

**DISTRIBUTION AND RELATIVE ABUNDANCE OF ANTARCTIC TOOTHFISH
(*DISSOSTICHUS MAWSONI*) ON THE ROSS SEA SHELF**

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Abstract

This paper summarises knowledge of the distribution and relative abundance of Antarctic toothfish (*Dissostichus mawsoni*) on the Ross Sea shelf (defined here as the continental shelf out to the edge of the shelf break at about 600–800 m depth). The focus is on *D. mawsoni* catches from the shelf, as this area is likely to have the greatest overlap between *D. mawsoni* and potential predators, and thus where any ecosystem effects would be most likely to occur. The shelf catch has been taken mainly in depths greater than 800 m from three localised fishing grounds of deep water off Terra Nova Bay, Ross Island, and in the south of small-scale research unit (SSRU) 881L (adjacent to the Ross Ice Shelf). The catch rates from the exploratory longline fishery typically show high temporal and spatial variability, even between consecutive sets within the main fishing grounds. Most toothfish caught in the southern Ross Sea were sub-adult and maturing fish, typically ranging from 60–130 cm in length, with some evidence for an ontogenetic migration from east to west as they grow. From the fisheries data available, there is no evidence for a northward contraction in the range of *D. mawsoni* over the course of the fishery. Nevertheless, it would seem prudent to have a monitoring system in place so that changes in relative abundance of these sub-adult fish could be detected. It is recommended that CCAMLR consider developing a sub-adult longline survey to monitor this part of the population.

Résumé

Cet article résume les connaissances sur la répartition et l'abondance relative de la légine antarctique (*Dissostichus mawsoni*) sur le plateau de la mer de Ross (par définition, le plateau continental jusqu'à la bordure, à environ 600–800 m de profondeur). On s'intéresse plus particulièrement aux captures de *D. mawsoni* provenant du plateau, car c'est dans ce secteur que le chevauchement entre *D. mawsoni* et des prédateurs potentiels pourrait être le plus important et, de ce fait, que les effets sur l'écosystème seront le plus probables. La capture du plateau a principalement été effectuée à plus de 800 m de profondeur en trois lieux de pêche localisés d'eaux profondes au large de la baie Terra Nova, de l'île de Ross et au sud de l'unité de recherche à échelle précise (SSRU) 881L (adjacente à la plate-forme glaciaire de Ross). Les taux de capture de la pêcherie exploratoire à la palangre montrent en général une forte variabilité spatio-temporelle, même entre des poses consécutives dans les principaux lieux de pêche. La plupart des légines capturées dans le secteur sud de la mer de Ross sont des subadultes et des poissons en période de maturation, en général de 60 à 130 cm de longueur ; une migration ontogénétique d'est en ouest liée à la croissance est mise en évidence. D'après les données de pêche disponibles, l'aire de répartition de *D. mawsoni* ne semble pas s'être rétrécie vers le nord depuis le début de la pêcherie. Néanmoins, il serait prudent de mettre en place un système de suivi qui permettrait de détecter les changements de l'abondance relative de ces subadultes. La CCAMLR pourrait envisager de mettre au point une campagne d'évaluation des subadultes par pêche palangrière pour suivre cette partie de la population.

Резюме

В настоящей статье обобщается информация о распределении и относительной численности антарктического клыкача (*Dissostichus mawsoni*) на шельфе моря Росса (определяемого здесь как континентальный шельф до границы кромки шельфа на глубине около 600–800 м). Внимание фокусируется на уловах *D. mawsoni*,

полученных на шельфе, поскольку в этом районе может быть самое большое перекрытие между *D. mawsoni* и возможными хищниками, и поэтому там скорее всего будут иметь место любые экосистемные последствия. Уловы на шельфе были в основном получены на глубинах более 800 м на трех локализованных глубоководных промысловых участках в районе залива Terra-Nova, о-ва Росса и в южной части мелкомасштабной исследовательской единицы (SSRU) 881L (примыкающей к шельфовому леднику Росса). Коэффициенты вылова в ходе поискового ярусного промысла, как правило, отличаются высокой временной и пространственной изменчивостью даже между последовательными постановками в пределах основных промысловых участков. Большинство особей клыкача, пойманных в южной части моря Росса, были предвзрослыми и созревающими особями, обычно в диапазоне длин 60–130 см; имелись некоторые свидетельства онтогенетической миграции с востока на запад по мере роста. Судя по имеющимся промысловым данным, нет никаких признаков сокращения ареала *D. mawsoni* в северном направлении со времени ведения промысла. Тем не менее, представляется целесообразным иметь систему мониторинга, с тем чтобы можно было выявлять изменения в относительной численности этих предвзрослых особей. Рекомендуется, чтобы АНТКОМ рассмотрел вопрос о разработке ярусной съемки предвзрослых особей для мониторинга этой части популяции.

Resumen

Este artículo resume el conocimiento actual sobre la distribución y abundancia relativa de la austromerluza antártica (*Dissostichus mawsoni*) en la plataforma del Mar de Ross (definida aquí como la plataforma continental hasta el borde de la misma, a unos 600–800 m de profundidad). La atención se centra en las capturas de *D. mawsoni* de la plataforma, pues es muy probable que esta área sea la que tiene una mayor superposición de las áreas de distribución de *D. mawsoni* y de sus posibles depredadores, y por ende, donde es más probable que se manifieste cualquier efecto en el ecosistema. La captura de la plataforma se ha extraído principalmente a más de 800 m de profundidad en tres caladeros de pesca de aguas profundas situados frente a bahía Terra Nova, en Isla Ross, y al sur de la unidad de investigación en pequeña escala (UIPE) 881L (aledaña a la plataforma de hielo de Ross). Las tasas de captura de la pesquería de palangre exploratoria muestran, como de costumbre, una alta variabilidad temporal y espacial, aún entre lances consecutivos dentro de los caladeros de pesca más importantes. La mayor parte de las austromerluzas capturadas al sur del Mar de Ross fueron peces subadultos e inmaduros, por lo general de 60–130 cm de talla, evidenciándose en parte una migración ontogénica de este a oeste durante su desarrollo. Los datos pesqueros disponibles indican que el rango de distribución de *D. mawsoni* disminuye hacia el norte durante el transcurso de la pesquería. No obstante, parecería prudente contar con un sistema de seguimiento para poder detectar los cambios en la abundancia relativa de estos peces subadultos. Se recomienda que la CCRVMA considere la elaboración de una prospección de palangre dirigida a los peces subadultos para estudiar esta parte de la población.

Keywords: Antarctic toothfish, *Dissostichus mawsoni*, Ross Sea shelf, toothfish fishery, distribution, length frequency, range contraction, CCAMLR

Introduction

An exploratory fishery for toothfish in CCAMLR Subarea 88.1 has been operating since 1996/97, conducted by commercial longliners (Figure 1). A large amount of data on toothfish and the associated by-catch has been collected. Annual summaries of fishing operations have been reported since 2000 (e.g. Hanchet et al., 2003; Stevenson et al., 2008). There have also been a large number of studies looking at aspects of Antarctic toothfish (*Dissostichus mawsoni*) biology, including stock structure, age and growth, reproduction, diet, movement and trophic status, much of which was reviewed and summarised by Hanchet et al.

(2003) and Hanchet (2006) and more recently used to develop a hypothetical life history (Hanchet et al., 2008b). There has been a research program on *D. mawsoni* at McMurdo Sound, which has been catching, sampling, and tagging and releasing toothfish in this locality since 1971 (Testa et al., 1985; DeVries et al., 2008). There is also other information on the distribution of *D. mawsoni* in the area derived from research surveys and studies focusing on marine mammals (e.g. Hanchet et al., 2008a; Fuiman et al., 2002).

There is currently some concern over the potential impact of the toothfish fishery on the viability of predator populations of *D. mawsoni* in the Ross

Sea (e.g. Ainley and Siniff, 2009; Ainley et al., 2009). At least part of this concern derives from a lack of published information over the areas and depths being fished by the exploratory fishery, the spatial management of the fishery and an understanding of the overlap between the distribution of *D. mawsoni* and its predators. An earlier draft of this paper was prepared for the Second Workshop on Fisheries and Ecosystem Models in the Antarctic (FEMA 2), where much of the existing data were reviewed (SC-CAMLR, 2009).

The purpose of this paper is to review the data from the exploratory fishery and discuss these in relation to data on *D. mawsoni* from other sources to provide a better understanding of the distribution and abundance of *D. mawsoni* on the Ross Sea shelf. The focus is particularly on the shelf because this area is likely to have the greatest overlap between *D. mawsoni* and its predators and is thus where any ecosystem effects would be most likely to occur. It should be noted that a paper providing a more comprehensive analysis of the entire Ross Sea region is being prepared for publication elsewhere. In this paper, the Ross Sea is defined as the continental shelf out to the edge of the shelf break at about 600–800 m depth (mainly small-scale research units (SSRUs) 881J, 881L and 881M – see Figure 1), whilst noting that this includes several regions of deeper water adjacent to the Antarctic continent itself. A detailed summary of the *D. mawsoni* fishery catches from the smaller fishing grounds on the Ross Sea shelf is provided here, including the catch, effort, distribution and abundance, and size composition of *D. mawsoni*. The fisheries data are also examined for any signs of contraction of the stock range since fishing began.

Materials and methods

The fishery data used in this report come from a CCAMLR extract of the vessel fine-scale catch and effort (C2) data for all fishing vessels in Subareas 88.1 and 88.2 for all years up to, and including, the 2007/08 fishing year. The observer data used in this report come from a CCAMLR extract of the observer logbook data for all fishing vessels in Subareas 88.1 and 88.2 for all years up to, and including, the 2007/08 fishing year.

Data error checking and grooming are a necessary and important first step before conducting a characterisation of fishery data. Algorithms have been developed by New Zealand scientists over time to identify and correct errors or to use median imputation for missing fields (e.g. Hanchet et al., 2006; Stevenson et al., 2008). Additional errors, including duplicate hauls, have been identified

through data quality work (e.g. Middleton and Dunn, 2008). Many of these errors have since been rectified, where possible, by the CCAMLR Secretariat.

Error detection and data cleaning were conducted in three steps: (i) visual detection of errors within the C2 data; (ii) visual detection of errors within the observer data; and (iii) correcting of errors in observer data based on a link to the C2 data. The spatial data recorded in the C2 records were assumed most likely to be correct, and were used to provide a basis for the detection and cleaning of the location data. A total of 10 827 fishing event records were available from the C2 data for the Ross Sea fishery between the years 1996/97 and 2007/08 (Table 1).

In this paper, the word 'season' refers to the period from December to May, the months of fishing in the middle of the CCAMLR fishing year (i.e. the 2008 season is part of the 2007/08 split-year). The area adjacent to the Ross Sea is divided into two subareas: Subarea 88.1 covering the western Ross Sea and Subarea 88.2 covering the eastern Ross Sea. These subareas are further divided into SSRUs for the purposes of finer-scale catch allocation and reporting purposes (Figure 1). Since 2004, several SSRUs have had catch limits set at zero to help concentrate fishing effort and improve returns from the tagging experiment (SC-CAMLR-2008). Following CCAMLR, the Ross Sea toothfish fishery is defined here as the area covered by all of Subarea 88.1 and the western SSRUs in Subarea 88.2 (i.e. 882A and 882B) (SC-CAMLR, 2005). Further defined is the slope as the 600–2 000 m depth interval on the northern slope of the Ross Sea proper, and the shelf as the area to the south of the continental slope, noting that it includes extensive areas of water deeper than 600 m, particularly in the southwest of the Ross Sea. For the purposes of this paper, this study has focused primarily on SSRUs 881J, 881L and 881M which are entirely within the shelf area. Depths provided in this paper are the mean of the depths at the start and end positions of the set as recorded in C2 data.

Results

Ross Sea fishery

Details of the exploratory toothfish fishery in the Ross Sea fishery are summarised in Table 1. The fishery saw a steady expansion of effort from 1997 to 2003, followed by a large increase in 2004. Since then effort has been slightly more stable ranging from 1 000–1 500 sets per year. The total catch of *Dissostichus* spp. has shown a steadier increasing

Table 1: Details of the toothfish (*Dissostichus* spp.) fishery in the Ross Sea, which includes Subarea 88.1 and SSRUs 882A and 882B. Catch set⁻¹ and catch hook⁻¹ are unstandardised.

Year	Ross Sea					88.1
	No. of vessels	Number of sets	Catch (tonnes)	Catch set ⁻¹	Catch hook ⁻¹	Catch limit (tonnes)
1997	1	2	<1	0.06	0.03	1 980
1998	1	82	41	0.51	0.16	1 980
1999	2	252	297	1.18	0.20	1 510
2000	3	489	752	1.57	0.33	2 281
2001	7	687	625	0.91	0.18	2 090
2002	2	434	1 365	3.17	0.56	2 064
2003	9	795	1 789	2.26	0.41	2 508
2004	21	2 160	2 184	1.01	0.18	3 760
2005	10	1 527	3 197	2.10	0.40	3 250
2006	13	1 040	2 968	2.85	0.47	2 964
2007	15	1 394	3 086	2.22	0.39	3 032
2008	15	1 012	2 259	2.23	0.34	2 660

Table 2: Catches (tonnes) of Antarctic toothfish by SSRU by year from C2 data.

SSRU	Fishing year											Total
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	
881A	0	0	0	0	0	0	*	*	1*	0*	*	1
881B	0	0	0	30	35	88	61	70	10	198	87	578
881C	0	0	0	33	361	1026	226	428	333	375	164	2 947
881D	0	0	0	0	0	0	*	*	*	*	*	0
881E	5	0	0	9	0	2	38	55	*	0*	*	109
881F	0	0	0	0	0	0	*	*	*	2*	*	2
881G	4	0	0	69	16	41	84	53	0	0	0	268
881H	4	99	181	98	433	480	1085	770	990	1504	1364	7 009
881I	26	149	376	246	345	126	651	613	396	557	126	3 612
881J	2	7	11	10	0	0	1	158	208	202	24	622
881K	0	31	183	0	121	0	0	736	588	0	60	1 719
881L	0	0	0	97	0	0	12	170	87	0	39	405
881M	0	9	0	2	0	0	0	0	337	236	386	971
882A	0	0	0	0	41	0	11	137	17*	*	*	207
882B	0	0	0	0	0	0	1	0	*	*	*	1
Total	41	296	752	594	1 353	1 764	2 171	3 190	2 967	3 074	2 250	18 453

* SSRUs with a zero catch limit – but note that in 2006–2008 a catch of up to 10 tonnes was permissible in each of these SSRUs under a research fishing exemption.

trend, peaking at about 3 000 tonnes between 2005 and 2007 before dropping to 2 300 tonnes in 2008, partly as a result of the reduction in catch limit. Almost all the targeted catch is *D. mawsoni* and the rest of the paper deals only with this species.

Location of fishing

The location of *D. mawsoni* catches has varied considerably over time (Table 2). Of the total catch of almost 19 000 tonnes, about 20% has been taken from the northern ground SSRUs (881A–881G),

70% from the continental slope SSRUs (881H, 881I, 881K, 882A, 882B) and 10% from the continental shelf SSRUs (881J, 881L, 881M).

In the first four years most of the catch was taken from the continental slope. In 2003, ice severely constrained the fishery on the slope and over 50% of the catch was taken from SSRU 881C. Since 2004, the highest catches have been taken consistently from SSRU 881H, and in the past two years this SSRU has contributed to >50% of the Ross Sea fishery catch. Moderate catches have also been taken from the slope SSRUs 881I and 881K. Catches

Table 3: Catch, effort and unstandardised CPUE (with CVs) for the main three fishing grounds on the Ross Sea shelf.

Year	Vessels	Effort (sets)	Catch (tonnes)	Raw CPUE (tonnes set ⁻¹)	
				Mean	CV
Terra Nova Bay					
2005	2	9	0.0	0.00	2.87
2006	2	88	337.4	3.83	0.57
2007	2	80	205.8	2.57	0.72
2008	3 ¹	171	383.6	2.24	0.70
Ross Island					
1999	1	18	10.3	0.57	0.66
2007	2	60	158.3	2.64	0.47
2008	2	14	7.9	0.57	1.03
881L below 77°30'S					
2001	2	156	102.4	0.66	0.52
2004	1	21	12.5	0.59	0.77
2005	1	8	2.2	0.28	0.58
2008	2	38	52.7	1.39	0.53

¹ An additional New Zealand vessel completed three sets at the end of the season.

from these SSRUs would undoubtedly have been higher, but in several years (e.g. 2008) much of the area was covered by ice. Catches in SSRU 881C are constrained by the catch limit for the northern area, rather than ice, which has been about 300–350 tonnes per year since 2004. This SSRU comprises a number of underwater topographic features including banks, ridges and seamounts, with characteristically high catch rates of large toothfish. Although much of SSRU 881M is relatively ice-free in most years, significant catches have been taken only in the 2006–2008 seasons. Toothfish caught in the southern and western Ross Sea are typically much smaller than on the slope and in the north.

Depth of fishing

The depth distribution of fishing in the Ross Sea fishery varies considerably between SSRUs (Figure 2). Fishing on the banks and ridges in the three northernmost SSRUs (881A–881C) tends to be deepest at ~1 500 m. Fishing in the southern SSRUs bordering the coast and ice shelf has ranged from about 500 to 1 200 m, with a median depth of only 600 m in SSRU 881L and median depths of 800 and 1 000 in SSRUs 881J and 881M respectively. Fishing on the continental slope SSRUs and elsewhere has typically averaged 1 000–1 200 m.

Fishing grounds on the shelf

The location of *D. mawsoni* catches in SSRUs 881J–881M, summed by small squares across all years, is shown in Figure 3. The fishing on the shelf is highly depth-dependent. Very little

fishing has been carried out in the extensive areas of water shallower than 600 m, and what fishing has been carried out has generally resulted in low catches and catch rates (Figures 3 and 4). Catches in SSRUs 881J and 881M generally showed an increasing trend in CPUE with depth down to at least 1 200 m, whilst catches in SSRU 881L showed no trend in catches over a depth range of 500 to 800 m (Figure 4). In comparison, catches from the fishery as a whole tend to peak between 1 000 and 1 500 m (Figure 4). The highest catches have generally been associated with waters deeper than 800 m and have been restricted to several different fishing grounds including the deep trough off Terra Nova Bay in SSRU 881M, the deep area to the northeast of Ross Island which straddles the south of SSRUs 881M and 881J, and the area adjacent to the ice shelf in the southwest of SSRU 881L (see Figure 3). High catches have also been made along the continental slope in SSRU 881K as well as in the northeast of SSRUs 881J and 881L, both of which are immediately adjacent to the continental slope and are associated with the more preferred slope habitat.

The annual catch, effort and raw CPUE for *D. mawsoni* for these three main fishing grounds on the shelf are summarised in Table 3. A feature of the toothfish catches in each of these grounds is the highly variable catch and CPUE, even in the same depth range, between adjacent cells (Table 3, Figure 3). A second feature is that all three grounds have been fished to differing extents, and by different vessels, over the course of the fishery making interpretation of catches and CPUE difficult due to the known very strong vessel effect on CPUE (e.g. Dunn and Hanchet, 2006).

The Terra Nova Bay ground is a deep trough running northeast from the mouth of Terra Nova Bay and extending from a maximum depth of ca. 1 200 m in the south to 600 m in the north. Highest catches have been from depths greater than 800 m (Figure 3). Most fishing was carried out in the three years from 2006 to 2008, with catches peaking in 2008, and a total catch of 927 tonnes (Table 3). Different autoline vessels fished this ground in each of the 2006, 2007 and 2008 seasons, so there is little vessel overlap between years to develop a consistent time series of CPUE indices. Most fishing was carried out during a 2–3 week period in January of each year.

The Ross Island ground lies in the area of deep water immediately to the north and east of Ross Island and adjacent to the Ross Ice Shelf. The location of the ice shelf and bathymetry here are unreliable but the C2 records indicate that most catches were taken at a depth of 800–900 m. Most fishing was carried out in 2007, with small catches in 1999 and 2008, and a total catch of 177 tonnes (Table 3). The fishing in 2007 was carried out by two vessels using the Spanish longline fishing method. Raw toothfish CPUE for 2007 was similar to that recorded for Terra Nova Bay in 2007, but the vessels and fishing methods (Spanish system compared to autoline) were different and so interpretation of trends in CPUE is difficult. All the fishing was carried out during a two-week period in January of that year.

The third main fishing ground was in the south of SSRU 881L adjacent to the ice shelf. Fishing has mainly been carried out between depths of 500 and 850 m, with most sets lying in the range 550–700 m. Most fishing was carried out by two autoline vessels in 2001 as a result of the slope fishing grounds being ice-covered during that season, whilst the second highest catch was recorded in 2008 (Table 3). A total of 170 tonnes toothfish has been taken from this area. Raw toothfish CPUE was lower than the CPUE recorded for the other two grounds on the shelf.

Tag recaptures

A tagging experiment has been under way in the Ross Sea fishery since the 2001 fishing season (Dunn et al., 2007). The inferred movement of the recaptured *D. mawsoni* is given in Figure 5. Most fish have moved only short distances, typically less than 100 n miles. The focus of this study is on the 13 fish which have moved further than 100 n miles, shown in Figure 5. These fish were all relatively small, ranging from 72 to 117 cm length at recapture, and comprised eight males and five

females. Five fish moved from the slope fishery (SSRUs 881H, 881I, or 881K) into the Terra Nova Bay fishing ground, whilst a sixth fish moved from the slope fishery (SSRU 881H) into the Ross Island fishing ground. These fish ranged in length from 72 to 96 cm. The other long-distance movements were along the slope between slope SSRUs (6 fish) and from the northern SSRU 881B into SSRU 881H (1 fish).

Size distribution

The scaled size distribution of toothfish caught in each of the three grounds, for years where more than 10 sets were completed, is shown by year in Figures 6 to 8. The size distribution was similar between sexes, with sex ratios close to 1:1, but varied between years within the same fishing ground and between fishing grounds. However, there were no clear trends in the size distribution of fish caught on each of the grounds over time. Fish in the south of SSRU 881L tended to be the smallest, ranging mainly from 65 to 120 cm (Figure 6). There was a mode at 85 cm in 2001, 105 cm in 2004 and 75 cm in 2008. Fish near Ross Island tended to be slightly larger, ranging mainly from about 70 to 135 cm (Figure 7). There was a mode at 80 cm in 1999 and 100–115 cm in 2007. The fish distribution near Terra Nova Bay tended to be bimodal, ranging from 70 to 135 cm, and with similar modal lengths to the Ross Island fish (Figure 8). There were modes at 80 cm and 100–115 cm in each of the three years. For comparison, the size distribution of the fish caught in the south of SSRUs 882A and 882B on the eastern Ross Sea shelf was also plotted (see Figure 3 for the location of the catches). This area was only fished in 2004 when it caught fish ranging from 60 to 110 cm (Figure 9), which is similar to the size of fish caught in the south of SSRU 881L.

Discussion

Distribution and relative abundance

The data collected from the exploratory fishery suggests that *D. mawsoni* are strongly associated with a particular depth range and therefore have a localised distribution in the Ross Sea region. They have been caught from bottom depths of 450 m to over 2 000 m in the fishery but have clearly been targeted at different depth ranges in different areas. Most fishing effort has been concentrated on depths greater than at least 500 m, on each of the grounds, with highest catches taken from depths greater than 800 m. Very few sets have been made in less than 500 m and most of these have zero, or very low, catch rates. Catch rates in SSRUs 881J

and 881M showed a positive trend with depth, whereas catches in SSRU 881L showed no trend with depth.

It is also clear that in some areas and at some times *D. mawsoni* range through the entire water column (e.g. Fuiman et al., 2002; Yukhov, 1971), but the spatial extent of its midwater distribution and the proportion of the population which occurs off the bottom are unknown. Vertical migrations into the water column have also been reported for 70–80 cm long *D. eleginoides* on the edge of the Heard Island Plateau using archival tags (Williams and Lamb, 2002). Most of the fish had periods of active vertical movement alternating with periods of relative inactivity, loosely correlated with moon phase, whilst there was also some indication of diurnal vertical migration, which is consistent with the preliminary findings of Fuiman et al. (2002) for *D. mawsoni* in the Ross Sea.

There is only very limited information on the distribution and relative abundance of toothfish from other sources. A US research program at McMurdo Sound has been carried out using vertical set lines since 1971 (DeVries et al., 2008). Most lines have been set in 500–550 m depth and the program has caught over 4 500 toothfish ranging from 90 to 160 cm with a mode at 130–140 cm. Catches by other methods have been much smaller. A total of only nine toothfish measuring 75–134 cm were caught from over 70 bottom trawls from three separate trawl surveys covering depths of 280–940 m over parts of the shelf and upper slope (Eastman and Hubold, 1999; O'Driscoll et al., 2004; Hanchet et al., 2008a). Vacchi et al. (2000) caught three toothfish ranging from 120–167 cm in gill nets and trammel nets in depths of 530–660 m. No toothfish were caught in over 50 midwater trawls made over the shelf and slope (DeWitt, 1970; Hanchet et al., 2008a).

As noted by Hanchet et al. (2008b) there appears to be spatial segregation between size classes within the Ross Sea itself. There is some evidence for an ontogenetic migration from east to west along the southern Ross Sea with smaller toothfish (60–120 cm long) found to the east and slightly larger toothfish (80–135 cm long) found off Ross Island and Terra Nova Bay. However, at the same time there also appears to be movement of smaller fish between the continental slope and Ross Island and Terra Nova Bay grounds as evidenced from the tag recaptures. Dunn et al. (2007) noted that smaller fish (<100 cm) moved the largest mean distance between release and recapture. It therefore seems likely that fish of this size move readily between the Ross Sea shelf and slope and

that the apparent east–west ontogenetic movement may also be associated with the increase in depth. The larger fish found in Terra Nova Bay are close to reaching sexual maturity and are probably developing energy reserves prior to migrating to the northern grounds for spawning (Fenaughty, 2006; Hanchet et al., 2008b). Several fish tagged by US scientists at McMurdo Sound have been recaptured in SSRU 881C (Hanchet et al., 2008b). The fish caught at McMurdo Sound by US scientists tend to be larger than those caught by the longline fishery at Terra Nova Bay and Ross Island (DeVries et al., 2008). The reason for this difference is unclear but could be related to the location, the hook size, or the different gear set-up (vertical set lines as opposed to horizontal longlines). Surprisingly, no *D. mawsoni* <50 cm long have been caught in any sampling or fishing in the Ross Sea.

In summary, the distribution of *D. mawsoni* is probably substantially wider than that depicted by the distribution of catches in Figure 3. Although toothfish appear to be more abundant in depths greater than 500 m, the fishery data and limited trawl data suggest that they are likely to be dispersed throughout much of the Ross Sea shelf, albeit in low numbers, extending at times onto the shallow banks at depths of 300 m or less.

Has there been a contraction in the range of *D. mawsoni* from the southern Ross Sea?

Ainley et al. (2009) hypothesised that there has been a northward contraction of the range of *D. mawsoni* since 2001, which has in turn caused a decline in killer whales at Ross Island. They note that evidence supporting this hypothesis has come from a decline in CPUE in a mark-recapture study conducted by scientists in McMurdo Sound from 0.0136 fish per hook-hour in 1987 to 0.0075 in 2001, to 0.0006 in 2007 (DeVries et al., 2008).

The only fishery data available which could potentially be used to detect changes in relative abundance, and hence range contraction, are CPUE data. As outlined earlier, these data are difficult to interpret because different vessels have fished each of the grounds in different years and there is a high variability in catch rates between adjacent cells in each of the grounds. Nevertheless, if there had been a large contraction in the range of the toothfish stock, it would be expected that this would be reflected, albeit at a coarse level, in the CPUE data. The data from the three grounds show somewhat conflicting trends with a decline between 2006 and 2008 at Terra Nova Bay, no obvious change at the Ross Island ground, and an increase in CPUE at the SSRU 881L south ground. There were also

no obvious trends in the size distribution of fish caught on the grounds over time which could be indicative of a contraction in the range of a part of the toothfish population.

How likely is it that a range contraction would be seen and when would it be most prevalent?

As noted earlier, although the toothfish fishery began in 1997, the early catches were relatively small, exceeding 1 000 tonnes per year for the first time in 2002, and only reaching 3 000 tonnes per year between 2005 and 2007. The 2009 stock assessment, based on the results of an extensive tag-recapture program, suggests that current spawning stock biomass is about 80% of the virgin level (Dunn and Hanchet, 2009). The biomass trajectory based on the model indicated that the spawning stock biomass had only dropped to 95% B_0 by 2005, and to 90% of B_0 by 2007. Furthermore, the biomass of all size classes of sub-adult and maturing fish, the fish most commonly occurring in the southern Ross Sea, is currently estimated to be at or above 90% B_0 (SC-CAMLR, 2009). It seems extremely unlikely that the 50% drop in the catch rate of toothfish at McMurdo Sound between 1987 and 2001 could have been caused by the low level of catches from the fishery before that time. Similarly, the 10-fold drop in catch rates between 2001 and 2007 seen at McMurdo Sound is quite inconsistent with the experience of the exploratory fishery during that time, which showed no evidence of a change in CPUE or size structure. Note that projections based on the assessment model suggest that even at a spawning stock biomass of 50% B_0 , the biomass of fish less than 100 cm long would remain above 90% B_0 , whilst the biomass of fish 100–130 cm long would remain above 75% B_0 (SC-CAMLR, 2009).

So what is the likely explanation for the apparent decline in CPUE at McMurdo Sound?

The Working Group on Ecosystem Monitoring and Management (WG-EMM) reviewed the paper by DeVries et al. (2008) at its meeting in 2008 and concluded that it was unable to adequately assess the conclusions of the paper at the current time (SC-CAMLR, 2008, Annex 4). It noted that one problem with the CPUE data collected from the tag-recapture experiment was that the fishing location was changed by several kilometres after the 2000 fishing season due to changes in fast-ice (DeVries et al., 2008). The catch rates from the exploratory long-line fishery typically show high (up to five-fold) variability between adjacent (ca. 15 × 15 km) cells in the fishing grounds off Ross Island and Terra Nova Bay. Such spatial heterogeneity could at least

partly explain the reduction in toothfish catches seen at McMurdo Sound after the fishing location had changed. Testa et al. (1985) showed there were significant differences in catch rates of *D. mawsoni* per 24-hour set at McMurdo Sound between fishing periods and also between years. Catch rates started low in mid-October, peaked in November but dropped away by mid-December. Therefore, changes in the timing of fishing during the season could have a large influence on catch rates and it is unclear whether this was accounted for by DeVries et al. (2008). Testa et al. (1985) also showed there was a significant difference in catch rates between years on catch per 24-hour set, so the use of a single year to illustrate trends is of limited use. Although spatial variability and the timing of fishing might explain some of the reduction in catch rates of toothfish at McMurdo Sound since 2000, they are unlikely to fully explain its absence from catches in the most recent years (A. DeVries, pers. comm.)

Since 2000, there have been quite substantial changes in the physical environment at McMurdo Sound. From 2001 to 2005 several large grounded icebergs led to extensive sea-ice in the southern Ross Sea (DeVries et al. 2008), which produced significant perturbations in the hydrological characteristics of the sea water at McMurdo Sound (M. Williams, NIWA, pers. comm.). Furthermore, the sea-ice at McMurdo Sound has not broken out since about 1998, and the multi-year ice has now reached a thickness of 2.5–8 m in various parts of the Sound, with unknown consequences for the food web. As recommended by WG-EMM, it would be necessary to analyse the complete time series of catch, effort, size distribution and physical environmental data from McMurdo Sound so that seasonal, spatial and temporal effects could be examined (SC-CAMLR, 2008, Annex 4), but the data have not yet been made available.

Recent management changes

For the 2008/09 fishing year, the catch limit for SSRU 881M was set to zero tonnes in recognition of the fact that the Terra Nova Bay fishing ground provided an important migration route for maturing fish. The catch limit allocated to the shelf SSRUs 881J and 881L was reduced accordingly (SC-CAMLR, 2008). In addition, fishing was prohibited in depths shallower than 550 m in order to protect benthic communities (Conservation Measure 41-09 (2008)).

Conclusions

This paper presents for the first time a detailed summary of the distribution of *D. mawsoni* catches from the fishery on the Ross Sea shelf. Fishing over the last 10 years has been sporadic, focusing on three quite localised grounds off Terra Nova Bay, Ross Island and the south of SSRU 881L. Most fishing effort has been concentrated on depths greater than at least 500 m on each of the grounds, with highest catches taken from depths greater than 800 m. However, it is likely that *D. mawsoni* has a much wider distribution than that indicated by the catches, with individuals extending at times onto the shallower banks at depths of 300 m or less. Most toothfish caught in the southern Ross Sea were sub-adult and maturing fish, typically ranging from 60–130 cm, with some evidence for an ontogenetic migration from east to west as they grew. From the fisheries data available, there is no evidence for a northward contraction in the range of *D. mawsoni* over the course of the fishery. Even at the target spawning stock biomass of 50% B_0 , it is uncertain whether the associated slight reduction of the biomass of sub-adult fish would lead to a contraction of their range in the southern Ross Sea. Nevertheless, it would seem prudent to have a monitoring system in place so that changes in relative abundance of these sub-adult fish could be detected. This would be an important early warning signal that the level of fishing could be having an effect on recruitment. It is recommended that CCAMLR consider developing a pre-recruit long-line survey to monitor this part of the population.

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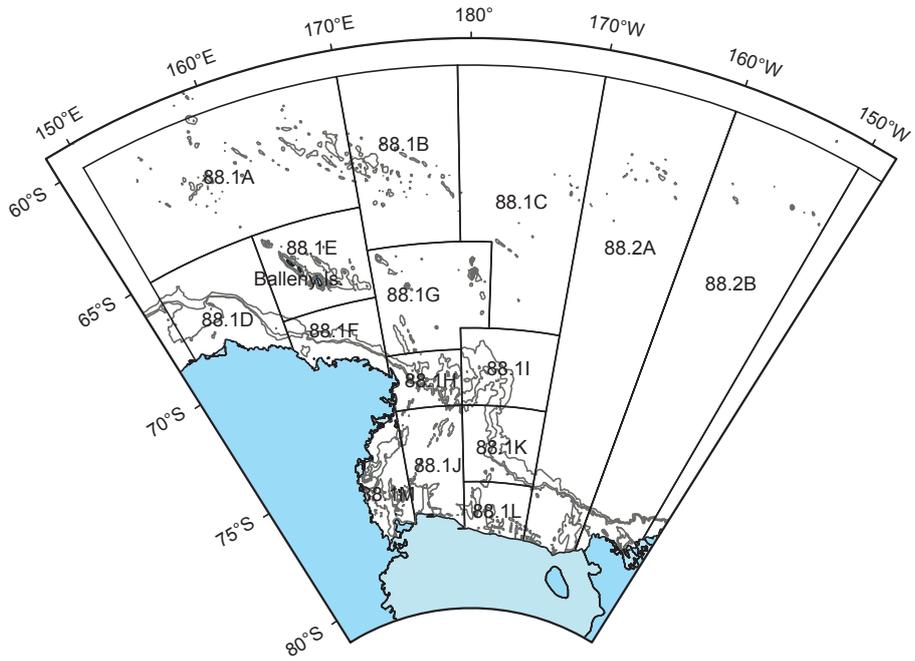


Figure 1: CCAMLR Subarea 88.1 and small-scale research units (SSRUs) 88.2A and 88.2B. Depth contours plotted at 600, 1 000 and 2 000 m.

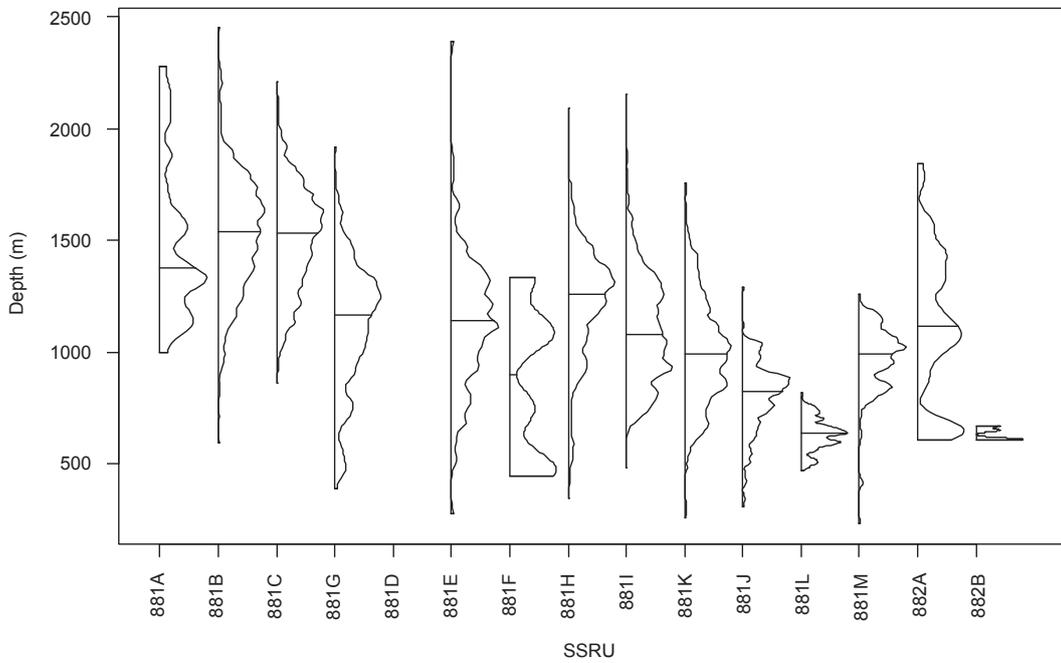


Figure 2: Depth distribution of longline sets made by all vessels in the Ross Sea fishery by SSRU, 1997–2008. Median depth fished indicated by the horizontal line.

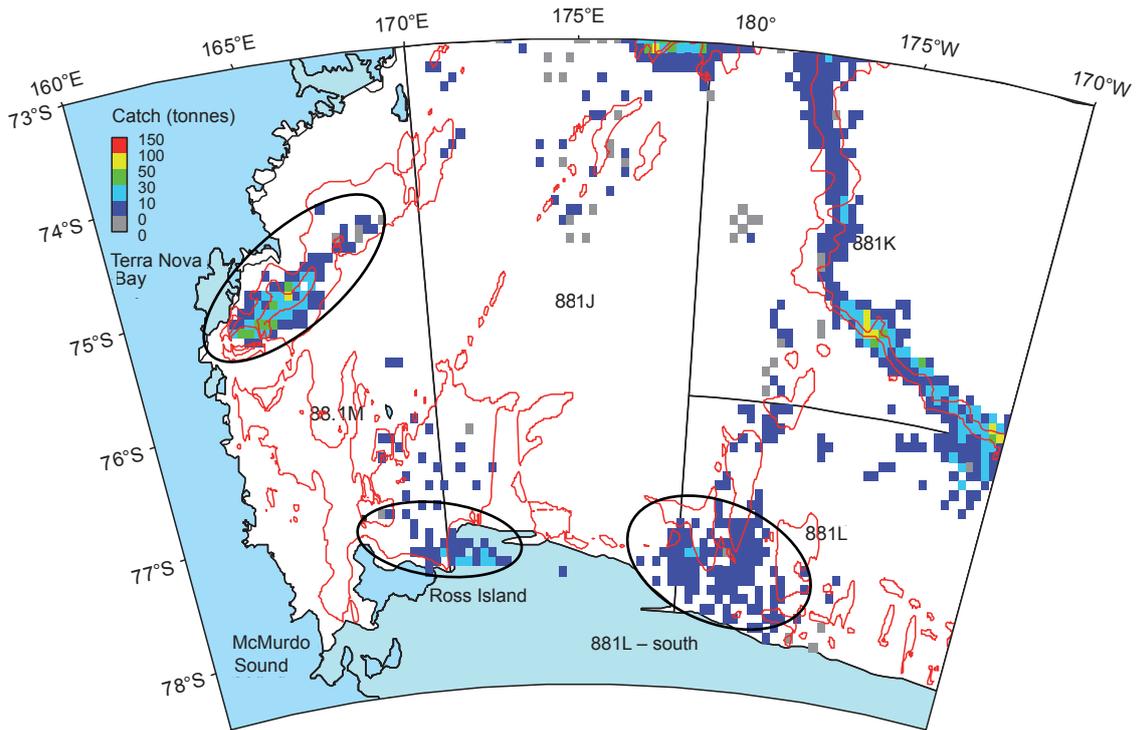


Figure 3: Total *Dissostichus mawsoni* catch from all vessels for 1997 to 2008, in equal-area rectangles (~15 × 15 km). Depth contours plotted at 600 and 1 000 m. The three fishing grounds used for further analysis are circled and labelled.

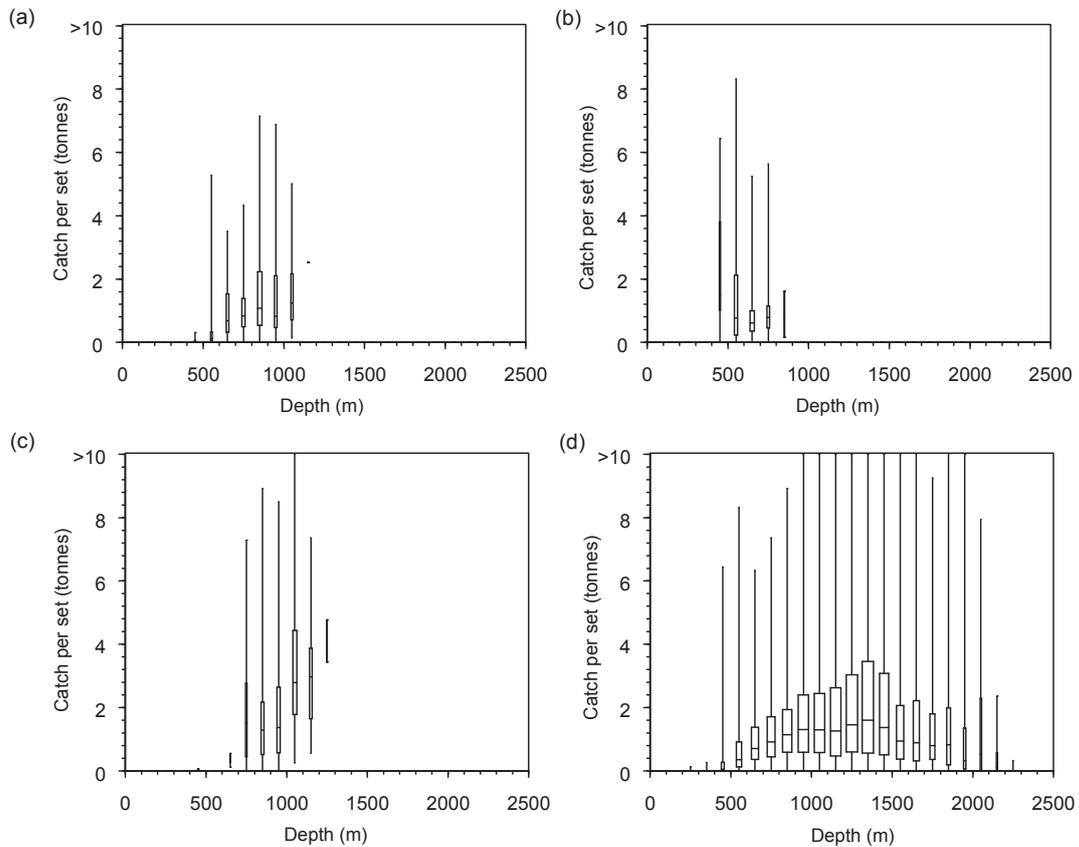


Figure 4: *Dissostichus mawsoni* unstandardised catch per set (tonnes) by depth for all vessels fishing in SSRUs (a) 881J, (b) 881L, (c) 881M and (d) the Ross Sea region. Box plots give mean, range and inter-quartile range, area of box is proportional to sample size.

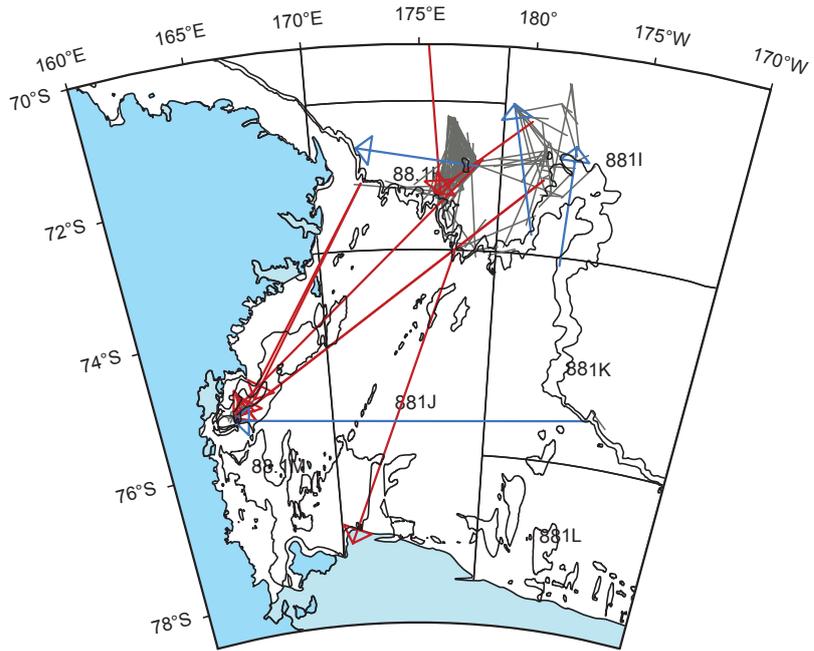


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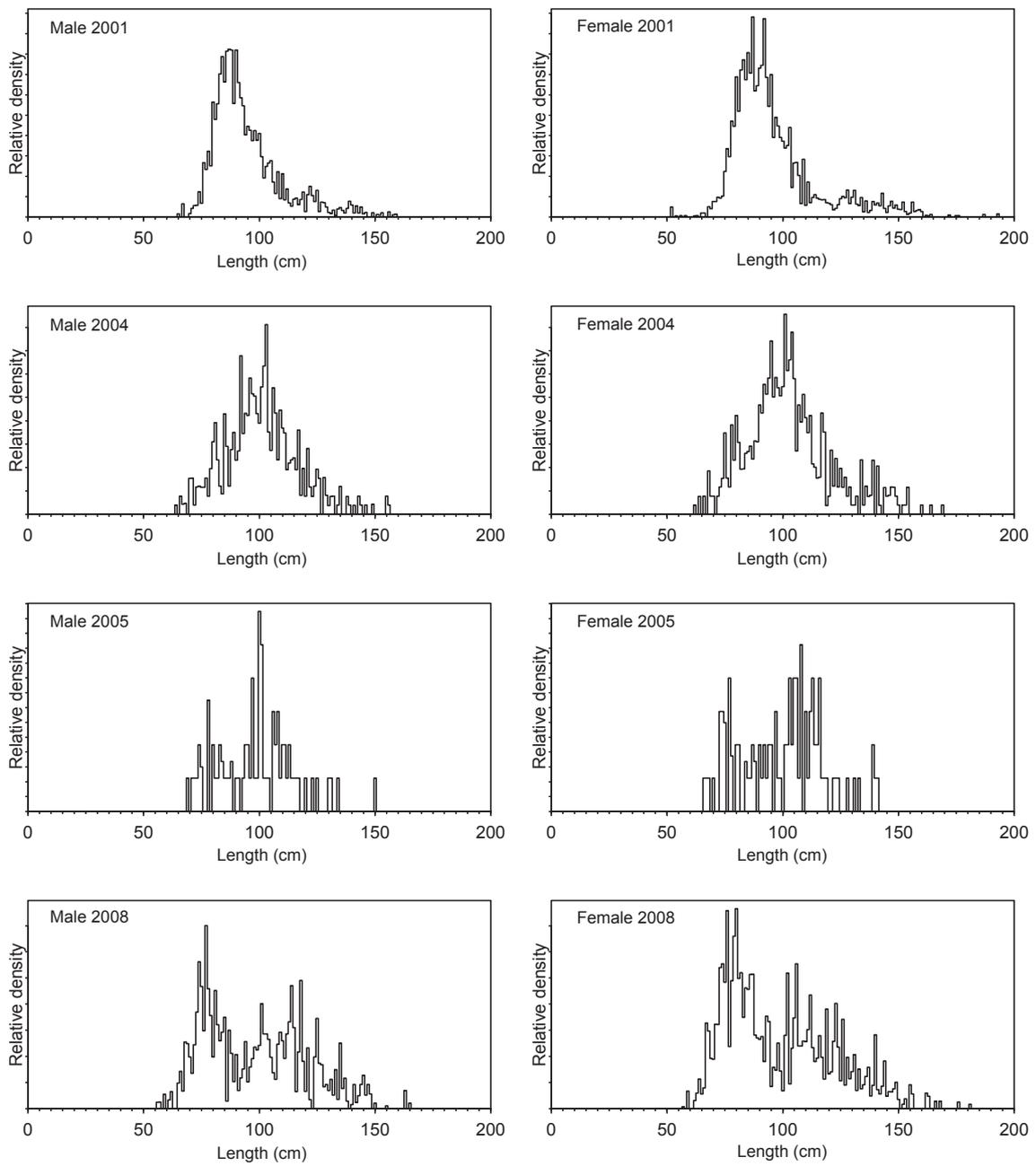


Figure 6: Estimated proportion of fish-at-length by sex for all vessels for the SSRU 881L south fishing ground for 2001, 2004, 2005 and 2008.

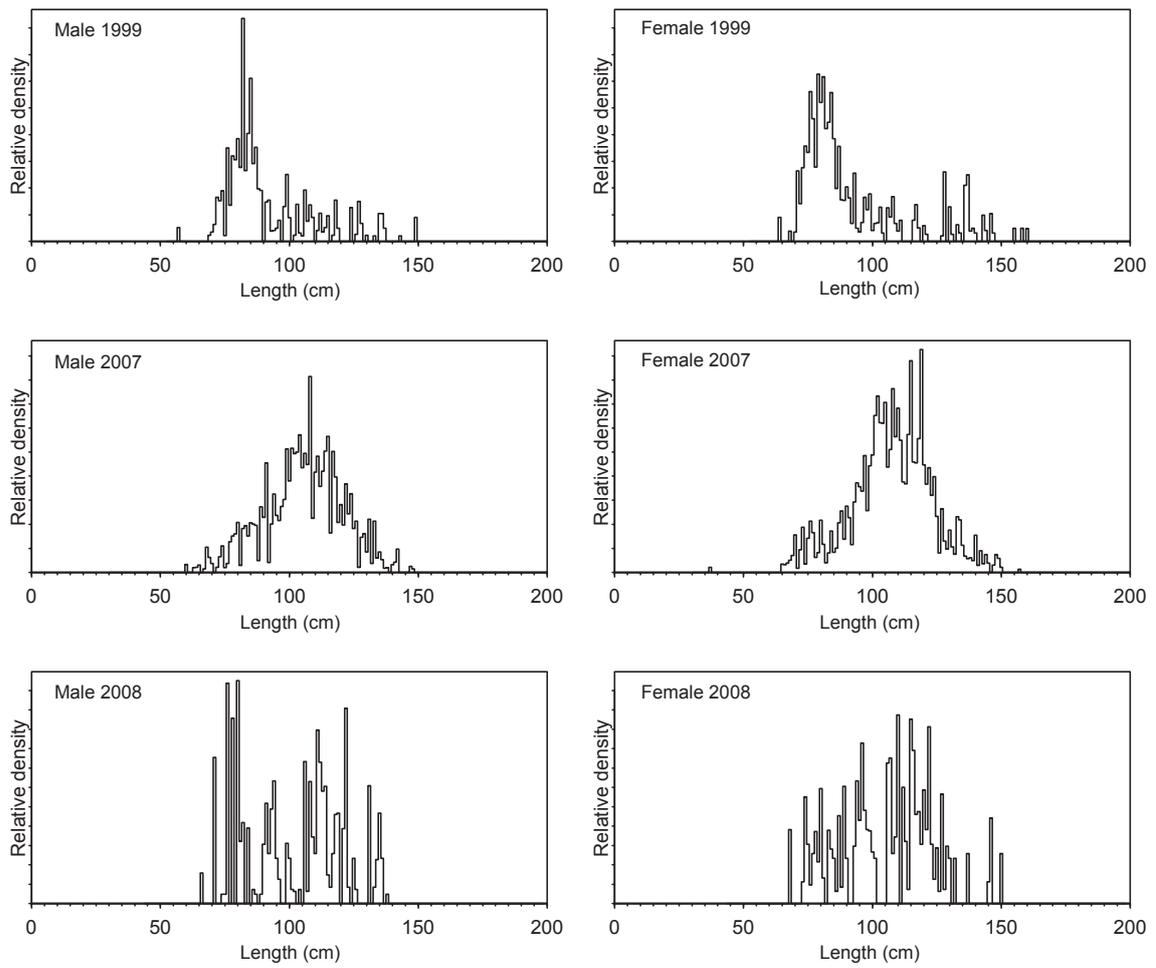


Figure 7: Estimated proportion of fish-at-length by sex for all vessels for the Ross Island fishing ground for 1999, 2007 and 2008.

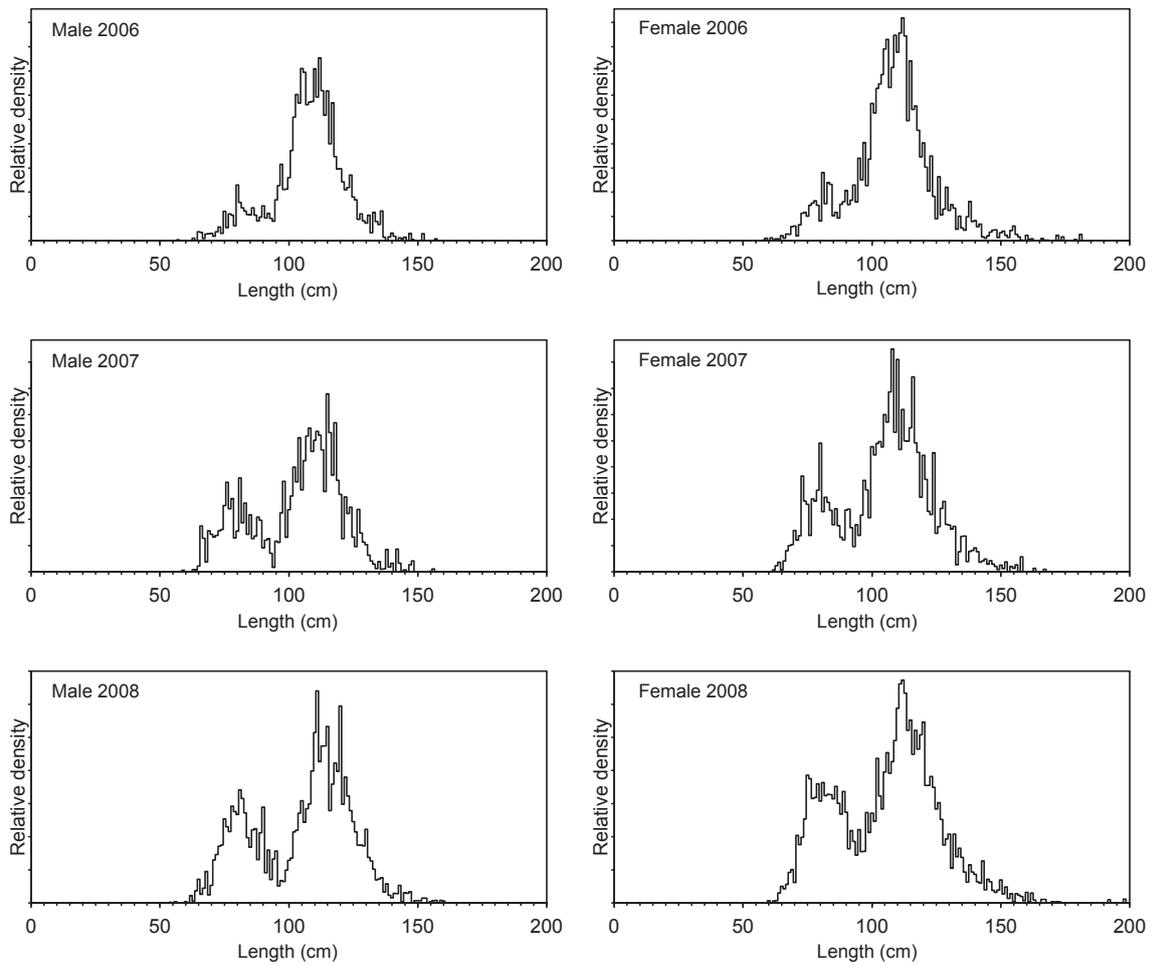


Figure 8: Estimated proportion of fish-at-length by sex for all vessels for the Terra Nova Bay fishing ground for 2006–2008.

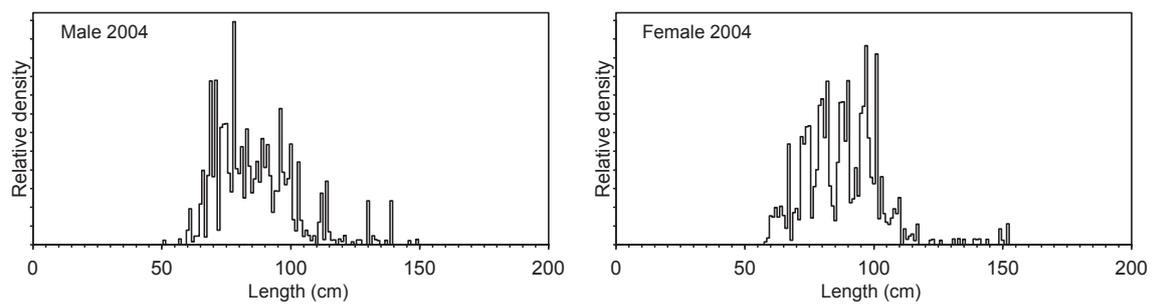


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- Figura 3: Captura total de *Dissostichus mawsoni* de todos los barcos durante el período de 1997 a 2008, en rectángulos iguales (~15 × 15 km). Mapa de las isóbatas de 600 y 1 000 m. Se ha trazado un círculo alrededor de los tres caladeros de pesca utilizados en análisis ulteriores y éstos han sido rotulados.

- Figura 4: Captura por lance no estandarizada de *Dissostichus mawsoni* (toneladas) por rango de profundidad para todos los barcos que pescaron en las UIPE (a) 881J, (b) 881L, (c) 881M y (d) en la región del Mar de Ross. Los diagramas de cajas y bigotes dan el promedio, el rango y el rango intercuartílico; el área de la caja es proporcional al tamaño de la muestra.
- Figura 5: Supuesto movimiento de *Dissostichus mawsoni* recapturado para los peces que fueron liberados durante las operaciones de pesca comercial (negro = movimiento ≤ 100 millas náuticas, rojo = movimiento > 100 millas náuticas en dirección sur, azul = movimiento > 100 millas náuticas en dirección norte, con las posiciones finales indicadas por flechas hasta la temporada 2008). Isóbatas de 600, 1 000 y 2 000 m.
- Figura 6: Proporción estimada de peces por talla y sexo para todos los barcos para la UIPE 881L en el caladero de pesca del sur en 2001, 2004, 2005 y 2008.
- Figura 7: Proporción estimada de peces por talla y sexo para todos los barcos en el caladero de Isla Ross en 1999, 2007 y 2008.
- Figura 8: Proporción estimada de peces por talla y sexo para todos los barcos en el caladero de pesca de bahía Terra Nova en 2006–2008.
- Figura 9: Proporción estimada de peces por talla y sexo para todos los barcos en los caladeros de pesca situados al sur de las UIPE 882A y 882B en 2004.

