0047	3.2046	4515	0.99
		2003/04	0.0098	3.0643	828	0.98
		2004/05	0.0031	3.2846	2001	0.93
Females	North	2000/01	0.0152	2.9511	59	0.98
		2001/02	0.0140	2.9413	434	0.92
		2002/03	0.0031	3.2508	1023	0.95
		2003/04	0.0134	2.9642	188	0.83
		2004/05	0.0116	2.9780	688	0.68
	South	2000/01	0.0050	3.1951	2556	0.99
		2001/02	0.0070	3.1253	3482	0.99
		2002/03	0.0047	3.2042	4515	0.99
		2003/04	0.0089	3.0865	1343	0.99
		2004/05	0.0052	3.1791	2845	0.94

Table 7: Number of observations, arithmetic mean, and standard deviation of coefficients of condition (*K*) by season and area. Sample type > 100 cm TL represents the Antarctic toothfish spawning population.

Sample type	Area	Season and sampling period	Males			Females		
			n	Mean (*K*)	Standard deviation (*K*)	*n*	Mean (*K*)	Standard deviation (*K*)
All	North	17–21 Mar 01	144	1.077	0.225	58	1.148	0.190
		20–25 Mar 02	476	0.955	0.167	401	1.027	0.184
		24 Dec 02–8 Jan 03 and 25 Feb–6 Mar 03	1085	0.986	0.177	998	1.088	0.184
		13–28 Dec 03	378	1.040	0.188	170	1.124	0.179
		5–12 Dec 04 and 1–13 Feb 05	860	1.027	0.173	682	1.053	0.178
	South	14 Jan–16 Mar 01	1787	1.243	0.146	2477	1.207	0.154
		27 Jan–17 Mar 02	2081	1.267	0.149	3402	1.278	0.169
		12 Jan–23 Feb 03	1034	1.267	0.150	1624	1.290	0.150
		6 Jan–21 Feb 04	770	1.318	0.150	1226	1.318	0.147
		27 Dec 04–29 Jan 05	1994	1.251	0.144	2840	1.239	0.149
>100 cm TL	North	17–21 Mar 01	143	1.077	0.226	58	1.148	0.190
		20–25 Mar 02	471	0.952	0.165	399	1.028	0.184
		24 Dec 02–8 Jan 03 and 25 Feb–6 Mar 03	1083	0.986	0.177	998	1.088	0.184
		13–28 Dec 03	376	1.038	0.185	170	1.124	0.179
		5–12 Dec 04 and 1–13 Feb 05	856	1.026	0.177	678	1.054	0.173
	South	14 Jan–16 Mar 01	993	1.274	0.153	1588	1.291	0.155
		27 Jan–17 Mar 02	1949	1.270	0.150	3220	1.280	0.170
		12 Jan–23 Feb 03	992	1.269	0.152	1588	1.292	0.150
		6 Jan–21 Feb 04	751	1.313	0.144	1202	1.316	0.143
		27 Dec 04–29 Jan 05	1899	1.252	0.144	2715	1.243	0.139

Table 8: Mean GSI for areas north and south by month and sex for all seasons.

Month:	December	January	February	March
Male				
North	2.62	3.18	6.52	7.05
South	0.37	0.85	0.77	0.37
Female				
North	4.58	5.14	7.73	7.28
South	1.04	1.47	1.41	1.04

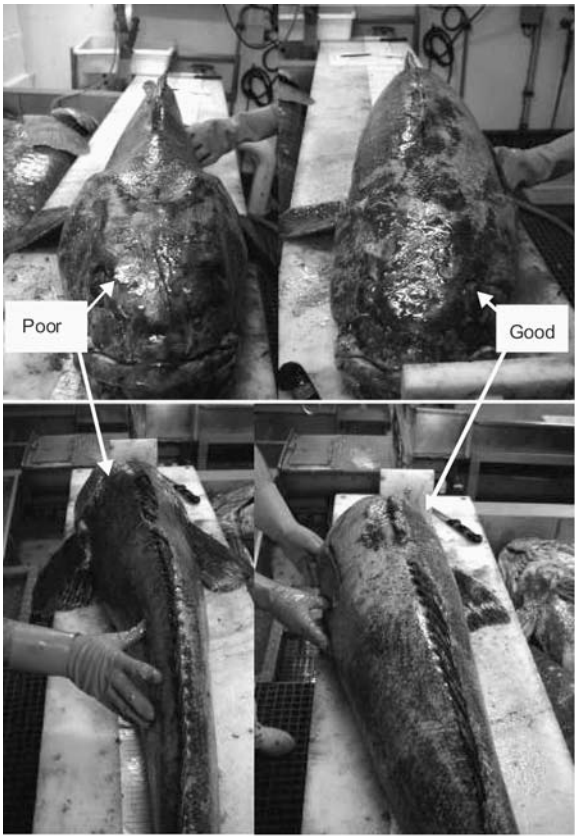

Figure 1: Physical appearance of *Dissostichus mawsoni* in good and poor physical condition, anterior and posterior views.

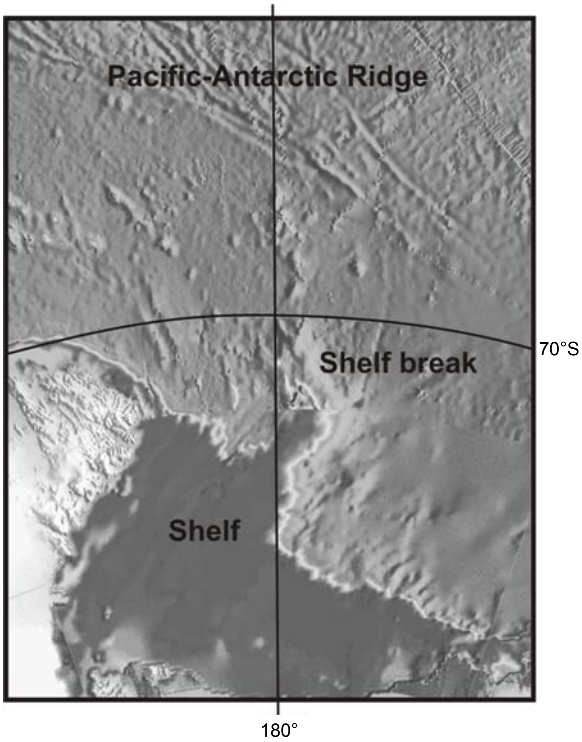

Figure 2: Location of the study area showing the 70°S division and general area descriptions used in the analysis.

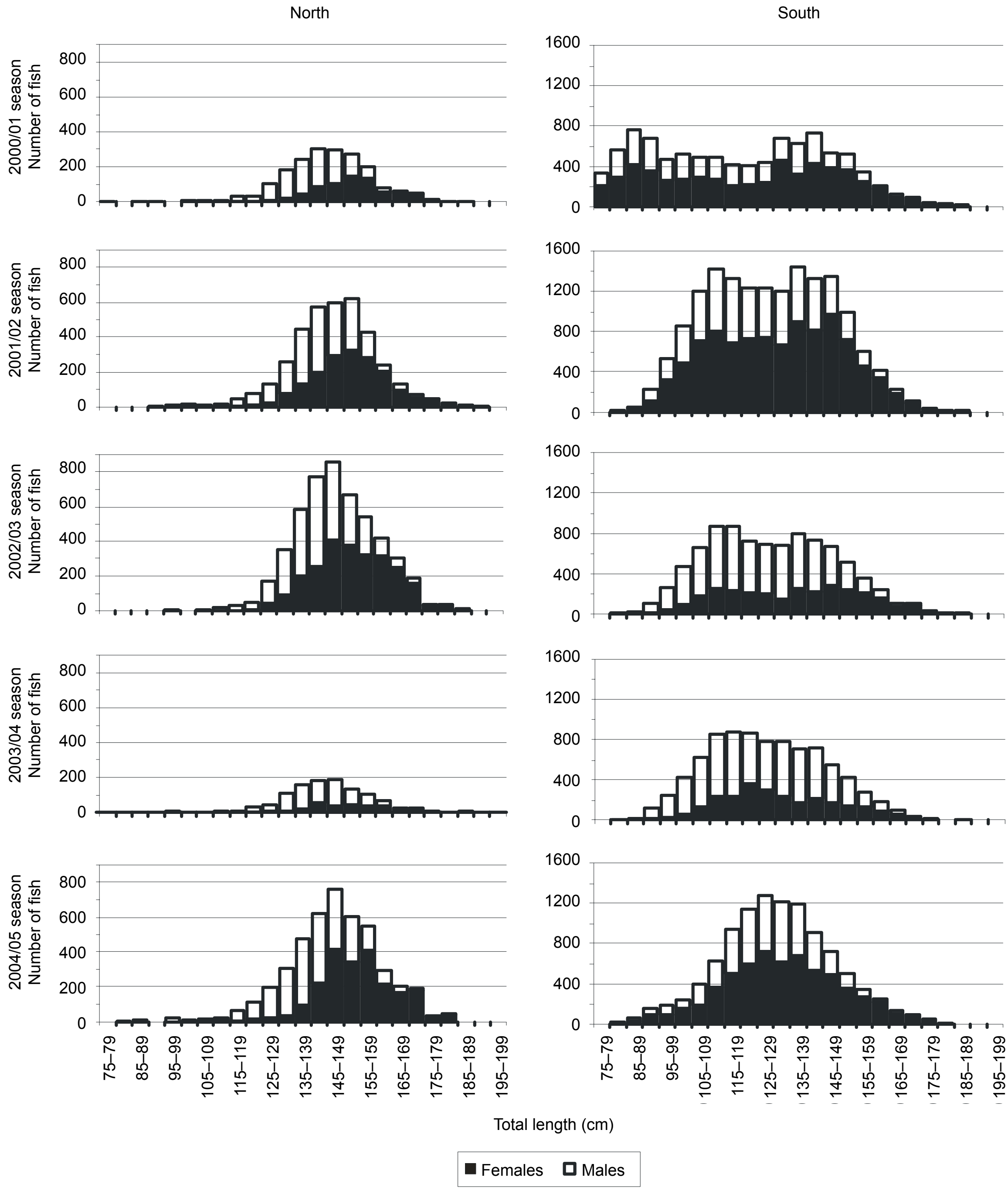

Figure 3: *Dissostichus mawsoni* catch-weighted length-frequency distribution for Subarea 88.1 for the areas defined as 'north' and 'south' for five seasons. Data are grouped by 5 cm interval; length is total length (TL).

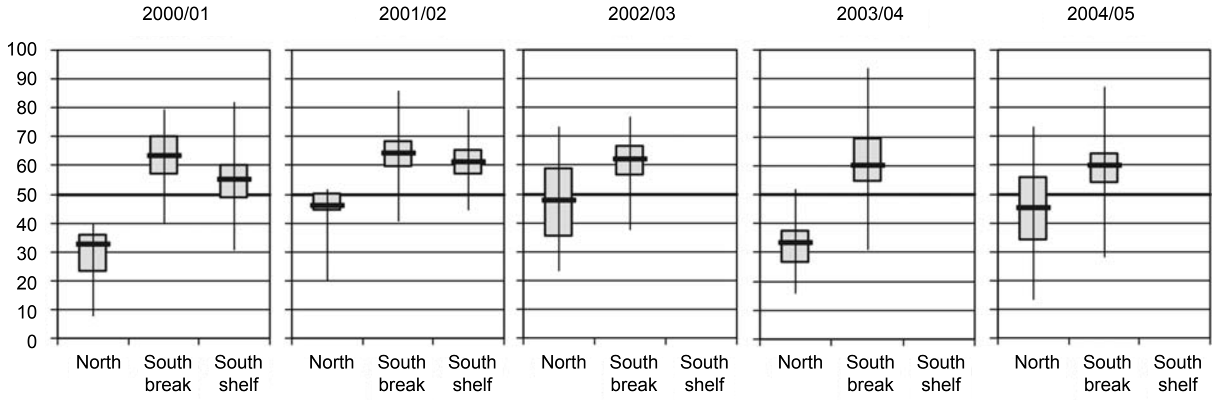

Figure 4: Ratio of females from research data for the seasons from 2000/01 to 2004/05 over the period December to April. Grouped by area, the data excludes samples where fewer than 10 fish were caught. The bar shows the median, the box the interquartile range, and the whisker, the range of values recorded for each interval. North is the part of Subarea 88.1 north of 70°S, the south shelf break, the sector between 70° and 72°S, and the south shelf, the area south of 72°S.

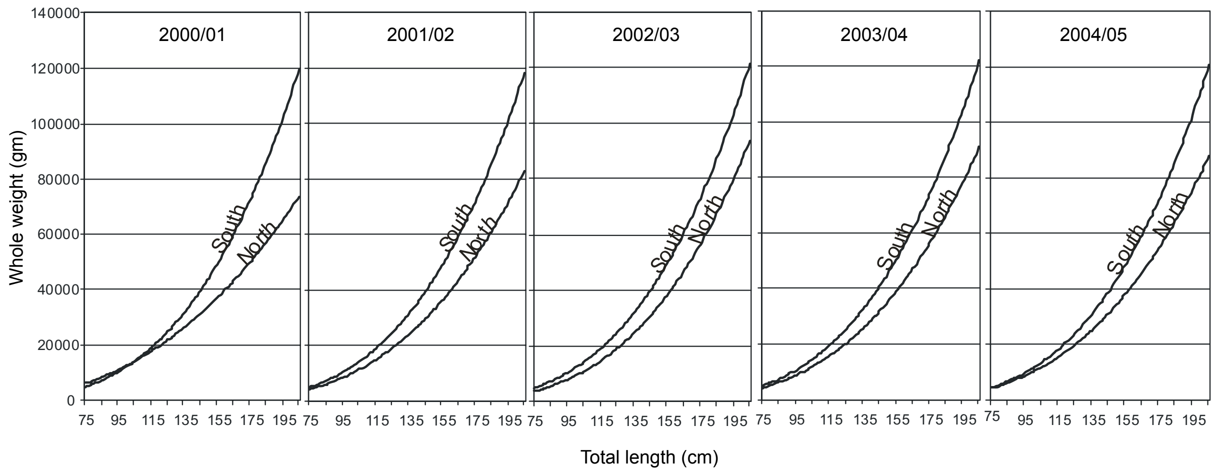

Figure 5: Fitted length–weight relationships for *Dissostichus mawsoni*, for both sexes combined, collected by the *San Aotea II* over five seasons, and plotted by northern and southern sampling area. The standard equation is $W = aL^b$.

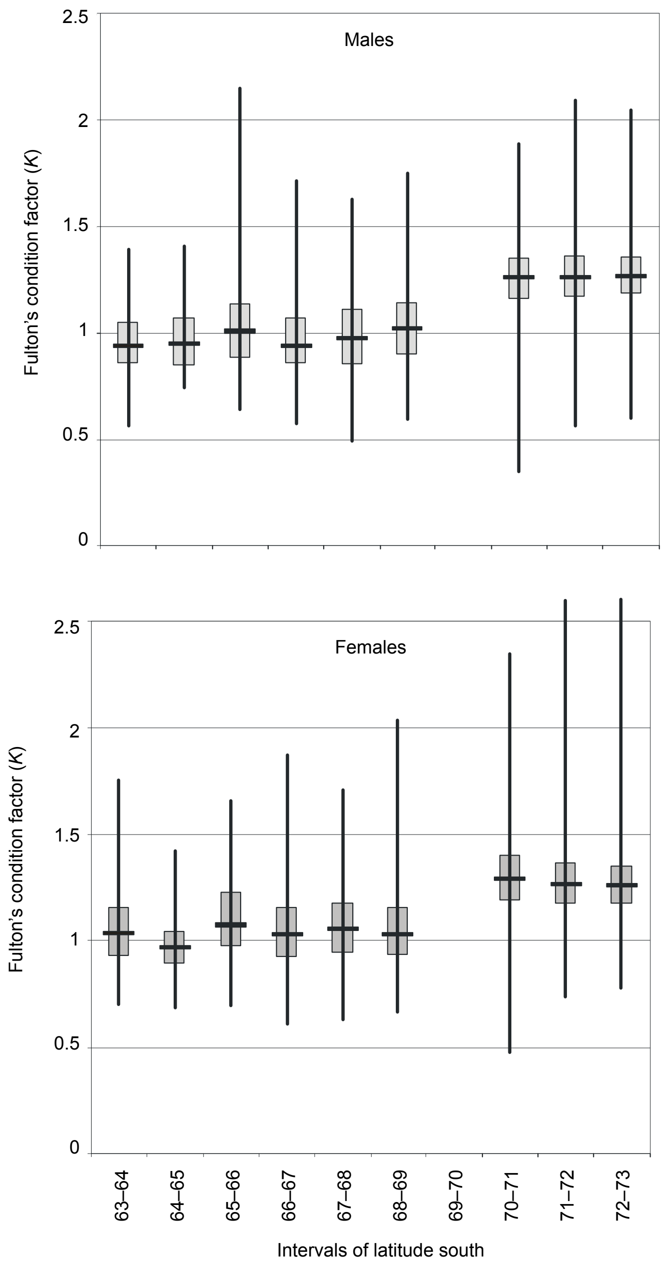

Figure 6: Coefficient of condition (*K*) for *Dissostichus mawsoni*, grouped by latitude south, for seasons between 2000/01 and 2004/05 and plotted by sex. The bar shows the median, the box, the interquartile range, and the whisker, the range of values recorded for each interval.

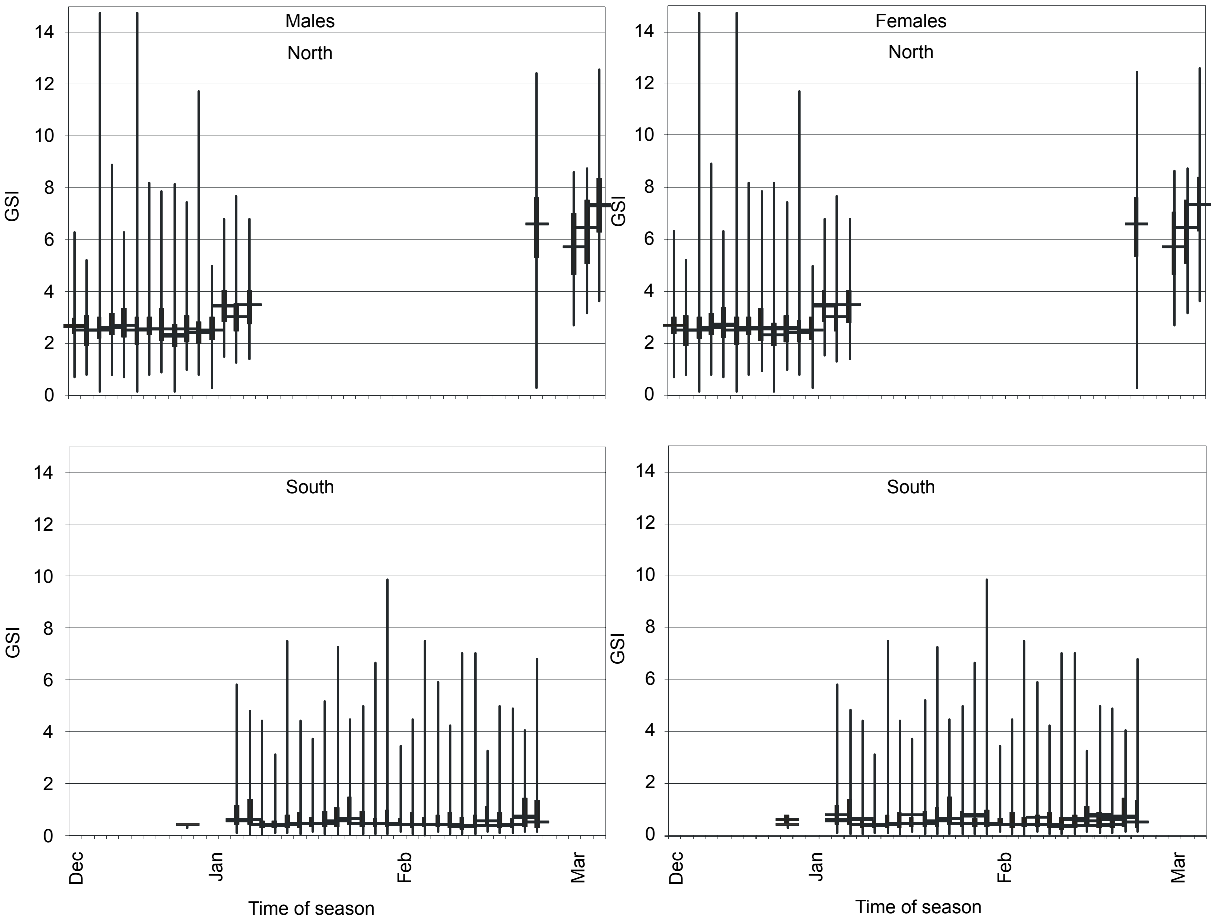

Figure 7: *Dissostichus mawsoni* GSI plotted by two-day intervals using data from 2002/03, 2003/04 and 2004/05. The bar shows the median, the box, the interquartile range, and the whisker, the range of values recorded for each interval.

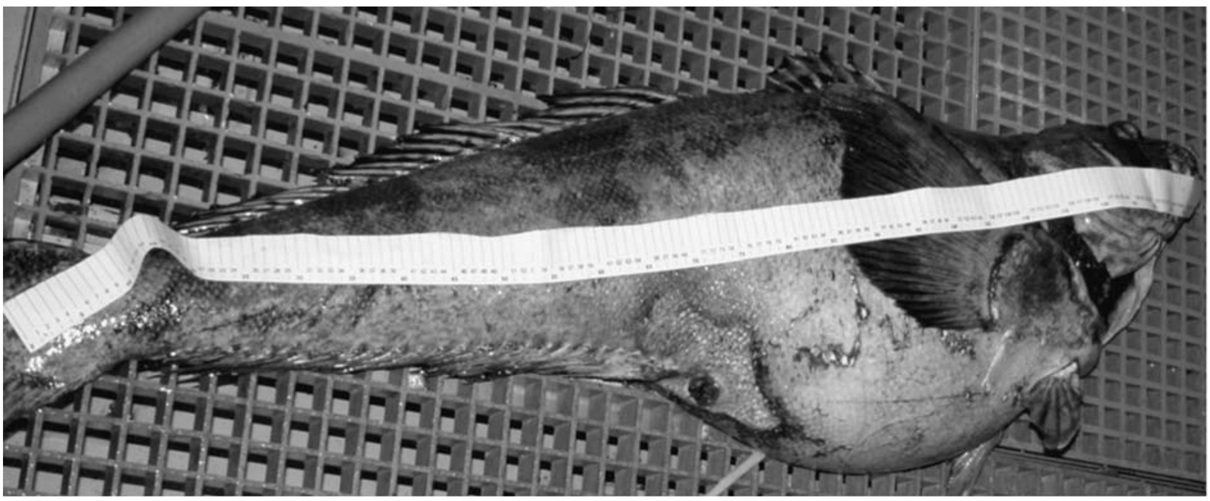

Figure 8: Spawning female caught 21 December 2004 in the northern area. Note the abdominal cavity swollen with eggs and the generally poor body condition shown by the slender tail section.

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