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

J.P. McKinlay✉, D.C. Welsford, A.J. Constable and G.B. Nowara
Department of the Environment, Water, Heritage and the Arts
Australian Antarctic Division
203 Channel Highway, Kingston 7050
Tasmania, Australia
Email – john.mckinlay@aad.gov.au

Abstract

In 2006, the CCAMLR Scientific Committee expressed concern as to the status of the stock on which the exploratory *Dissostichus* spp. fishery on BANZARE Bank (CCAMLR Division 58.4.3b) was based. This paper presents a summary of fine-scale catch and effort data held by CCAMLR for BANZARE Bank, as well as descriptive analyses of biological data submitted by scientific observers on board vessels in the fishery. Results of a Leslie depletion analysis of stratified catch and effort data indicate that there is strong evidence for depletion of toothfish at the scale of individual fishing grounds in the 2004/05 and 2005/06 seasons. This result, coupled with high estimated levels of illegal, unreported and unregulated (IUU) fishing, and evidence of poor recent recruitment, indicates that the stock is likely to have been overfished. Several inconsistencies are noted between historical data and those submitted in the 2006/07 season, with Patagonian toothfish (*D. eleginoides*) reportedly replacing Antarctic toothfish (*D. mawsoni*) as the dominant toothfish species in catches in one ground for the first time. Incomplete reporting of biological information for by-catch species by on-board scientific observers was noted, limiting meaningful analysis of patterns in by-catch catch and effort. Further research, particularly research surveys, would greatly assist with assessing the status and stock structure of *Dissostichus* spp. in this area. The potential for similar analyses in other exploratory toothfish fisheries should be investigated, as this study indicates that severe depletion can occur in the space of just two or three seasons.

Résumé

En 2006, le Comité scientifique de la CCAMLR s'inquiétait de l'état du stock sur lequel reposait la pêcherie exploratoire de *Dissostichus* spp. du banc BANZARE (division 58.4.3b de la CCAMLR). Cet article présente un résumé des données de capture et d'effort de pêche à échelle précise détenues par la CCAMLR pour le banc BANZARE, ainsi que des analyses descriptives des données biologiques soumises par les observateurs scientifiques embarqués sur des navires de cette pêcherie. Les résultats d'une analyse de la réduction du stock par la méthode de Leslie, au moyen des données stratifiées de capture et d'effort de pêche, mettent en évidence un déclin de la légine à l'échelle des lieux de pêche pendant les saisons 2004/05 et 2005/06. Ces résultats, couplés à des estimations élevées des niveaux de pêche illicite, non déclarée et non réglementée (INN) et aux preuves d'un recrutement faible récemment, indiquent que le stock a probablement fait l'objet d'une surpêche. Plusieurs contradictions sont notées entre les anciennes données et les données soumises pendant la saison 2006/07, selon lesquelles sur un lieu de pêche, pour la première fois, l'espèce de légine dominante dans les captures aurait été la légine australe (*D. eleginoides*) et non plus la légine antarctique (*D. mawsoni*). Il est noté que l'analyse des tendances de la capture et de l'effort de pêche relatifs aux captures accessoires est limitée par la déclaration incomplète des informations biologiques relatives aux espèces concernées par les observateurs scientifiques embarqués. D'autres recherches, notamment par des campagnes d'évaluation, permettraient de faire avancer l'étude de l'état et de la structure du stock de *Dissostichus* spp. dans cette région. Les possibilités d'analyses de ce type dans d'autres pêcheries exploratoires de légine devraient être étudiées. En effet, la présente étude indique qu'une diminution grave des stocks peut se produire en l'espace de deux ou trois saisons.

Резюме

В 2006 г. Научный комитет АНТКОМа выразил озабоченность по поводу состояния запаса, облавливаемого при поисковом промысле видов *Dissostichus* на банке БАНЗАРЕ (Участок 58.4.3b АНТКОМа). В данной статье приведена сводка хранящихся в АНТКОМе мелкомасштабных данных по уловам и усилию на банке БАНЗАРЕ, а также описательный анализ биологических данных, представленных научными наблюдателями с судов, проводящих этот промысел. Результаты анализа истощения по Лесли с использованием стратифицированных данных по уловам и усилию указывают на наличие убедительных доказательств истощения запасов клыкача в масштабе отдельных промысловых участков в сезонах 2004/05 и 2005/06 гг. Этот результат в сочетании с высокими оценочными уровнями незаконного, нерегистрируемого и нерегулируемого (ННН) промысла, а также признаки плохого пополнения в последнее время свидетельствуют о возможном перелове этого запаса. Отмечен ряд несоответствий между ретроспективными данными и данными, представленными в сезоне 2006/07 г., когда патагонский клыкач (*D. eleginoides*), по сообщениям, впервые заменил антарктического клыкача (*D. mawsoni*) как преобладающий в уловах вид клыкача на одном участке. Также отмечено, что находящиеся на борту научные наблюдатели представляли неполную биологическую информацию о видах прилова, что ограничило эффективный анализ закономерностей в вылове прилова и усилии. Дальнейшие исследования, особенно научно-исследовательские съемки, будут очень способствовать оценке состояния и структуры запаса видов *Dissostichus* в этом районе. Следует изучить возможность проведения аналогичного анализа для других поисковых промыслов клыкача, т.к. данное исследование показывает, что сильное истощение может произойти всего за два-три сезона.

Resumen

En 2006, el Comité Científico de la CCRVMA indicó su preocupación por el estado del stock que la pesquería exploratoria de *Dissostichus* spp. estaba explotando en el banco de BANZARE (División 58.4.3b de la CCRVMA). Este trabajo presenta un resumen de los datos de captura y esfuerzo en escala fina para el Banco BANZARE archivados por la CCRVMA, y análisis descriptivos de los datos biológicos presentados por observadores científicos a bordo de barcos que participaron en esta pesquería. Los resultados de un análisis de Leslie de reducción de stock que se valió de los datos de captura y esfuerzo estratificados muestran señales convincentes de una disminución de la población de austromerluza a nivel de caladero de pesca en las temporadas 2004/05 y 2005/06. Este resultado, sumado a los altos niveles estimados de pesca ilegal, no declarada y no reglamentada (INDNR) y a las señales de un bajo reclutamiento reciente, indica que es muy probable que el stock haya sido sobreexplotado. Se han detectado varias incongruencias entre los datos históricos y aquellos presentados en la temporada 2006/07. Según se informa, por primera vez la austromerluza negra (*D. eleginoides*) habría reemplazado a la austromerluza antártica (*D. mawsoni*) como especie predominante en la captura de un caladero. Se notó que la información biológica de las especies retenidas de la captura secundaria, notificada por los observadores científicos estaba incompleta, restringiendo importantes análisis de las características de la captura secundaria y del esfuerzo. Estudios posteriores, en especial las campañas de investigación, ayudarán en gran medida a evaluar el estado y la estructura del stock de *Dissostichus* spp. en esta área. Se deberá estudiar la posibilidad de efectuar análisis similares en otras pesquerías exploratorias de austromerluza, pues este estudio señala que puede haber una gran reducción en un espacio de sólo dos o tres temporadas.

Keywords: Antarctic toothfish, *Dissostichus mawsoni*, Patagonian toothfish, *Dissostichus eleginoides*, Leslie depletion, BANZARE Bank, CPUE (catch-per-unit-effort), CCAMLR

Introduction

The Patagonian toothfish (*Dissostichus eleginoides*) and the Antarctic toothfish (*D. mawsoni*) are the most commercially important finfish species targeted in the CAMLR Convention Area. The exploratory fishery on BANZARE[1] Bank (Division 58.4.3b), which is the southern extension of the greater Kerguelen Plateau in the Indian Ocean, commenced in the 2003/04 season. Nearby fisheries for *Dissostichus* spp. include exploratory toothfish fisheries on the Antarctic continental shelf (primarily catching *D. mawsoni* – Divisions 58.4.1 and 58.4.2), and Elan Bank (primarily catching *D. eleginoides* – Division 58.4.3a) and an established fishery for *D. eleginoides* around Heard and McDonald Islands (Division 58.5.2) (CCAMLR, 2007a). The relationship between the population of toothfish fished on BANZARE Bank and those in adjacent areas is unknown (SC-CAMLR, 2007a).

1 Named for the British, Australian and New Zealand Antarctic Research Expedition, 1929–1931.

CCAMLR regulates the fishery in Division 58.4.3b through conservation measures limiting entry to vessels, avoiding by-catch by having vessels move when by-catch thresholds are exceeded, requiring vessels to tag toothfish at a specified rate per tonne caught, and applying shipboard measures to mitigate seabird by-catch. All vessels must regularly report fine-scale catch and effort data to the CCAMLR Secretariat and carry scientific observers to collect operational and catch data from all fishing activity (CCAMLR, 2007b). Vessels in the fishery use both Spanish and autoline longlines to target toothfish, with the overwhelming majority of catches comprising *D. mawsoni*. As an exploratory fishery, the catch limit for the division has been nominally set at 300 tonnes each season up to 2006/07. In 2004/05 and 2005/06, the fishery was closed by CCAMLR due to the catch limit being reached or exceeded before the conclusion of the season (SC-CAMLR, 2006c).

In 2006, the CCAMLR Scientific Committee expressed concern about the status of exploratory *Dissostichus* spp. fisheries in the southern Indian Ocean (Subarea 58.4), requesting urgent consideration of methods for assessing these stocks (SC-CAMLR, 2006a). Of particular concern was the level of illegal, unreported and unregulated (IUU) fishing on BANZARE Bank. Total removals by IUU vessels since 2003, using both longline and gillnets, are estimated at more than 5 400 tonnes, while legal catches total 918 tonnes over the same period. Furthermore, IUU activity seems to be increasing, with catches estimated to have exceeded the catch limit for this region in the 2005/06 and 2006/07 seasons by 5.2 and 7.6 times respectively (SC-CAMLR, 2006b; SC-CAMLR, 2007a). Of additional concern, recent catch-weighted length-frequency data indicated that no small (<50 cm) *Dissostichus* spp. were present on BANZARE Bank (SC-CAMLR, 2006b; Welsford et al., 2007a), verifying an earlier result from a trawl survey in this area in 1999 (van Wijk et al., 2000).

This paper describes the spatio-temporal patterns in catch and effort of the fishery for *Dissostichus* spp. and major by-catch groups on BANZARE Bank. Estimates of biomass and rates of depletion of *Dissostichus* spp. using catch-per-unit-effort (CPUE) data are developed for areas of concentrated effort in the division. This study also attempts to evaluate if the fishery is likely to be sustainable in the long term.

Assessment methodology

Data sources and analysis software

Two sets of data submitted to the CCAMLR Secretariat were used in this analysis: fine-scale catch and effort data submitted by vessels operating in the fishery and fine-scale biological data submitted by on-board observers between 2003 and 2007. Data holdings for all Flag States and vessels were considered for analysis. All analyses and figures were produced using the R language for statistical computing (R Development Core Team, 2007; Sarkar, 2008). Scripts are available from the corresponding author.

Spatial distribution of catch and effort

The spatial distribution of effort within the fishery was investigated to identify areas of consistently high effort that might lead to local stock depletion. Previous studies of localised toothfish depletion (e.g. Parkes et al., 1996; Agnew and Pearce, 2004) devoted some effort to identifying areas and time periods where local depletions – should they be occurring – might reasonably be observed. The present study adopted a less formal approach, considered appropriate given the large size of fishing grounds and low level of data coverage available for an exploratory fishery of this kind. Plots of all commercial and research longline positions occurring within Division 58.4.3b were examined to identify broad areas of consistently high effort between seasons. Separate plots were examined for *D. eleginoides*, *D. mawsoni* and combined by-catch species for each area of concentrated effort in the fishery. Given the short period fished by vessels in each season (December to March), no restriction was placed on the temporal proximity of catches within season. Plots revealed two areas of highly concentrated effort and a third area of less concentrated effort, together accounting for 80% of all effort within a combined area of 53 000 km^2 over the life of the fishery. Together, these grounds represent 31% of the total fishable area (i.e. depth < 2 000 m) in the division.

Anomalous or missing data

Of the 2 063 separate longline sets reported for BANZARE Bank since the fishery commenced in 2003/04, 49 (2.4%) were excluded from analysis due to missing data. Of these, 20 events had no data recorded for total catch weight, 21 had no data recorded for total number of fish caught, and the remainder had no soak time recorded. Of the latter, recorded longline set and haul times could not reasonably be used to infer soak times. Excluding these records effectively omitted 591 kg of by-catch and 1 860 kg of *D. mawsoni* totalled over the 2003/04 to 2006/07 seasons.

Leslie estimates of population size

Stock depletion models for estimating initial biomass can be developed to varying levels of complexity depending on the type and quality of data available. In the absence of data for BANZARE Bank relating to recruitment, migration and natural mortality of the target species, a simple model was considered assuming a closed population and no natural mortality within season for all fishing grounds. As the legal fishing season is relatively brief, and data available from tagged toothfish in other fisheries suggesting that movement at a temporal scale of a few months is likely to be low (Dunn et al., 2007; Welsford et al., 2007b), it is a reasonable assumption that each ground represents an effectively closed population for the purposes of this analysis.

Following the notation of Hilborn and Walters (1992), in its simplest form the Leslie depletion estimator (Leslie and Davis, 1939) makes use of the catch equation and a basic population model to construct a linear model of the form:

$$y_t = qN_1 - qK_{t-1} \tag{1}$$

where y_t is an index of abundance such as CPUE, q is the catchability coefficient, N_1 is the initial population size, and K_{t-1} is the accumulated harvest immediately prior to t. Fitting by linear regression provides slope equal to q and ratio of intercept to slope equal to N_1. For the BANZARE Bank toothfish data, separate models were developed independently for each season considering y_t as kilograms per hook and as numbers of fish per hook for the predominant species in the fishery, *D. mawsoni*. Confidence bounds for initial biomass and initial CPUE estimates were derived using non-parametric bootstrap (Efron and Tibshirani, 1993). For each model considered, residuals were resampled with replacement, added to fitted values from the original model, then used to construct 1 000 bootstrap estimates of parameter values. By considering bootstrap distributions at $\alpha/2$ and $1-\alpha/2$ percentile points, $100(1-\alpha)\%$ confidence intervals (CIs) for parameters were constructed. Potential bias was checked by comparing the difference between point estimates from the original model and the bootstrap distribution mean with the standard error of the bootstrap distribution.

Standardising CPUE data to account for possible differences between vessels was considered, however the data did not support such an approach. Of the two main fishing grounds (A and B), very little overlap in fishing arose between different nationalities, negating any possibility of standardisation. This pattern of fishing was evident despite CCAMLR Conservation Measure 41-07 that, while limiting the number of vessels individual Flag States can have fishing in the division to one at a time, does not otherwise prescribe the number of vessels that can fish at once.

Catch and by-catch composition

To determine the composition of by-catch species caught within the BANZARE Bank fishery, catch records provided by vessels and biological data independently provided by scientific observers (required to be on board all toothfish vessels in the CAMLR Convention Area) were summarised and compared. By-catch rates from fine-scale catch and effort data were derived and plotted against total catch for each longline fishing event. The distribution of mean fish weights in hauls was compared between seasons and fishing grounds using boxplots (Tukey, 1977). Here, the median average fish weight is plotted inside a box whose extremes represent the first and third quartile of the distribution, 'whiskers' extend to 1.5 times the interquartile range, and potential outliers are plotted as open points beyond the whiskers. Box widths are proportional to the square-root of sample size, and sample sizes themselves can be found in Table 2.

Results

Fishery status

Since its commencement in 2003/04, seven CCAMLR Members have fished in the exploratory longline fishery for *Dissostichus* spp. on BANZARE Bank (hereafter designated Flag State A to G, Table 1). A combined total of 650 commercial and research longlines were deployed during the 2003/04 to 2006/07 fishing seasons, resulting in reported landings of 843 tonnes of *D. mawsoni*, 75 tonnes of *D. eleginoides* and 42 tonnes of by-catch species, comprising primarily macrourids and skates (Table 1). Of all fishing effort expended between 2003 and 2007, only 11 longlines failed to capture any *D. mawsoni*, compared with 485 longlines (75% of total effort) that captured no *D. eleginoides*.

While clearly *D. mawsoni* has proved the primary species captured by the fishery, it is noteworthy that catches of *D. mawsoni* in the 2006/07 season

Table 1: Summary of BANZARE Bank (Division 58.4.3b) longline fishing data showing effort (days fished and numbers of research (R) and commercial (C) longlines deployed) and catch (numbers and weight for *Dissostichus mawsoni* (TOA), *Dissostichus eleginoides* (TOP) and by-catch species) stratified by Flag State and season.

Season			Flag State							Totals
			A	B	C	D	E	F	G	
2003/04	Effort	C	6	-	-	-	-	-	-	6
		R	13	-	-	-	-	-	-	13
		Days fished	7	-	-	-	-	-	-	7
	Catch	TOA (*n*)	275	-	-	-	-	-	-	275
		TOA(kg)	6 268	-	-	-	-	-	-	6 268
		TOP(*n*)	37	-	-	-	-	-	-	37
		TOP(kg)	531	-	-	-	-	-	-	531
		By-catch (*n*)	212	-	-	-	-	-	-	212
		By-catch (kg)	238	-	-	-	-	-	-	238
2004/05	Effort	C	-	9	75	-	6	-	-	90
		R	-	10	48	-	10	-	-	68
		Days fished	-	15	71	-	9	-	-	95
	Catch	TOA(*n*)	-	1 335	8 821	-	553	-	-	10 709
		TOA(kg)	-	40 555	241 607	-	13 226	-	-	295 388
		TOP(*n*)	-	-	17	-	-	-	-	17
		TOP(kg)	-	-	225	-	-	-	-	225
		By-catch (*n*)	-	816	9 499	-	1 327	-	-	11 642
		By-catch (kg)	-	872	9 791	-	1 476	-	-	12 139
2005/06	Effort	C	-	-	110	-	-	-	20	130
		R	-	11	27	-	-	-	23	61
		Days fished	-	5	94	-	-	-	22	121
	Catch	TOA(*n*)	-	325	15 611	-	-	-	1 776	17 712
		TOA(kg)	-	7 072	310 867	-	-	-	47 097	365 036
		TOP(*n*)	-	-	14	-	-	-	-	14
		TOP(kg)	-	-	141	-	-	-	-	141
		By-catch (*n*)	-	179	8 499	-	-	-	6 710	15 388
		By-catch (kg)	-	90	5 016	-	-	-	3 916	9 022
2006/07	Effort	C	-	-	17	128	-	32	27	204
		R	-	-	20	20	-	18	20	78
		Days fished	-		18	56	-	36	31	141
	Catch	TOA(*n*)	-	-	2 899	2 219	-	915	182	6 215
		TOA(kg)	-	-	80 643	73 022	-	19521	3 067	176 253
		TOP(*n*)	-	-	-	1 958	-	331	2 229	4 518
		TOP(kg)	-	-	-	34 679	-	4784	34 810	74 273
		By-catch (*n*)	-	-	2 286	11 573	-	1401	9 503	24 763
		By-catch (kg)	-	-	1 755	8 597	-	2154	8 078	20 584

Table 2: Estimates of initial biomass and initial CPUE based on the Leslie depletion estimator for the 2004/05 season, and summary catch and effort statistics for *Dissostichus mawsoni* in three fishing grounds within BANZARE Bank (Division 58.4.3b) for the 2003/04 to 2006/07 seasons.

		Ground A	Ground B	Ground C	Totals
Area (km^2)		6 123	11 486	35 377	52 986
Initial CPUE (n hook^{-1})		0.00913	0.01765	-	
(95% CI)		(0.00658, 0.01176)	(0.01487, 0.02064)		
Initial CPUE (kg hook^{-1})		0.26924	0.53323	-	
(95% CI)		(0.19619, 0.34776)	(0.44970, 0.62787)		
Initial biomass (n)		1 982	8 369	-	
(95% CI)		(1 478, 4 271)	(7 356, 10 089)		
Initial biomass (kg)		61 279	241 013	-	
(95% CI)		(45 969, 135 768)	(215 143, 292 246)		
2003/04	Effort (lines)	-	8	8	16
	Catch (n)	-	220	42	262
	Catch (kg)	-	5 065	917	5 982
2004/05	Effort (lines)	20	67	8	95
	Catch (n)	1 366	6 859	303	8 528
	Catch (kg)	41 178	200 365	6 823	248 366
2005/06	Effort (lines)	39	91	22	152
	Catch (n)	4 504	8 718	798	14 019
	Catch (kg)	88 311	173 644	16 412	278 367
2006/07	Effort (lines)	27	45	183	255
	Catch (n)	145	3 030	2 936	6 111
	Catch (kg)	2 553	83 990	87 451	173 994
Total effort (lines)		86	211	221	518
Total catch (n)		6 015	18 827	4 079	28 921
Total catch (kg)		132 042	463 064	111 603	706 709

were around half those experienced in previous seasons, while catches of *D. eleginoides* were observed to increase substantially (Table 1). While *D. eleginoides* would be expected to occur in this area, such a dramatic shift might be caused by a number of factors, including depletion of *D. mawsoni*, finding and fishing 'hotspots' for *D. eleginoides*, a change in underlying ecosystem processes, or misreporting. Inspection of the data revealed that this change was largely reported by just two vessels and occurred in two different areas of the fishery that had not previously shown appreciable catches of *D. eleginoides* (Table 1). Furthermore, in at least one of these areas the distribution of fishing effort in 2006/07 was very similar to previous seasons, indicating the discovery of a new ground with high densities of *D. eleginoide*s, misidentification of *D. mawsoni* in the 2006/07 season, or conversely that *D. eleginoides* has been misidentified as *D. mawsoni* in prior seasons. In the absence of any firm evidence to evaluate these alternatives, data were accepted at face value pending future investigation into the distribution and relative abundance of *Dissostichus* spp. on BANZARE Bank.

Spatial distribution of catch and effort

A number of features in the distribution of catch and effort were evident (Table 1; Figures 1 to 4):

(i) Only a small number of records with low catches were available for the 2003/04 season. These are presented for completeness but not analysed further.

(ii) Catches of *D. eleginoides* were negligible in the 2003/04 to 2005/06 seasons (68 fish total) and are not considered for estimating depletion models. While catches for this species did increase substantially for some countries in 2006/07 (e.g. Flag State G, 92% of the *Dissostichus* spp. catch), catches were still dominated by *D. mawsoni* for three of the four countries that participated in the fishery.

(iii) Two areas (hereafter denoted Ground A and Ground B, 6 123 km^2 and 11 486 km^2 respectively) were identified as having experienced consistently high levels of fishing effort, and substantial catch rates of *D. mawsoni*, in a relatively small area over the 2004/05 to 2006/07 seasons. Local depletions in these areas were investigated using the Leslie method to determine estimates of initial biomass and levels of stock depletion.

(iv) Substantial but less consistent fishing effort was expended in a large area separate from Grounds A and B, hereafter referred to as Ground C (35 377 km^2). While this ground is described in terms of catch and effort characteristics, the overlap in spatial distribution of effort between years was insufficient to warrant interannual comparisons of potential stock depletion.

(v) Combined, fishing grounds A, B and C were subject to 80% of all fishing effort expended in BANZARE Bank during the period from 2003/04 to 2006/07, accounting for 84% of all *D. mawsoni* landed from the division. Information on the exact location of catches cannot be shown for reasons of confidentiality, however the bathymetric range and relative location of fishing grounds is shown diagrammatically in Figure 1. Fishing depths within Grounds A and B were similar and comparable across seasons, with most longlines set in depths of 1 700–1 800 m. Fishing depths in Ground C were more variable and substantially shallower than other grounds, with most fishing reported as occurring in 1 100–1 500 m.

(vi) The trotline fishing method, employed by the vessel from Flag State D in 2006/07, produced strikingly different catch and effort characteristics from the Spanish and autoline longline systems. Trotline fishing involves multiple lines set in comparatively close proximity (e.g. in the west of Ground C in 2006/07) (Figure 4). In comparison, other longlining methods involve much longer lines spaced further apart and often set in parallel. Since trotline fishing only occurred in Ground C it was not included in depletion analyses.

(vii) Examination of the distribution of commercial and research longlines showed that they are of comparable length and occur in close spatial and (within season) temporal proximity to one another within Grounds A and B (Figures 2 to 4). This allowed sample sizes to be increased for the purposes of deriving depletion estimates by combining research and commercial fishing.

Leslie estimates of initial biomass

Estimates of initial available biomass in numbers and weight, and initial CPUE, were determined for *D. mawsoni* in Grounds A and B for the 2004/05 and 2005/06 seasons (Table 2; Figures 5 to 8). Data were insufficient to provide estimates for *D. eleginoides* in any fishing ground within BANZARE Bank and are not presented. Fitted regression lines are only displayed for those models having a significant negative slope. In determining CIs for biomass estimates, the ratio of bias to standard error of the bootstrap distribution was acceptable for all models considered (i.e. less than 0.25 *sensu* Efron and Tibshirani, 1993).

Estimates indicate Ground B to be more productive than Ground A, with estimated initial biomass of 241 013 kg (95% CI: 215 143–292 246 kg) for its area of 11 486 km^2 (~21 kg km^{-2}) compared with 61 279 kg (95% CI: 45 969–135 768 kg) for an area of 6 123 km^2 (~10 kg km^{-2}) (Figure 9).

Within any one season the fraction of initial biomass estimated to be captured by the fishery is large (e.g. 67% of initial biomass captured in Ground A in 2004/05, and 83% in Ground B in the same season). Although there is some evidence that removals are partially replaced by fish moving into these grounds between fishing seasons (e.g. partial recovery of catch rates between 2004/05 and the start of the 2005/06 season in Grounds A and B, with no obvious changes to stock recruitment or fleet fishing patterns), this source of replacement was effectively exhausted by 2006/07, with catch rates generally remaining low across both grounds (Figures 5 to 8).

While plots of cumulative catch against CPUE for *D. mawsoni* are also presented for Ground C (Figures 10 and 11), effort for this large area was too sparse for the purposes of estimating initial biomass by the Leslie method. With the exception of the Flag State D trotline vessel which fished over a relatively large area and maintained relatively high catch rates, catch rates in Ground C were consistently low for all shots in this region, indicating low densities of fish relative to Grounds A and B prior to depletion.

Mean weight of toothfish

Mean weight of toothfish was estimated by haul across all grounds using the estimated number of fish and total weight of catch in the fine-scale catch and effort dataset (Figures 12 and 13). Data for *D. eleginoides* are sparse, but results indicate the median mean weight for this species is almost uniformly below 20 kg across all seasons and grounds. In comparison, median mean weight for *D. mawsoni* is typically greater than 20 kg. *Dissostichus mawsoni* in Ground A have been declining in size with each season. With little evidence that small fish (<10 kg) are present in any of the fishing grounds, results suggest that the area is populated by large fish moving in from elsewhere as adults, or that recruitment of juveniles to the area has not occurred for many years.

By-catch

A plot of total catch against the proportion of by-catch shows no consistent pattern of proportionately high by-catch arising from individual Flag States or seasons (Figure 14). While individual longlines did occasionally capture up to 20% by-catch by weight (typically macrourids or rajiformes), most events of this kind only occurred when total catches were relatively small.

The distribution and biological characteristics of by-catch in this fishery could not be reliably compared across vessels, grounds or seasons because of substantial inconsistencies for some vessels between vessel fine-scale catch and effort reports of by-catch composition and those of scientific observers (Table 3). This was particularly evident for a Flag State G vessel, two Flag State C vessels, and one Flag State B vessel, all of which reported catching several tonnes of macrourids but for which no biological observations were reported.

Discussion

The main fishing grounds in BANZARE Bank show clear evidence of rapid within-season declines in CPUE, followed by partial recovery in subsequent seasons, and finally uniformly low catch rates in the most recent season, 2006/07. These observations are consistent with a situation where fish are generally distributed in low densities, with a small number of areas of attractive habitat supporting high densities and, initially, high catch rates. If these patches are fished down, fish from surrounding (low density) areas might be expected to reoccupy areas of attractive habitat over time. After sufficient rest from fishing, catch rates for these areas will initially be high again. Under continued fishing pressure, however, eventually immigration of fish from surrounding low-density areas would be exhausted, and catch rates would catastrophically decline with any recovery dependant on processes such as arrival of new recruits and larger-scale movements, all of which are likely to occur over time scales greater than individual seasons. Hence, the observed decline in toothfish catch rates in Grounds A and B may not reverse for many years, even in the absence of fishing.

Analyses in this paper confirm the broad conclusions of Welsford et al. (2007a) regarding the status of the *Dissostichus* spp. fishery on BANZARE Bank. The distribution of catch and effort in this fishery is highly concentrated in space, with 80% of all effort and 84% of all catches coming out of areas accounting for just 31% of fishable sea floor (deeper than 2 000 m) in the division. Low catch rates are reported to be the norm except in Grounds A and B, where initially high catches have rapidly dwindled. Estimates of initial biomass in these small areas indicate that historical allowable catches (300 tonnes in 2006/07) are unsustainable, particularly if the great majority of removals come from 'hotspots' where fish are apparently attracted and hence readily targeted and depleted. Catch rates in Ground C were relatively low, indicating low densities of fish relative to Grounds A and B. For that ground, it seems likely that rapid depletion would result if fishing were to be concentrated in that area at similar levels experienced by the other grounds.

Evidence of depletion, as derived from commercial catch and effort data, needs to be considered against a background of high levels of IUU fishing thought to occur in the BANZARE Bank area (SC-CAMLR, 2006b; SC-CAMLR, 2007a). The timing of IUU fishing will impact on how the initial biomass estimated from legal removals, the relative depletion of the stock relative to the initial biomass and the rate of depletion are interpreted (Figure 15). If legal operators exclude IUU fishers, and IUU activity is confined to occur prior to the legal season, then the initial biomass at the commencement of legal fishing in a season is an underestimate of initial biomass prior to all fishing, but the rate of depletion will be an accurate reflection of the response of the stock to the legal fishery, and the relative depletion of the stock will be an underestimate (Figure 15b). If IUU fishing all occurs after the legal fishery, then the rate of depletion and the initial biomass estimates for that season will not be affected by IUU removals, but the stock will be depleted further (Figure 15c). If IUU fishing occurred simultaneously with legal fishing, then the rate of depletion determined from legal fishing alone and relative depletion of the stock will be overestimated, and the initial biomass will be underestimated (Figure 15d). Quantifying the impact of the timing and intensity of large IUU catches on depletion estimates using a simulation framework are worthy avenues for further investigation. However, none of the scenarios discussed would significantly alter the conclusion that unsustainable levels of depletion are occurring on BANZARE Bank through the combination of IUU and legal fishing.

Table 3: By-catch taxa (CCAMLR codes in parenthesis) reported in fine-scale catch and effort data by vessels from BANZARE Bank (Division 58.4.3b) showing total weight (kg) of by-catch species by Flag State and vessel. Shaded cells show instances where catch of a species/group was reported in the vessel dataset, but no biological data were reported in the scientific observer dataset.

	Flag State										Total
	A	B		C			D	E	F	G	
Vessel number:	1	1	2	1	2	3	1	1	1	1	
By-catch species											
Antimora rostrata (ANT)	-	-	14	13	120	75	519	4	10	38	793
Bathyraja mccaini (BAM)	-	-	-	-	-	-	-	810	-	-	810
Bathyraja spp. (BHY)	-	-	-	-	-	-	-	-	-	1 395	1 395
Macrourus spp. (GRV)	131	40	478	1 955	5 337	4 139	-	663	-	10 384	23 126
Somniosus microcephalus (GSK)	-	-	-	-	300	-	-	-	-	-	300
Channichthyidae (ICX)	-	-	-	2	-	-	-	-	4	-	6
Invertebrata (INV)	-	7	-	-	-	-	-	-	-	10	17
Lithodes spp. (KCX)	-	-	-	-	-	20	13	-	-	-	33
Lithodidae (KCZ)	-	-	-	-	-	-	-	-	-	13	13
Lampris immaculatus (LAI)	-	-	15	-	-	-	-	-	-	-	15
Muraenolepis spp. (MRL)	-	1	-	-	4	2	67	-	-	-	73
Notothenia squamifrons (NOS)	-	-	-	-	-	-	234	-	17	-	251
Octopodidae (OCT)	-	1	-	-	-	-	-	-	-	-	1
Rajiformes (RAJ)	-	42	-	-	-	-	-	-	-	-	42
Salilota australis (SAO)	-	-	-	-	-	-	-	-	-	35	35
Raja Georgiana (SRR)	-	-	-	-	4 328	1	-	-	-	-	4 328
Raja spp. (SRX)	114	-	365	533	-	319	-	-	1 452	354	3 137
Macrourus whitsoni (WGR)	-	-	-	-	-	-	7 764	-	671	-	8 435

Catch composition data suggest that the mix of *Dissostichus* species in the division has changed dramatically in 2006/07 compared with previous seasons. While *D. mawsoni* and *D. eleginoides* overlap in areas near 60°S, with small numbers of *D. eleginoides* reported in the northern part of the Ross Sea (Subarea 88.1) *Dissostichus* spp. fishery (SC-CAMLR, 2007b), such an apparently rapid change in species composition is unprecedented. This, coupled with the fact that the *D. mawsoni* stock in this division is dominated by large fish, suggests that the stock structure of *Dissostichus* spp. in the area is likely to be complex, involving links with stocks in other regions in the southern Indian Ocean and around the Antarctic Continent. Future research sampling in this area should be specifically directed at determining the distribution of *Dissostichus* species.

As in many other fisheries in the Convention Area, by-catch is dominated by macrourids and rajiformes. Unfortunately, the inconsistent level of data collected to date by observers on some vessels in this fishery makes it impossible to assess the population characteristics of by-catch groups, or even to be confident in the identification of species composition of catches.

Conclusions

Analyses of the patterns of catch and effort in the legal fishery on BANZARE Bank indicates for the first time that severe depletion has resulted over the life of the fishery. The stock structure in the area, with an apparent lack of recruitment over the past three seasons, indicates that stock recovery in Grounds A and B may be unlikely to occur for several years. Although the absolute quantities will be affected by IUU fishing, relatively low estimates of initial biomass, rapid rates of stock depletion and apparently high relative depletion (in excess of 80% of initial biomass taken within a season) derived from the depletion analyses (based on legal fishing alone), indicate that the standing stock of *D. mawsoni* in this division could not sustain the levels of IUU and legal fishing that have occurred since 2003.

It is contended that the issues of evaluating BANZARE Bank catch rates, catch composition, population dynamics and stock structure of target and main by-catch species are unlikely to be resolved with the types of data currently being collected. Although the tagging program for the area has potential for use in stock assessments in the longer term, tag return rates are low (SC-CAMLR, 2007a). This study shows that severe, possibly irreversible, depletion can be evident in the space of two or three seasons, before sufficient tag returns or other sources of information on stock status may become available and are analysed. Furthermore, using such data to estimate stock status is also confounded by issues of species misidentification and IUU fishing. A research survey across the area, as endorsed by CCAMLR in 2007 (SC-CAMLR, 2007c), should help verify some of the trends in relative catch rates and catch composition seen in the main fishing areas, and represents a viable option to collect the data necessary to further develop the assessment of this division. Scrutiny of other exploratory fisheries, where high levels of IUU fishing or concentrated legal fishing may be causing depletions, should be considered a matter of priority.

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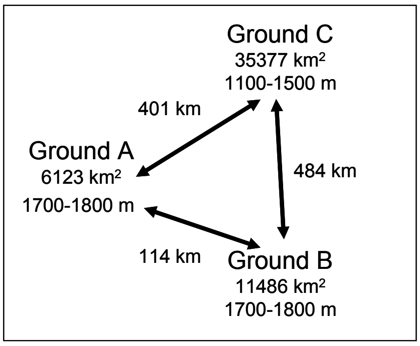

Figure 1: Diagram showing the area (km^2), depth range (m) and relative position of fishing grounds A, B and C on BANZARE Bank (Division 58.4.3b) (not to scale). Distance between grounds is the nearest distance between the edges of the grounds.

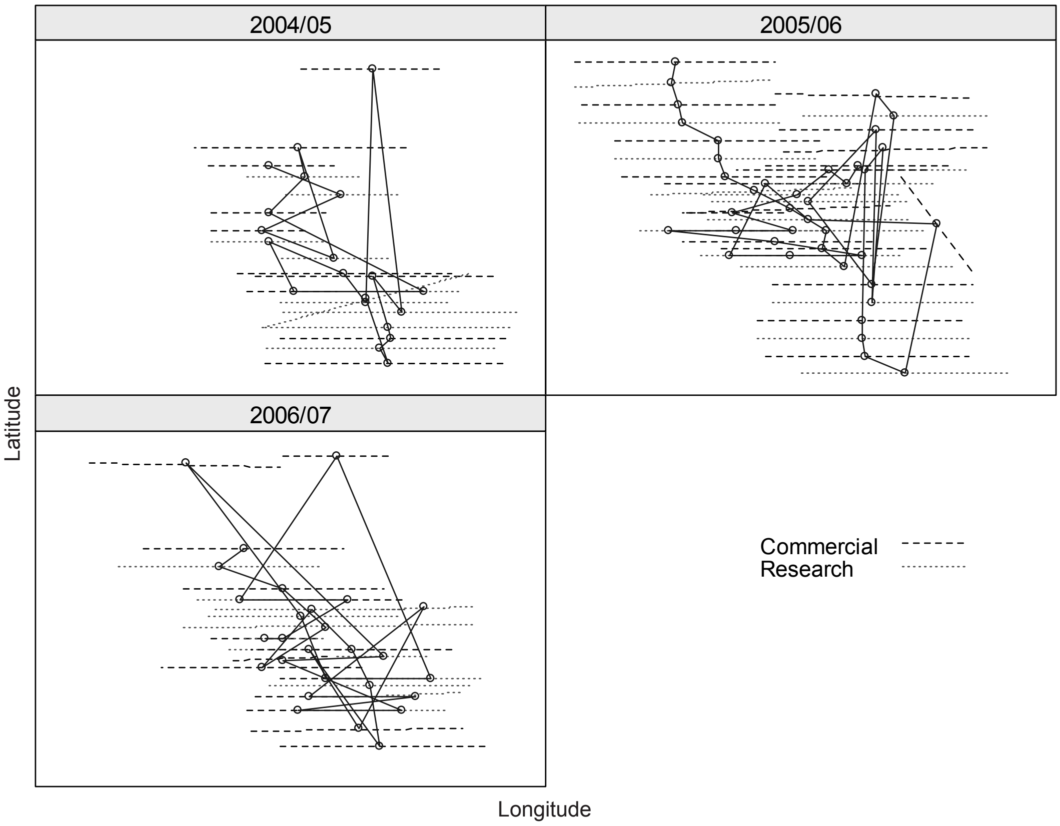

Figure 2: Spatial distribution of commercial and research longlines (dashed lines) in each season for BANZARE Bank Ground A. Consecutive longlines are joined at their midpoint (solid lines) to indicate the relative order of fishing activity. Maximum line lengths in each season were between 30 and 40 km, giving an indication of the relative size of the ground.

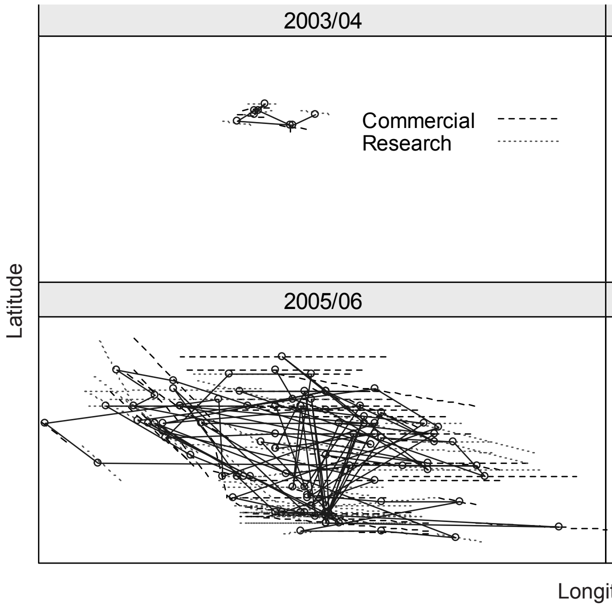

Figure 3: Spatial distribution of commercial and research longlines (dashed lines) in each season for BANZARE Bank Ground B. Consecutive longlines are joined at their midpoint (solid lines) to indicate the relative order of fishing activity. Maximum line lengths for the 2004/05 to 2006/07 seasons were around 30, 50 and 30 km respectively, giving an indication of the relative size of the ground.

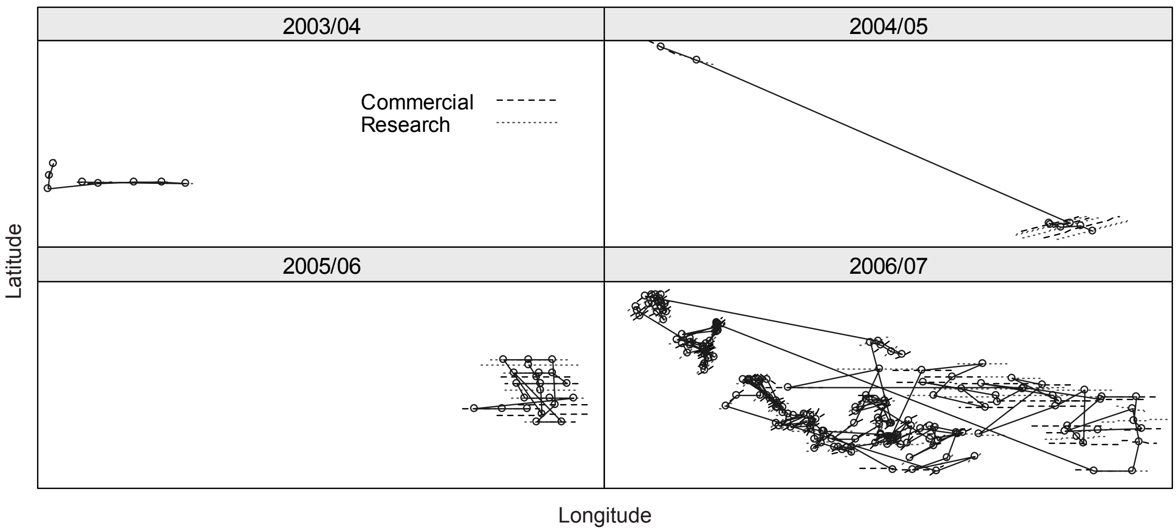

Figure 4: Spatial distribution of commercial and research longlines (dashed lines) in each season for BANZARE Bank Ground C. Consecutive longlines are joined at their midpoint (solid lines) to indicate the relative order of fishing activity. Maximum line lengths for the 2004/05 to 2006/07 seasons were between 30 and 40 km, giving an indication of the relative size of the ground.

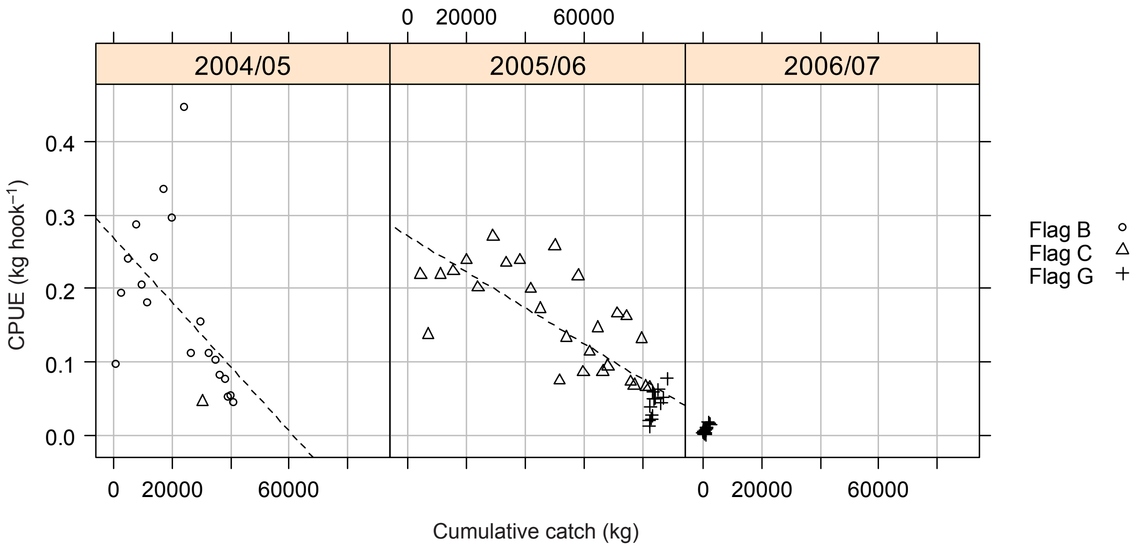

Figure 5: CPUE (kg hook^{-1}) against cumulative catch (kg) of *Dissostichus mawsoni* for Ground A in the 2003/04 to 2006/07 seasons on BANZARE Bank (Division 58.4.3b). Fitted regression lines have been added to those relationships showing a significant negative slope ($p < 0.05$).

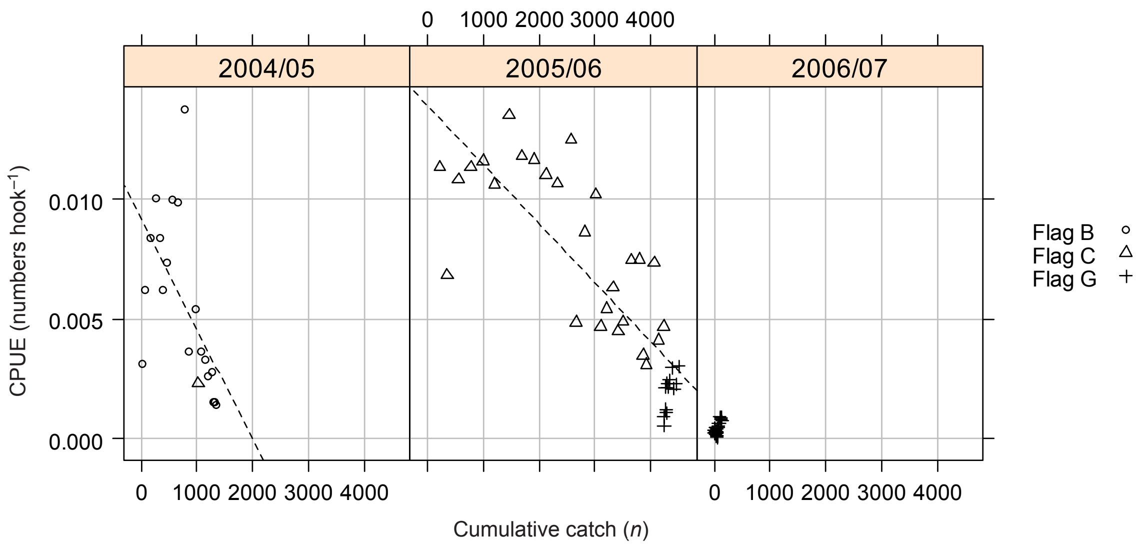

Figure 6: CPUE (numbers hook^{-1}) against cumulative catch (number of fish) of *Dissostichus mawsoni* for Ground A in the 2003/04 to 2006/07 seasons on BANZARE Bank (Division 58.4.3b). Fitted regression lines have been added to those relationships showing a significant negative slope ($p < 0.05$).

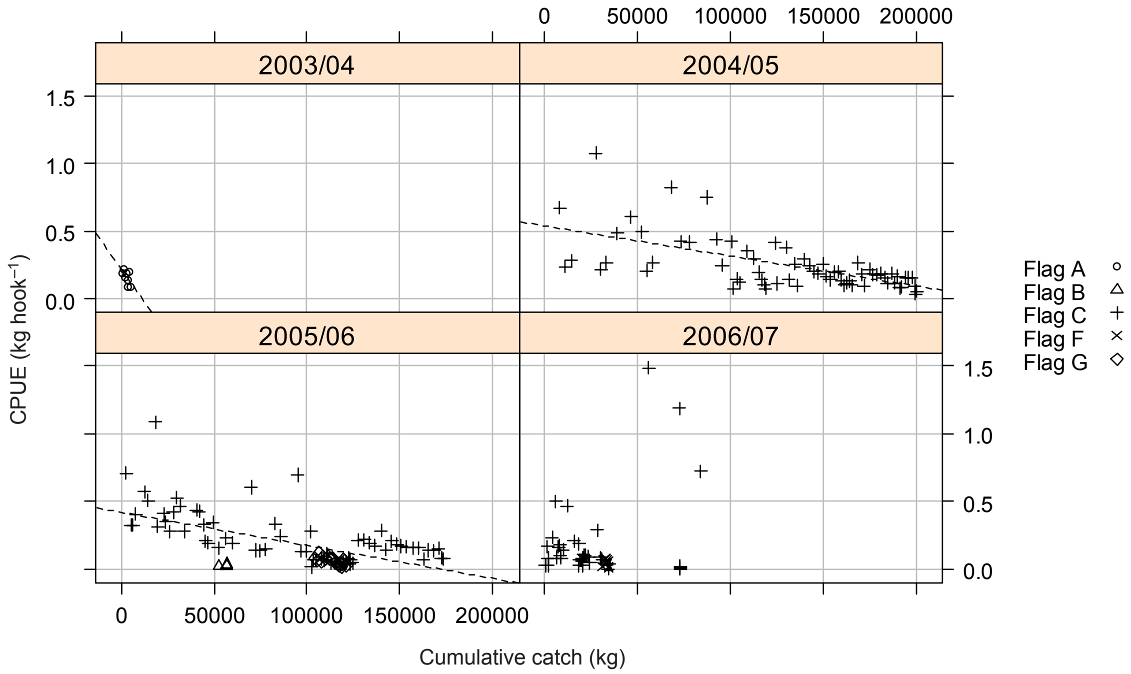

Figure 7: CPUE (kg hook^{-1}) against cumulative catch (kg) of *Dissostichus mawsoni* for Ground B in the 2003/04 to 2006/07 seasons on BANZARE Bank (Division 58.4.3b). Fitted regression lines have been added to those relationships showing a significant negative slope ($p < 0.05$).

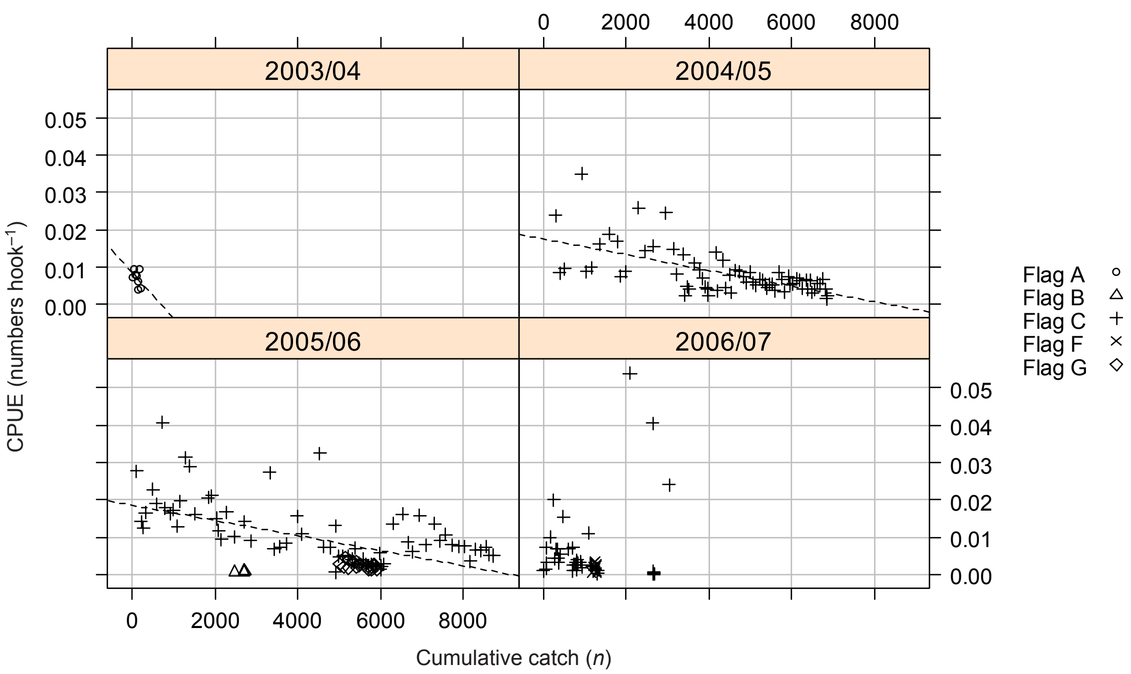

Figure 8: CPUE (numbers hook^{-1}) against cumulative catch (number of fish) of *Dissostichus mawsoni* for Ground B in the 2003/04 to 2006/07 seasons on BANZARE Bank (Division 58.4.3b). Fitted regression lines have been added to those relationships showing a significant negative slope ($p < 0.05$).

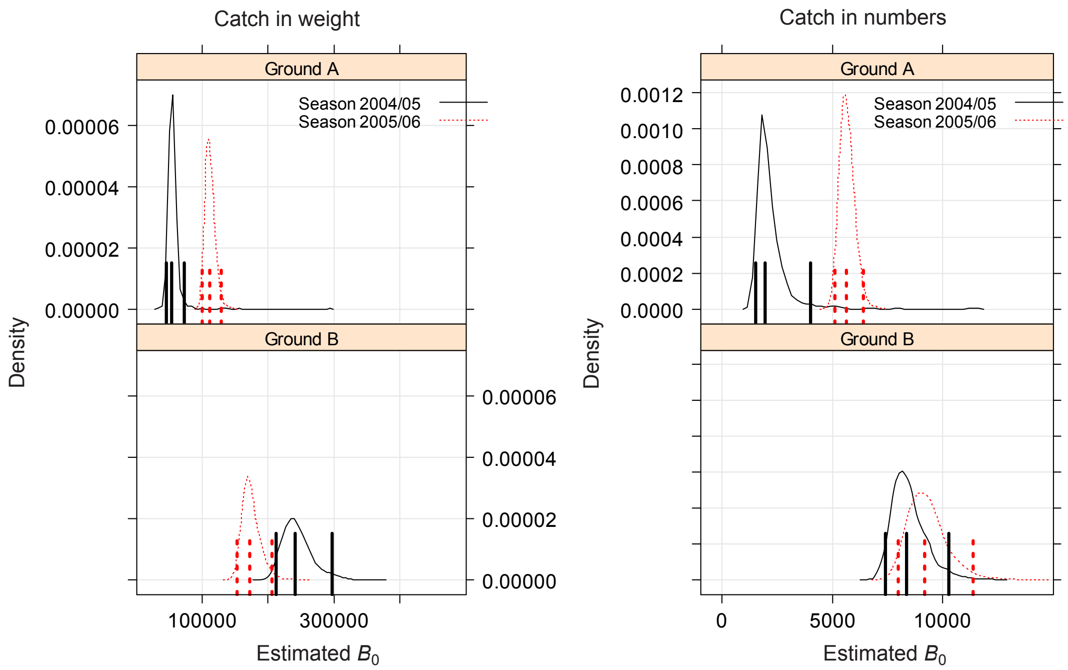

Figure 9: Distribution of initial biomass, B_0 (kg), derived from 1 000 bootstrap replicates for each season and ground, separately for models derived using catch in weight and catch in numbers. Fitted curves are the result of applying a Gaussian kernel density estimator and short vertical lines indicate the 0.025, 0.5 and 0.975 percentile positions.

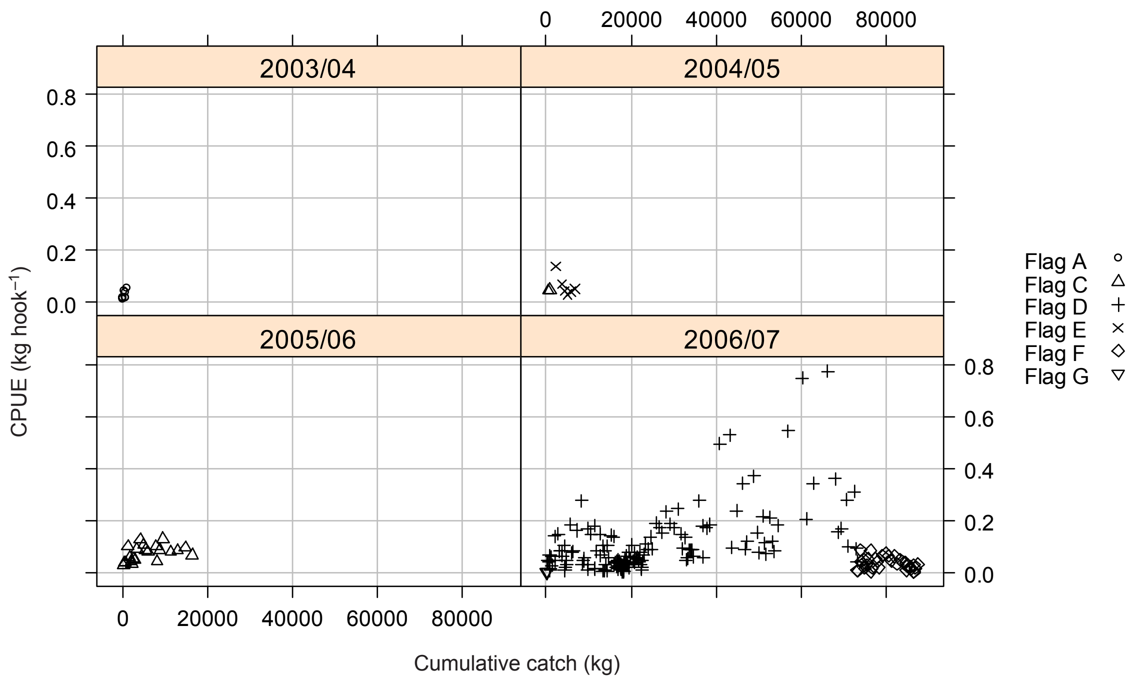

Figure 10: CPUE (kg hook^{-1}) against cumulative catch (kg) of *Dissostichus mawsoni* for Ground C in the 2003/04 to 2006/07 seasons on BANZARE Bank (Division 58.4.3b). No significant negative relationships were apparent.

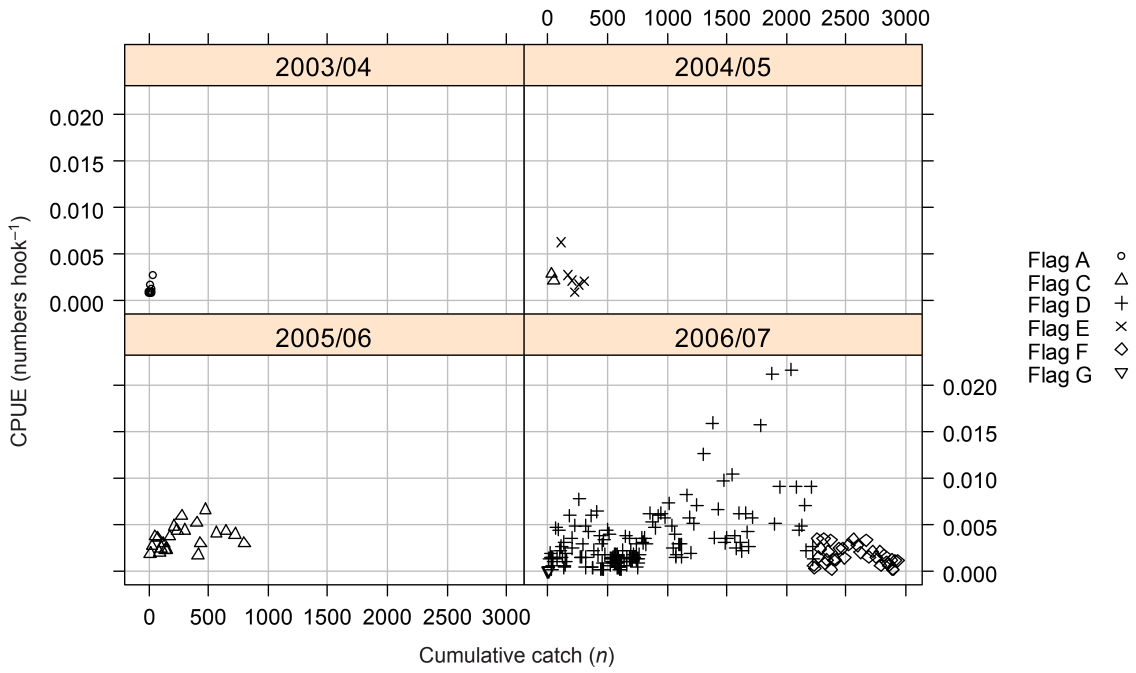

Figure 11: CPUE (numbers hook^{-1}) against cumulative catch (number of fish) of *Dissostichus mawsoni* for Ground C in the 2003/04 to 2006/07 seasons on BANZARE Bank (Division 58.4.3b). No significant negative relationships were apparent.

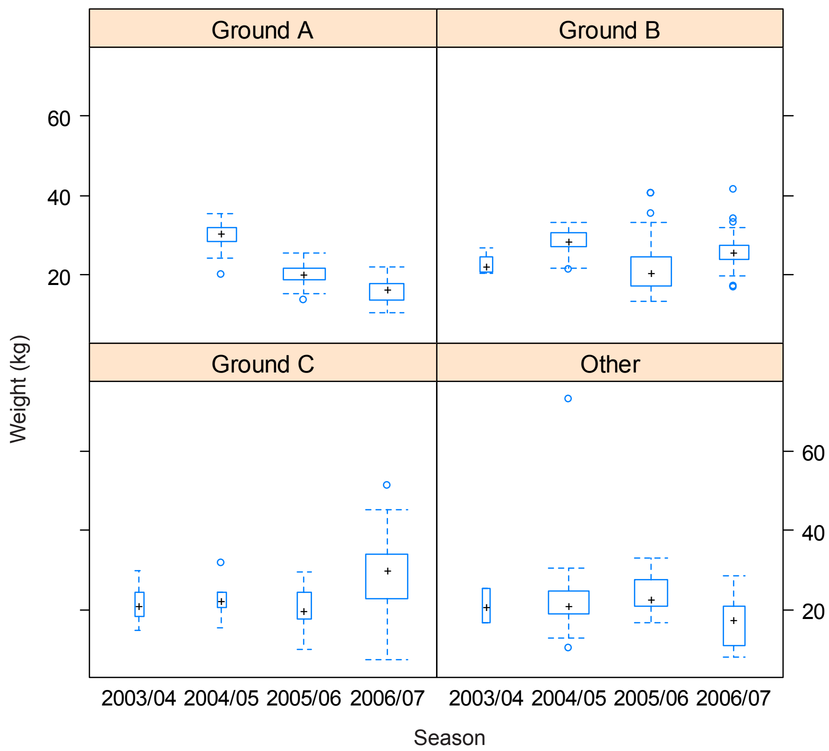

Figure 12: Boxplots showing the distribution of mean weights for *Dissostichus mawsoni* derived from individual longlines within each season in each ground for BANZARE Bank (Division 58.4.3b). Box width is proportional to the square root of the sample size.

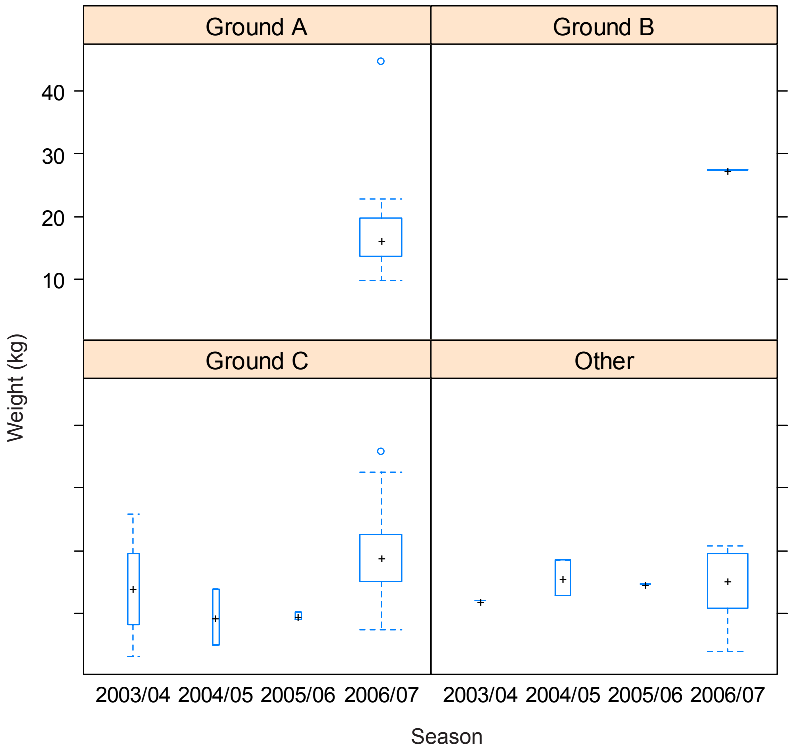

Figure 13: Boxplots showing the distribution of mean weights for *Dissostichus eleginoides* derived from individual longlines within each season in each ground for BANZARE Bank (Division 58.4.3b). Box width is proportional to the square root of the sample size.

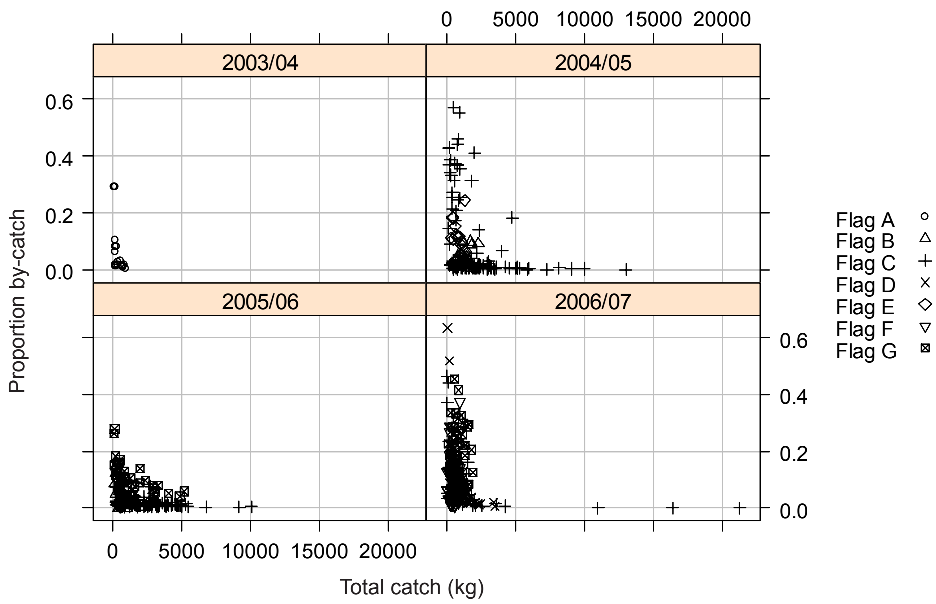

Figure 14: Total landed catch weight (all species) against proportion of the catch weight attributable to by-catch (non-*Dissostichus*) species for individual longlines on BANZARE Bank (Division 58.4.3b). Fishing seasons are shown as separate panels, with symbol type representing Flag State.

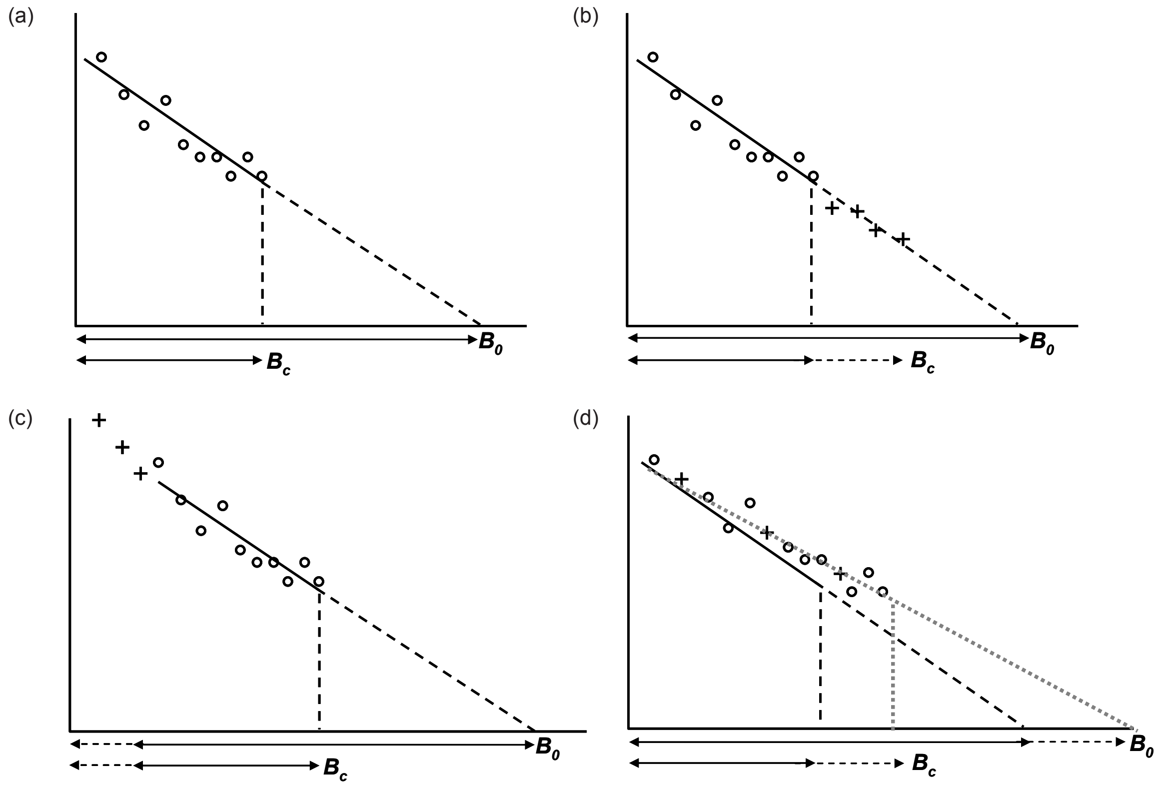

Figure 15: Diagram representing the hypothetical impact of the timing of IUU fishing (crosses) on the initial biomass (B_0), current biomass removals (B_c), the relative depletion (B_c/B_0) and the rate of depletion (slope of the regression through the points) based on legal fishing (circles). The x-axis in all cases represents cumulative catch, and the y-axis represents CPUE, with the origin at (0,0). (a) Depletion due to legal fishery (circles) only, which is the situation assumed in this study. The regression line (solid line) and the positions of the projected B_0 and B_c (with dotted guidelines projecting from the data) for this case are shown in all panels for comparison. (b) When IUU fishing (crosses) occurs exclusively after the legal fishery, B_c and B_c/B_0 are underestimated, however; B_0 and the rate of depletion is unaffected. (c) When IUU fishing occurs before the legal fishery, B_0 and B_c and B_c/B_0 are underestimated, however; the rate of depletion is unaffected. (d) When IUU fishing occurs during legal fishing, B_0 , B_c and B_c/B_0 are all underestimated, and the rate of depletion is overestimated.

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соединены в средней точке (сплошные линии), с тем чтобы показать относительный порядок проведения промысла. Максимальная длина ярусов в сезонах 2004/05–2006/07 гг. составляла 30–40 км, что дает представление об относительном размере участка.

Рис. 5: CPUE (кг/крючок) по сравнению с кумулятивным выловом (кг) *Dissostichus mawsoni* в сезонах 2003/04–2006/07 гг. на участке A банки БАНЗАРЕ (Участок 58.4.3b). Показаны соответствующие линии регрессии для зависимостей с существенным отрицательным углом наклона ($p < 0.05$).

Рис. 6: CPUE (особей/крючок) по сравнению с кумулятивным выловом (количество особей) *Dissostichus mawsoni* в сезонах 2003/04–2006/07 гг. на участке A банки БАНЗАРЕ (Участок 58.4.3b). Показаны соответствующие линии регрессии для зависимостей с существенным отрицательным углом наклона ($p < 0.05$).

Рис. 7: CPUE (кг/крючок) по сравнению с кумулятивным выловом (кг) *Dissostichus mawsoni* в сезонах 2003/04–2006/07 гг. на участке B банки БАНЗАРЕ (Участок 58.4.3b). Показаны соответствующие линии регрессии для зависимостей с существенным отрицательным углом наклона ($p < 0.05$).

Рис. 8: CPUE (особей/крючок) по сравнению с кумулятивным выловом (количество особей) *Dissostichus mawsoni* в сезонах 2003/04–2006/07 гг. на участке B банки БАНЗАРЕ (Участок 58.4.3b). Показаны соответствующие линии регрессии для зависимостей с существенным отрицательным углом наклона ($p < 0.05$).

Рис. 9: Распределение исходной биомассы B_0 (кг), полученное по 1000 бутстрап повторов для каждого сезона и участка, отдельно для моделей, использующих вылов в весовом и вылов в количественном выражении. Подобранные кривые получены в результате применения гауссовой ядерной оценки плотности; короткими вертикальными отрезками показано положение процентилей 0.025, 0.5 и 0.975.

Рис. 10: CPUE (кг/крючок) по сравнению с кумулятивным выловом (кг) *Dissostichus mawsoni* в сезонах 2003/04–2006/07 гг. на участке C банки БАНЗАРЕ (Участок 58.4.3b). Существенной обратной зависимости не отмечено.

Рис. 11: CPUE (особей/крючок) по сравнению с кумулятивным выловом (число особей) *Dissostichus mawsoni* в сезонах 2003/04–2006/07 гг. на участке C банки БАНЗАРЕ (Участок 58.4.3b). Существенной обратной зависимости не отмечено.

Рис. 12: Коробчатые диаграммы, показывающие распределение среднего веса *Dissostichus mawsoni*, полученного по отдельным ярусам для каждого сезона на каждом участке банки БАНЗАРЕ (Участок 58.4.3b). Ширина коробки пропорциональна квадратному корню из размера выборки.

Рис. 13: Коробчатые диаграммы, показывающие распределение среднего веса *Dissostichus eleginoides*, полученного по отдельным ярусам для каждого сезона на каждом участке банки БАНЗАРЕ (Участок 58.4.3b). Ширина коробки пропорциональна квадратному корню из размера выборки.

Рис. 14: Общий вес выгруженного улова (все виды) по сравнению с долей веса улова, приходящейся на виды прилова (не-*Dissostichus*) для отдельных ярусов на банке БАНЗАРЕ (Участок 58.4.3b). Промысловые сезоны показаны на отдельных частях рисунка; государства флага обозначены символами.

Рис. 15: Гипотетическое воздействие времени проведения ННН промысла (крестики) на исходную биомассу (B_0), изъятие существующей биомассы (B_c), относительное истощение (B_c /B_0) и темпы истощения (наклон регрессии по точкам) на основании данных о законном промысле (кружки). Ось x во всех случаях представляет кумулятивный вылов, а ось y – CPUE, с началом координат (0,0). (a) Истощение в результате только законного промысла (кружки), что является ситуацией, принятой в данном исследовании. Линия регрессии (сплошная линия) и положение рассчитанных B_0 и B_c (экстраполированные по данным пунктирные линии) для данного случая показаны на всех частях рисунка для сравнения. (b) Когда ННН промысел (крестики) ведется только после законного промысла, оценка B_c и B_c /B_0 занижается; однако это не влияет на темпы истощения и B_0. (c) Когда ННН промысел ведется до законного промысла, оценки B_0 и B_c, и B_c /B_0 занижаются; однако это не влияет на темпы истощения. (d) Когда ННН промысел ведется одновременно с законным промыслом, все оценки B_0, B_c и B_c /B_0 занижаются, а темпы истощения завышаются.

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en peso y en número. Las curvas de ajuste se han obtenido mediante la aplicación de un estimador kernel gaussiano de la densidad, y las líneas verticales cortas indican la posición de los percentiles 0.025, 0.5 y 0.975.

Figura 10: CPUE (kg·anzuelo^{-1}) en función de la captura acumulada (kg) de *Dissostichus mawsoni* para el caladero C en las temporadas 2003/04 a 2006/07 en el banco BANZARE (División 58.4.3b). No se advirtieron relaciones negativas de importancia.

Figura 11: CPUE (número·anzuelo^{-1}) en función de la captura acumulada (número de peces) de *Dissostichus mawsoni* para el caladero C en las temporadas 2003/04 a 2006/07 en el banco BANZARE (División 58.4.3b). No se advirtieron relaciones negativas de importancia.

Figura 12: Diagrama de cajas mostrando la distribución de los pesos promedios de *Dissostichus mawsoni* derivados de palangres individuales en cada temporada y caladero del banco de BANZARE (División 58.4.3b). El ancho de la caja es proporcional a la raíz cuadrada del tamaño de la muestra.

Figura 13: Diagrama de cajas mostrando la distribución de los pesos promedios de *Dissostichus eleginoides* derivados de palangres individuales en cada temporada y caladero del banco de BANZARE (División 58.4.3b). El ancho de la caja es proporcional a la raíz cuadrada del tamaño de la muestra.

Figura 14: Peso total de la captura subida a bordo (todas las especies) en función de la proporción del peso de la captura atribuible a especies de la captura secundaria (no *Dissostichus*) de palangres individuales en el banco BANZARE (División 58.4.3b). Las temporadas de pesca se muestran en cuadros separados, con símbolos representando a cada Estado del pabellón.

Figura 15: Diagrama representando el posible impacto de la época en que se realiza la pesca INDNR (cruces) en la biomasa inicial (B_0), las extracciones actuales de biomasa (B_c), la reducción relativa de la biomasa (B_c/B_0) y la tasa de reducción (pendiente de la regresión a través de los puntos) sobre la base de la pesca legal (círculos). El eje de las 'x' representa en todos los casos la captura acumulada y el eje de las 'y' representa la CPUE, con el origen en (0,0). (a) Reducción producida por la pesquería legal solamente (círculos), que es la suposición en este estudio. La línea de regresión (línea continua) y las posiciones de los valores proyectados de B_0 y B_c (con líneas punteadas proyectándose desde los datos) para este caso se muestran en todos los cuadros a título comparativo; (b) cuando la pesca INDNR (cruces) ocurre exclusivamente después de la pesca legal, se subestima B_c y B_c/B_0; sin embargo, B_0 y la tasa de reducción no se ve afectada; (c) cuando la pesca INDNR ocurre antes del inicio de las actividades de la pesquería legal, se subestima B_0, B_c y B_c/B_0; sin embargo, la tasa de reducción no se ve afectada; (d) cuando la pesca INDNR y la pesca legal se desarrollan al mismo tiempo, se subestima B_0, B_c y B_c/B_0, y se sobreestima la tasa de reducción.