SHORT NOTE

DISTRIBUTION AND POPULATION STRUCTURE OF *DISSOSTICHUS ELEGINOIDES* AND *D. MAWSONI* ON BANZARE BANK (CCAMLR DIVISION 58.4.3B), INDIAN OCEAN

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Abstract

The distribution, size composition, sex ratio and sexual maturity of *Dissostichus eleginoides* and *D. mawsoni* from BANZARE Bank were investigated using biological data collected by a Japanese commercial fishing vessel during the austral summer fishing seasons (December–February) from 2006/07 to 2008/09. *Dissostichus eleginoides* was mainly caught on shallower banks (<1 000 m), while *D. mawsoni* was caught on deeper slopes (>1 500 m). Separation of the two species by depth may be related to physical intolerance to cooler temperatures because of the lack of antifreeze in the former species. *Dissostichus eleginoides* showed a resting stage in sexual maturity, while *D. mawsoni* was in developing condition. In *D. mawsoni*, small fish contributed a very low proportion to abundance, suggesting that no substantial recruitment takes place on BANZARE Bank and the populations consist primarily of adults migrating from adjacent Antarctic coastal areas. The life cycle of *D. mawsoni* on BANZARE Bank is similar to that hypothesised for the Ross Sea population with analogous latitudinal patterns in sexual maturity and size composition. The study indicates that the management of *Dissostichus* spp. on BANZARE Bank and adjacent waters needs to consider species-specific distribution and possible migration.

Keywords: BANZARE Bank, depth, *Dissostichus eleginoides*, *Dissostichus mawsoni*, distribution, population structure, CCAMLR

Introduction

Toothfish are the largest nototheniid species in the Southern Ocean, with two species having a circumpolar distribution. *Dissostichus eleginoides* is widely distributed around sub-Antarctic islands and seamounts, between 50 and 60°S, and on the Patagonian Shelf and the southern coast of Chile to 30°S. *Dissostichus mawsoni* is generally found

south of 55°S, which corresponds approximately to the Polar Front (PF) (Fischer and Hureau, 1985; Gon and Heemstra, 1990). However, there is overlap with *D. eleginoides* and confusion over species identity in some areas, notably Elephant Island (Gon and Heemstra, 1990). One of the reasons for the dramatic decrease in *D. mawsoni* landings on BANZARE Bank in the 2006/07 season is thought to be due to species misidentification prior to the season (McKinlay et al., 2008).

The exploratory fishery on BANZARE Bank (Division 58.4.3b), the southernmost portion of the Greater Kerguelen Plateau in the Indian Ocean, commenced in the 2003/04 season under the auspices of CCAMLR (SC-CAMLR, 2009). However, the CCAMLR Scientific Committee expressed concern about the high level of illegal, unreported and unregulated fishing on BANZARE Bank and requested urgent consideration of methods for assessing these stocks (SC-CAMLR, 2006). Since then, there have been a number of studies on the stock assessment of toothfish on the bank (e.g. McKinlay et al., 2008).

BANZARE Bank is located south of the southern branches of the PF and the northern branch of the Southern Antarctic Circumpolar Current Front (SACCF), and north of the southern jet of the SACCF (Sokolov and Rintoul, 2009). Both *Dissostichus* species are found on BANZARE Bank (McKinlay et al., 2008); however, to date, the distribution pattern and population structure of the two species on the bank have received little attention (Welsford et al., 2008). The present study aims to clarify the distribution, size composition, sex ratio and sexual maturity of these two species of toothfish on BANZARE Bank, using biological data collected by a Japanese commercial fishing vessel during the austral summers.

Materials and methods

A Japanese commercial vessel, the FV *Shinsei Maru No. 3*, has been operating a longline exploratory fishery for toothfish in the western-central area of BANZARE Bank during the austral summer (from late December to mid-February) since the 2006/07 fishing season. A total of 148, 134 and 46 hauls were made in the 2006/07, 2007/08 and 2008/09 fishing seasons respectively. A Shinsei Maru trotline system was usually deployed, but experimental gear consisting of trotline and Spanish longline segments was deployed for 23 hauls in the 2008/09 season (Delegation of Japan, 2009). A total of 4 525–5 025 hooks per line were used for normal operations, while 1 950 and 2 016 hooks per line were used in the trot and Spanish segments respectively for the experimental gear. Catch per unit effort (CPUE) was calculated as the number of fish caught per 1 000 hooks for all operations. It should be noted that the different gear types used in the 2008/09 season could affect the results to some degree. Operations were conducted on the seafloor at depths ranging from 630 to 1 960 m.

Haul-by-haul catch and effort data and biological data for toothfish during the three fishing seasons (2006/07–2008/09) were used for analyses. Biological data were collected by scientific observers in accordance with the CCAMLR Scheme of International Scientific Observation (CCAMLR, 2006). For *Dissostichus* spp., total lengths (TL) of randomly selected individuals, up to 100 per haul, were measured. In addition, weight, sex and maturity were recorded for up to 30 individuals. Gonad stages were usually recorded using the CCAMLR five-point staging system (Kock and Kellermann, 1991) as a sexual maturity index, and gonad weight was also measured to the nearest 10 g during the 2006/07 and 2008/09 fishing seasons. These gonad weights were used to calculate a gonadosomatic index (GSI) (Fenaughty, 2006).

Seafloor depths were recorded with a color echo sounder (JFV-250; Japan Radio Co. Ltd, Tokyo, Japan). Data for analyses involving depth as a parameter were limited to hauls where the difference in seafloor depth between the start and endpoint of the longline set was <200 m. The ratio of hauls with a depth difference ≥200 m to the total hauls was 33.1% in the 2006/07, 19.4% in the 2007/08 and 13.0% in the 2008/09 season.

Results

Dissostichus eleginoides was mainly caught in shallower areas (<1 000 m), centred at approximately 58°40'S and 77°30'E, for the three fishing seasons (Figure 1), and rarely occurred at depths >1 300 m (Figure 2). CPUE differed significantly among the three depth ranges of 500–1 000, 1 000–1 500 and 1 500–2 000 m (ANOVA, $P < 0.001$), with the highest for the 500–1 000-m range for each fishing season (Figure 2).

Dissostichus mawsoni was mainly caught on deeper slopes (>1 500 m), centred at approximately 58°S and 77°E; it was also caught on shallower banks (<1 000 m), but in smaller numbers (Figure 1). CPUE differed significantly among the three depth ranges (ANOVA, $P < 0.001$), with the highest for the 1 500–2 000 m range for each fishing season (Figure 2).

For *D. eleginoides*, the smallest and largest fish recorded during the three fishing seasons were 42 and 206 cm TL respectively (Table 1). The mean TL of females (110.6–114.7 cm) was significantly larger than that of males (97.5–106.3 cm) (two-sample t-test; $P < 0.001$) for each fishing season (Table 1). Size structure varied between fishing seasons, but females had a similar modal size of approximately 120 cm TL for the three fishing seasons (Figure 3). Smaller fish (≤70 cm TL) contributed a low proportion to abundance (4.2–9.9%).

For *D. mawsoni*, the smallest and largest fish recorded over the three seasons were 82 and 190 cm TL respectively (Table 1). The mean TL of females (147.5–148.6 cm) was significantly larger than that of males (134.6–137.3 cm) ($P < 0.001$) for each fishing season (Table 1). The size structure was similar for the three fishing seasons and showed a unimodal distribution for both sexes. Smaller fish (≤100 cm TL) contributed a low proportion (0.1–0.9%) to abundance. In addition, in both species, the proportion of males decreased with increasing TL.

In *D. eleginoides*, gonad stages I and II were dominant for both sexes over the three fishing seasons, showing reproductive condition in the resting stage (Table 2). The mean GSI was 0.26–0.66 for females and 0.08–0.3 for males in the 2006/07 and 2008/09 seasons (Table 1). In *D. mawsoni*, gonad stages II and III were dominant for both sexes over the three fishing seasons, showing sexual maturity on BANZARE Bank as maturing/resting and developing (Table 2). The mean GSI was 7.8–7.9 for females and 5.3–6.0 for males in the 2006/07 and 2008/09 seasons (Table 1).

Discussion

Yukhov (1972) suggested that the distribution of the two toothfish species rarely overlaps and the PF serves as an ecological barrier preventing overlapping in the ranges of the two species. However,

data from exploratory *Dissostichus* spp. fisheries show that there is considerable overlap between the two species in some areas in the Southern Ocean (Hanchet, 2010). The degree of the overlap appeared to be primarily a function of latitude in the Ross Sea region (60–77°S), where the proportion of *D. eleginoides* to the total *Dissostichus* spp. catch tended to be higher in the northern latitude (Hanchet, 2010). However, the area of high abundance for *D. eleginoides* was apparently south of that for *D. mawsoni*, on the western part of BANZARE Bank (Figure 1); thus, latitude is not a primary factor in determining spatial distribution for this much smaller area (57–60°S). On the other hand, the relationship between mean depth of longline set and mean CPUE for the two species suggests that the habitat of the two species on BANZARE Bank is clearly separated by seafloor depth (Figure 2). This is consistent with the result of a randomised longline survey in May 2008 which found a greater abundance of *D. eleginoides* in shallow areas on the western part of the bank, while *D. mawsoni* occupied the deeper slopes (Welsford et al., 2008).

Yukhov (1972) recorded *D. mawsoni* from areas with surface temperatures ranging from 1.8 to 2.3°C, while Duhamel et al. (1983) found *D. eleginoides* in areas with surface temperatures higher than 3°C. Gon and Heemstra (1990) hypothesised that the reason *D. eleginoides* was not found in waters with surface temperatures <2°C was the lack of antifreeze in body fluids and fewer glomeruli in the kidneys. Thus, the separation of the two species by depth, as observed on BANZARE Bank, may be related to temperature conditions. The narrow depth range distribution, mostly restricted to <1 300 m, for all sizes of *D. eleginoides*, compared to the wider distribution of *D. mawsoni*, may be related to physical intolerance to cooler temperatures as a result of the lack of antifreeze in the former species. However, habitat temperatures of the two benthopelagic species are unknown. Zhivov and Krivoruchko (1990) recorded *D. eleginoides* at depths ranging from 140 to 1 460 m and at temperatures in the near-bottom layer of 1.0–2.2°C in the region of Shag Rocks and South Georgia, the southern edge of its distribution. Collins et al. (2006) photographed *D. eleginoides* at depth in temperatures as low as 1.4°C, but did not encounter *D. eleginoides* at lower temperatures in the South Georgia region. According to Donohue et al. (1999), cooler temperatures (<1°C) occurred below 1 000–1 500 m depths on the eastern BANZARE

Table 1: Number of fish caught, number observed, mean total length (TL), TL range and mean gonadosomatic index (GSI) by sex for the two *Dissostichus* species during the 2006/07 and 2008/09 seasons on BANZARE Bank. ns – not sampled.

	Year	No. of fish caught	No. of fish observed		Mean TL (SD)		TL range		Mean GSI (SD)	
			Female	Male	Female	Male	Female	Male	Female	Male
D. eleginoides	31 Dec–23 Feb 2006/07	1995	746	288	110.6 (24.8)	100.8 (21.5)	49–206	50–148	0.66 (0.69)	0.30 (0.42)
	30 Dec–19 Feb 2007/08	2376	447	259	110.7 (20.9)	97.5 (18.6)	44–158	42–137	ns	ns
	19 Jan–07 Feb 2008/09	904	320	126	114.7 (17.8)	106.3 (14.7)	59–150	57–150	0.26 (0.13)	0.08 (0.08)
D. mawsoni	31 Dec–23 Feb 2006/07	2291	639	879	148.1 (12.2)	134.6 (12.8)	94–190	90–180	7.8 (2.7)	5.3 (2.3)
	30 Dec–19 Feb 2007/08	2166	695	610	147.5 (11.4)	135.8 (12.3)	109–189	82–177	ns	ns
	19 Jan–07 Feb 2008/09	759	353	303	148.6 (11.3)	137.3 (10.5)	120–185	110–180	7.9 (2.3)	6.0 (2.3)

Table 2: Gonad stages of *Dissostichus eleginoides* and *D. mawsoni*.

Species	Fishing season	Sex (No. of samples)	Gonad stage (%)				
			I	II	III	IV	V
D. eleginoides	2006/07 (31 Dec–23 Feb)	Female (745)	30.6	69.4	0.0	0.0	0.0
		Male (288)	60.1	39.9	0.0	0.0	0.0
	2007/08 (30 Dec–19 Feb)	Female (441)	49.4	50.1	0.5	0.0	0.0
		Male (256)	91.0	9.0	0.0	0.0	0.0
	2008/09 (19 Jan–07 Feb)	Female (318)	27.4	72.0	0.6	0.0	0.0
		Male (127)	37.0	61.4	1.6	0.0	0.0
D. mawsoni	2006/07 (31 Dec–23 Feb)	Female (628)	0.6	1.9	94.9	2.4	0.2
		Male (794)	0.3	5.5	92.2	2.0	0.0
	2007/08 (30 Dec–19 Feb)	Female (685)	0.3	32.7	66.1	0.7	0.1
		Male (609)	28.6	76.8	21.7	1.1	0.0
	2008/09 (19 Jan–07 Feb)	Female (350)	0.0	4.0	96.0	0.0	0.0
		Male (305)	0.0	3.3	96.4	0.3	0.0

Bank. Thus, ~1°C appears to be the lower limit of habitat temperature for *D. eleginoides*, but further investigations are needed on the habitat temperature of these two species on BANZARE Bank.

The similar modal size of approximately 120 cm TL for female *D. eleginoides* over the three fishing seasons suggests the presence of a strong female cohort at this size. Recruitment strength in *D. eleginoides* shows tremendous interannual variability, and the presence of a dominant cohort has been detected in the length-frequency distribution of juveniles at South Georgia (Belchier and Collins, 2008) and the Patagonian Shelf (Laptikhovsky and Brickle, 2005). Age determination from otoliths is necessary to detect the birth year of the presumably dominant cohort from BANZARE Bank.

In *D. mawsoni*, small fish contributed a very low proportion to abundance, suggesting that no substantial recruitment takes place on BANZARE Bank. Agnew et al. (2009) surveyed the stock status of coastal *D. mawsoni* in Divisions 58.4.1 and 58.4.2 (East Antarctica) and showed that a high proportion of juveniles were west of 90°E, but rarely in the eastern area. Thus, a certain proportion of adult *D. mawsoni* on BANZARE Bank could originate from recruitment in adjacent Antarctic coastal areas west of 90°E (mainly in Division 58.4.2).

The mean GSIs of 6.52 for males and 7.73 for females in *D. mawsoni*, recorded in the northern Ross Sea area in February (Fenaughty, 2006), are comparable to those in a similar season on BANZARE Bank. The unimodal distribution, the dominance of adults in developing condition of sexual maturity and the low proportion of smaller fish (<100 cm TL) for both sexes of *D. mawsoni* were also identical to observations from the northern Ross Sea area (Fenaughty, 2006). Small adults of *D. mawsoni* in the Ross Sea shelf and slope are considered to move northwards as they mature and spawn in the northern ridges and banks of the Ross Sea during winter/spring (Hanchet et al., 2008). BANZARE Bank is also a possible spawning ground for *D. mawsoni*. The life cycle of *D. mawsoni* on BANZARE Bank is similar to that hypothesised for the Ross Sea (Hanchet et al., 2008) with analogous latitudinal patterns in sexual maturity and size composition, as suggested by Welsford et al. (2008). Further studies on the movement of larvae and juveniles in surface current systems, combined with the migration of sub-adults

and adults using tagging experiments, will clarify the lifecycle of this species in BANZARE Bank and adjacent East Antarctica.

This study demonstrates that species-specific distribution and possible migration need to be considered in the management of *Dissostichus* spp. on BANZARE Bank and adjacent waters.

Conclusions

1. *Dissostichus eleginoides* was mainly caught on shallow banks (<1 000 m), while *D. mawsoni* favoured deeper slopes (>1 500 m). The separation of the two species by depth may be related to physical intolerance to cooler temperatures because of lack of antifreeze in *D. eleginoides*.

2. Size structure varied between fishing seasons, but females of *D. eleginoides* had a similar modal size of approximately 120 cm TL for the three fishing seasons, while in *D. mawsoni* size structure was very similar among fishing seasons and showed a unimodal distribution. The mean TL of females was significantly larger than that of males for both species.

3. *Dissostichus eleginoides* showed a resting stage in sexual maturity, while *D. mawsoni* was in developing condition. The analogy to *D. mawsoni* in the northern Ross Sea area during the same season suggests that BANZARE Bank is a possible spawning ground for *D. mawsoni*.

4. In *D. mawsoni*, small fish contributed a low proportion to total abundance, which suggests that no substantial recruitment takes place on BANZARE Bank and the population may consist primarily of adults migrating from adjacent Antarctic coastal areas.

References

Agnew, D.J., C. Edwards, R. Hillary, R. Mitchell and L.J. López Abellán. 2009. Status of the coastal stocks of *Dissostichus* spp. in East Antarctica (Divisions 58.4.1 and 58.4.2). *CCAMLR Science*, 16: 71–100.

Belchier, M. and M.A. Collins. 2008. Recruitment and body size in relation to temperature in juvenile Patagonian toothfish (*Dissostichus eleginoides*) at South Georgia. *Mar. Biol.*, 155 (5): 493–503.

CCAMLR. 2006. *Scheme of International Scientific Observation: Scientific Observers Manual.* CCAMLR, Hobart, Australia.

Collins, M.A., I. Everson, R. Patterson, P.M. Bagley, C. Yau, M. Belchier and S. Hawkins. 2006. *In situ* observations of the scavenging fauna of the South Georgia slope. In: Shotton, R. (Ed.). *Deep Sea 2003: Conference on the Governance and Management of Deep-sea Fisheries. Part 2: Conference poster papers and workshop papers*. *FAO Fisheries Proceedings*, 3/2. FAO, Rome: 45–53.

Delegation of Japan. 2009. Revised research plan for toothfish in Division 58.4.4a and b by *Shinsei Maru No. 3* in 2009/10. Document *WG-FSA-09/12*. CCAMLR, Hobart, Australia: 16 pp.

Donohue, K.A., G.E. Hufford and M.S. McCartney. 1999. Sources and transport of the Deep Western Boundary Current east of the Kerguelen Plateau. *Geophys. Res. Lett.*, 26 (7): 851–854.

Duhamel, G., J.-C. Hureau and C. Ozouf-Costaz. 1983. Ecological survey of the notothenioid fishes in the Southern Ocean from Bouvet to Kerguelen Islands. *Mem. Nat. Inst. Polar Res.*, 27: 176–182.

Fenaughty, J.M. 2006. 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). *CCAMLR Science*, 13: 27–45.

Fischer, W. and J.-C. Hureau (Eds). 1985. *FAO Species Identification Sheets for Fishery Purposes. Southern Ocean (CCAMLR Convention Area, Fishing Areas 48, 58 and 88).* FAO, Rome: 471 pp.

Gon, O. and P.C. Heemstra (Eds). 1990. *Fishes of the Southern Ocean*. J.L.B. Smith Institute of Ichthyology, Grahamstown, South Africa: 462 pp.

Hanchet, S.M. 2010. Updated species profile for Antarctic toothfish (*Dissostichus mawsoni*). Document *WG-FSA-10/24*. CCAMLR, Hobart, Australia: 34 pp.

Hanchet, S.M., G.J. Rickard, J.M. Fenaughty, A. Dunn and M.J. Williams. 2008. A hypothetical life cycle for Antarctic toothfish (*Dissostichus mawsoni*) in the Ross Sea region. *CCAMLR Science*, 15: 35–53.

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

Laptikhovsky, V. and P. Brickle. 2005. The Patagonian toothfish fishery in Falkland Islands' waters. *Fish. Res.*, 74: 11–23.

McKinlay, J.P., D.C. Welsford, A.J. Constable and G.B. Nowara. 2008. An assessment of the exploratory fishery for *Dissostichus* spp. on BANZARE Bank (CCAMLR Division 58.4.3b) based on fine-scale catch and effort data. *CCAMLR Science*, 15: 55–78.

SC-CAMLR. 2006. *Report of the Twenty-fifth Meeting of the Scientific Committee (SC-CAMLR-XXV)*. CCAMLR, Hobart, Australia: 523 pp.

SC-CAMLR. 2009. Report of the Working Group on Fish Stock Assessment. Fishery report: Exploratory fishery for *Dissostichus* spp. in Division 58.4.3b. In: *Report of the Twenty-eighth Meeting of the Scientific Committee (SC-CAMLR-XXVIII),* Annex 5, Appendix J. CCAMLR, Hobart, Australia.

Sokolov, S. and S.R. Rintoul. 2009. Circumpolar structure and distribution of the Antarctic Circumpolar Current fronts: 1. Mean circumpolar paths. *J. Geophys. Res.*, 114, C11018: 19 pp, doi:10.1029/2008JC005108.

Welsford, D., T. Robertson and G. Nowara. 2008. Report on a longline survey conducted by the FV *Janas* in May 2008 on BANZARE Bank, and an assessment of the status of *Dissostichus* spp. in Division 58.4.3b. Document *WG-FSA-08/57*. CCAMLR, Hobart, Australia: 22 pp.

Yukhov, V.L. 1972. The range of fish of the genus *Dissostichus* (Fam. Nototheniidae)

in the Antarctic waters of the Indian Ocean. *J. Ichthyol.*, 12 (2): 346–347.

Zhivov, V.V. and V.M. Krivoruchko. 1990. On the biology of the Patagonian toothfish, *Dissostichus eleginoides*, of the Antarctic part of the Atlantic. *J. Ichthyol.*, 30 (7): 142–146. Translated from *Vopr. Ikhtiol.*, 30 (5): 861–864.
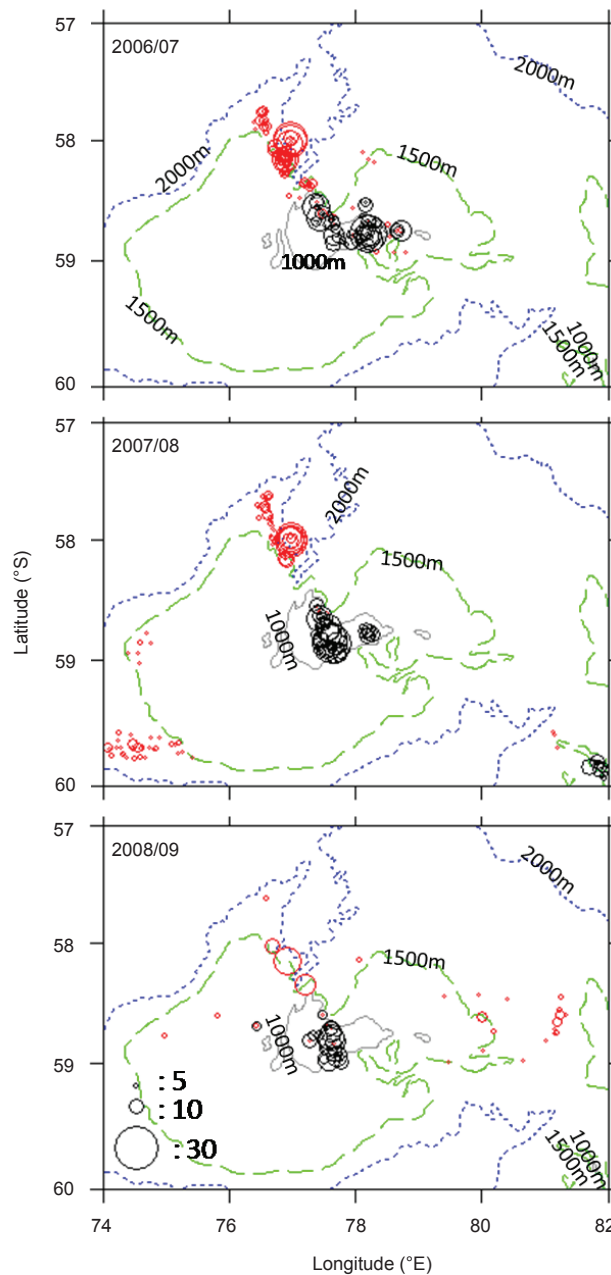
Figure 1: CPUE (number of fish caught per 1 000 hooks) for *Dissostichus eleginoides* (black circle) and *D. mawsoni* (red circle). Diameters of circles are proportional to CPUE.
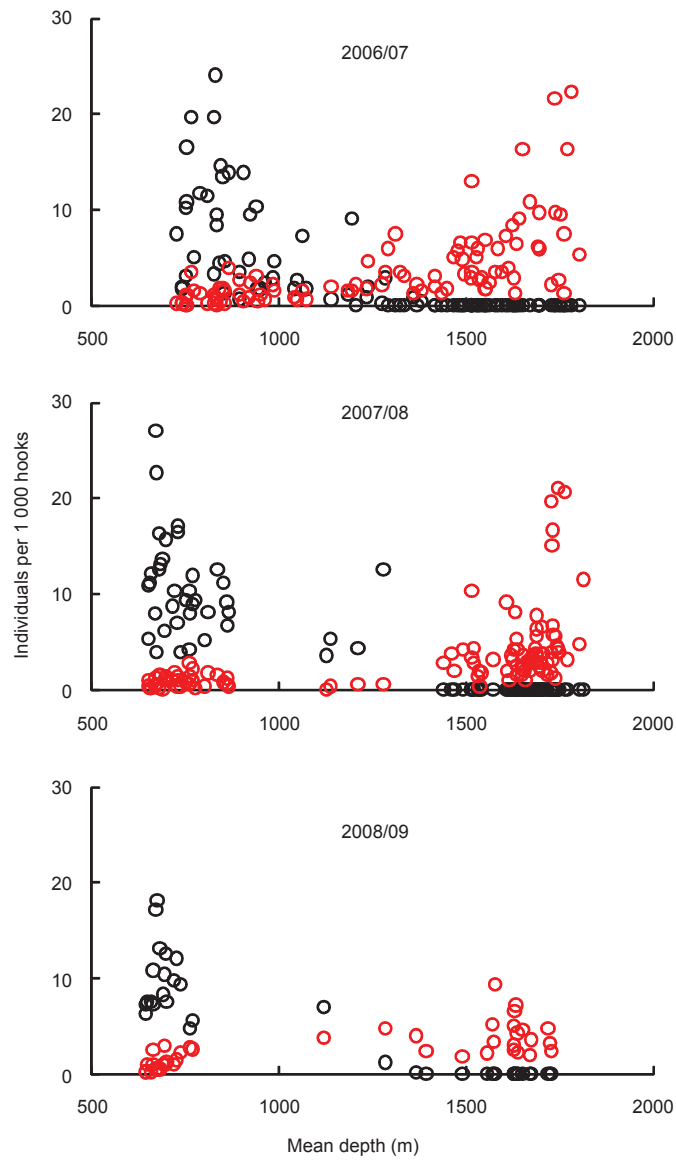
Figure 2: Relationship between mean depth of longline set and mean CPUE for *Dissostichus eleginoides* (black) and *D. mawsoni* (red).
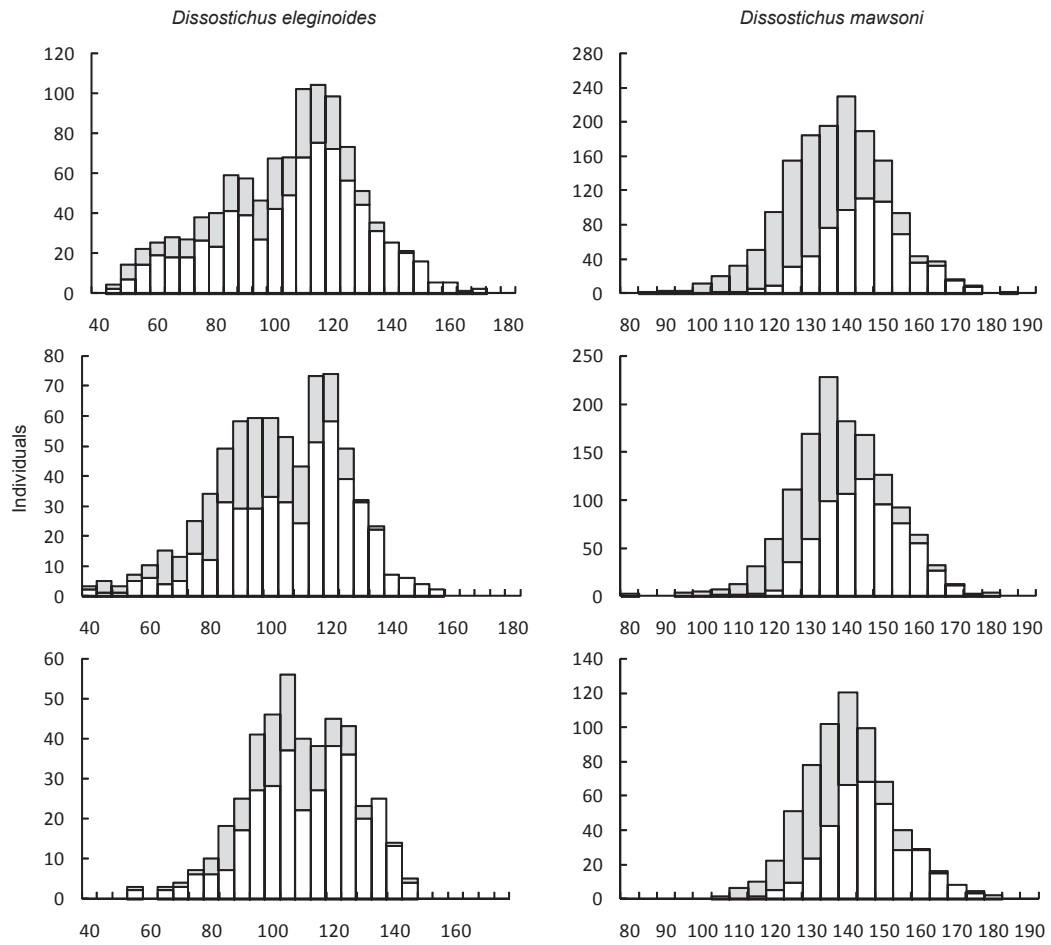
Figure 3: Length-frequency distribution of male (hatched column) and female (white column) *Dissostichus eleginoides* and *D. mawsoni*.