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SHORT NOTE

ASSESSMENTS OF BY-CATCH IN TRAWL FISHERIES AT HEARD AND MCDONALD ISLANDS

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Abstract

This paper assesses the potential for the commercial trawl fisheries in the Heard Island area (Statistical Division 58.5.2) to significantly affect, in the long term, spawning biomass of three taxa caught as by-catch: *Channichthys rhinoceratus*, *Lepidonotothen squamifrons* and *Bathyraja* spp. (deep-water skates). The long-term annual yield for each of the three taxa was estimated using the generalised yield model (GYM) used by the CCAMLR Working Group on Fish Stock Assessment (WG-FSA). Input data included biomass estimates from surveys in the region from 1990 to 1993 and a limited amount of biological data from the local area. Where possible, values for missing input parameters were obtained from the literature, for the same species from other areas, otherwise proximate data for similar species elsewhere in the world were used. The second part of the analysis examined the amount of each species caught during commercial operations and the effectiveness of by-catch provisions (the 5% rule) set by CCAMLR in 1996 to ensure that the status of these commercial species is not affected by these commercial fisheries. The ranges of estimates of long-term annual yields for *C. rhinoceratus*, *L. squamifrons* and skates were 62 to 87 tonnes, 7 to 911 tonnes and 50 to 210 tonnes respectively. While refinement of these estimates is needed, they enable a preliminary examination of the potential for the fishery to be exceeding long-term sustainable annual yields. For *C. rhinoceratus*, *L. squamifrons* and skates (principally *B. eatoni*), the total by-catch during commercial activities in 1996/97 was approximately 5%, 58% and 11% of the respective lowest estimates of yield. These results indicate that the current commercial trawl fisheries around Heard Island are unlikely to be negatively affecting these stocks. Notably, by-catch species appeared as a high proportion of the catch (greater than 5%) when only small amounts of fish were caught (less than 100 kg of by-catch), which was usually during prospecting. By-catch was usually very low as a proportion of the total catch when large catches of target species were taken, indicating that CCAMLR's 1996 by-catch rules need revising in order that prospecting may be undertaken. Thus, to enable prospecting for commercial aggregations of *Champsocephalus gunnari* or *Dissostichus eleginoides* while protecting the by-catch species from excessive fishing effort, the rules governing by-catch for the Heard Island area could be a combination of (i) limiting the total by-catch in a year to the estimates of long-term annual yield, (ii) allowing catches of by-catch species of up to 100 kg in any one haul and (iii) changing fishing grounds if the catch of any one of the by-catch species exceeds 100 kg and the total by-catch is greater than 5% of the total catch in a single haul.

Résumé

Les auteurs examinent dans quelle mesure les pêcheries industrielles au chalut du secteur de l'île Heard (division statistique 58.5.2) affectent, à long terme, la biomasse reproductrice de trois taxons des captures accessoires : *Channichthys rhinoceratus*, *Lepidonotothen squamifrons* et *Bathyraja* spp. (raies d'eaux profondes). Le rendement

annuel à long terme de chacun de ces trois taxons est estimé au moyen du modèle de rendement généralisé (GYM) dont se sert le groupe de travail de la CCAMLR chargé de l'évaluation des stocks de poissons (WG-FSA). Parmi les données d'entrée figurent les estimations de biomasse des campagnes d'évaluation réalisées dans le secteur de 1990 à 1993 et quelques données biologiques du secteur local. Lorsque cela s'est avéré possible, les valeurs des paramètres d'entrée manquants ont été tirées de la littérature qui traite des mêmes espèces d'autres secteurs, sinon on se sert de données proches sur des espèces similaires vivant ailleurs. Dans la deuxième partie, l'analyse porte sur la quantité de chacune de ces espèces capturées au cours des opérations commerciales et l'efficacité des dispositions relatives aux captures accessoires (la règle des 5%) fixées par la CCAMLR en 1996 en vue de garantir que l'état de ces espèces commercialisées n'est pas affecté par les pêcheries en question. Les estimations des rendements annuels à long terme de *C. rhinoceratus*, *L. squamifrons* et des raies sont comprises dans les fourchettes respectives de 62 à 87 tonnes, 7 à 911 tonnes et 50 à 210 tonnes. Bien que ces estimations doivent encore être affinées, elles permettent toutefois une première étude de la possibilité que la pêcherie excède les rendements admissibles annuels à long terme. En ce qui concerne *C. rhinoceratus*, *L. squamifrons* et les raies (notamment *B. eatoni*), la capture accessoire de toutes les activités commerciales de 1996/97 correspond respectivement à environ 5%, 58% et 11% des estimations les plus faibles du rendement. Selon ces résultats, les pêcheries commerciales au chalut autour de l'île Heard ne devraient pas avoir d'effet néfaste sur ces stocks. En effet, les espèces des captures accessoires comptaient pour une grande partie de la capture (plus de 5%) lorsque le volume de la capture était faible (moins de 100 kg de capture accessoire), ce qui était typique durant la prospection. La capture accessoire était en général très faible par rapport au total de la capture lorsque d'importantes captures des espèces visées étaient effectuées, ce qui indique que les règles sur les captures accessoires de 1996 de la CCAMLR doivent être revues si l'on veut faire de la prospection. Ainsi, pour permettre la prospection de concentrations commerciales de *Champsocephalus gunnari* ou de *Dissostichus eleginoides* tout en protégeant les espèces des captures accessoires d'un effort de pêche excessif, les règles gouvernant les captures accessoires du secteur de l'île Heard pourraient combiner i) une limitation de la capture accessoire annuelle totale aux estimations de rendement annuel à long terme, ii) des captures accessoires d'un maximum de 100 kg par chalut et iii) un changement de lieu de pêche lorsque la capture accessoire d'une espèce est supérieure à 100 kg et que le total de la capture accessoire dépasse 5% de la capture totale d'un chalut.

Резюме

В настоящей работе приводится долгосрочная оценка степени влияния коммерческого тралового лова в районе о-ва Херд (Статистический подрайон 58.5.2) на нерестовую биомассу трех входящих в прилов таксонов – *Channichthys rhinoceratus*, *Lepidonotothen squamifrons* и видов *Bathyraja* (глубоководные скаты). Оценка долгосрочного годового вылова каждого из этих таксонов была получена с помощью обобщенной модели вылова (GY-модели), применяемой Рабочей группой АНТКОМа по оценке рыбных запасов (WG-FSA). В качестве входных данных использовались оценки биомассы, полученные в результате съемок, проводившихся с 1990 по 1993 г., а также ограниченное количество биологических данных, полученных в изучаемом районе. По возможности, значения отсутствующих параметров (для данного вида, но обитающего в других районах) были взяты из литературы – в противном случае были использованы приблизительные данные по подобным видам, встречающимся в других частях мира. Второй компонент анализа включал в себя расчет объема каждого вида, прилавливаемого в ходе коммерческого промысла, а также рассмотрение эффективности положений о 5%-ном прилове, принятых АНТКОМом в 1996 г. с целью обеспечения того, чтобы коммерческий промысел не сказался на состоянии этих видов. Полученные оценки долгосрочного годового вылова *C. rhinoceratus*, *L. squamifrons* и скатов составили 62-87 т, 7-911 т и 50-210 т соответственно. Хотя эти оценки нуждаются в уточнении, они все-таки позволяют предварительно рассмотреть возможность превышения долгосрочного устойчивого годового вылова. Общий прилов *C. rhinoceratus*, *L. squamifrons* и скатов (в основном *B. eatoni*) в ходе коммерческого промысла в 1996/97 г. составил соответственно 5%, 58% и 11% от наименьших оценок вылова этих видов. Эти результаты показывают маловероятность того, что современный

траловый промысел в районе о-ва Херд отрицательно сказывается на этих запасах. Примечательно, что входящие в прилов виды составляли большую долю улова (больше 5%) в случаях, когда было выловлено только небольшое количество рыб (меньше 100 кг прилова), что обычно случалось в ходе разведывательных работ. Прилов обычно составлял очень низкую долю общего вылова тогда, когда были получены крупные уловы объекта лова. Это говорит о том, что принятые АНТКОМом в 1996 г. положения о прилове нуждаются в изменении для того, чтобы включать промысловую разведку. Так, чтобы разрешить разведку агрегаций *Champsocephalus gunnari* и *Dissostichus eleginoides* и в то же время защитить входящие в прилов виды от чрезмерных промысловых усилий, можно было бы установить такие правила о прилове в районе о-ва Херд, которые предусмотрели бы (i) ограничение общего прилова в течение какого-либо года оценками долгосрочного годового вылова, (ii) разрешение улова видов прилова за одну выборку до 100 кг и (iii) переход на другой промысловый участок, если прилов какого-либо вида прилова превышает 100 кг и общий прилов превышает 5% улова за одну выборку.

Resumen

Este estudio es una evaluación de la capacidad de las pesquerías comerciales de arrastre (en el área de la isla Heard, (División estadística 58.5.2) para afectar de manera significativa, y a largo plazo, la biomasa en desove de tres especies de la captura secundaria: *Channichthys rhinoceratus*, *Lepidonotothen squamifrons* y *Bathyraja* sp. (rayas de aguas profundas). El rendimiento anual a largo plazo de las tres especies fue estimado mediante el modelo de rendimiento generalizado (GYM) utilizado por el grupo de trabajo para la evaluación de las poblaciones de peces (WG-FSA) de la CCRVMA. Los datos de entrada incluyen las estimaciones de biomasa de prospecciones realizadas en la región desde 1990 hasta 1993 y unos cuantos datos biológicos de la zona. Cuando fue posible, se obtuvieron los valores de los parámetros de entrada que faltaban de la información sobre las mismas especies en otras áreas, cuando no, se utilizaron datos aproximados de especies similares en otras partes del mundo. La segunda parte del análisis examinó el volumen de la captura de cada especie durante las operaciones comerciales y la efectividad de las medidas impuestas por la CCRVMA en 1996 con respecto a la captura secundaria (la regla del 5%) para asegurar que el estado de estas especies comerciales no se vea afectado por las pesquerías comerciales. Las estimaciones del rendimiento a largo plazo oscilaron entre 62 y 87 toneladas para *C. rhinoceratus*, 7 a 911 toneladas para *L. squamifrons* y 50 a 210 toneladas para las rayas. Si bien es necesario afinar estas estimaciones, ellas permiten una evaluación inicial del riesgo de que los rendimientos anuales sostenibles a largo plazo se vean excedidos por parte de la pesquería. En el caso de *C. rhinoceratus*, *L. squamifrons* y rayas (principalmente *B. eatoni*), la captura secundaria total durante las operaciones comerciales de 1996/97 fue aproximadamente 5%, 58% y 11% de las estimaciones respectivas más bajas del rendimiento. Estos resultados indican que es poco probable que las pesquerías comerciales de arrastre que se desarrollan actualmente alrededor de la isla Heard tengan un efecto negativo en estas poblaciones. Cabe destacar que las especies de la captura secundaria sólo constituyeron una proporción alta de la captura (mayor de 5%) cuando la captura de peces fue escasa (menos de 100 kg de captura secundaria), y normalmente esto ocurrió durante la prospección. Cuando la captura de la especie objetivo fue cuantiosa, la proporción de la captura secundaria fue muy baja con respecto a la captura total, y esto indica que las reglas de la captura secundaria de la CCRVMA dispuestas en 1996 deben ser revisadas con el fin de permitir la exploración. Por lo tanto, a fin de permitir la prospección de agrupaciones comerciales de *Champsocephalus gunnari* o de *Dissostichus eleginoides* y proteger simultáneamente a las especies de la captura secundaria de un esfuerzo pesquero excesivo, las reglas que gobiernan la captura secundaria en el área de la isla Heard podrían resultar de una combinación de: (i) limitar la captura secundaria total en un año a las estimaciones del rendimiento anual a largo plazo, (ii) permitir capturas secundarias de hasta 100 kg en cualquier lance y (iii) cambiar la zona de pesca si la captura de cualquier especie secundaria excede de 100 kg y la captura secundaria total excede del 5% de la captura total en un solo lance.

Keywords: trawl fishery, Division 58.5.2, by-catch, assessment, species, sustainable yield, by-catch regulation, CCAMLR

INTRODUCTION

Species of finfish taken as by-catch in fisheries may include previously targeted species that are now protected due to over-harvesting and/or non-commercial species that coincide in their distribution with currently targeted species. The degree to which these by-catch species are vulnerable to over-fishing depends on (i) the rate they are caught relative to their production and (ii) their distribution and abundance relative to the activities of the fishery.

Two main strategies are usually employed to avoid large by-catches of these species. The first relates to restricting the types of fishing that may be carried out to those that maintain the by-catch at 'tolerable' levels relative to the catch of the target species (e.g. through mesh size restrictions or type of trawl, e.g. pelagic versus benthic trawl). The second is to restrict fishing activities to fishing grounds at which the by-catch species are low in abundance relative to other parts of their distribution. For example, this second strategy is illustrated in the directed trawl fisheries for *Dissostichus eleginoides* and *Champsocephalus gunnari* around Heard Island (Statistical Division 58.5.2) where three main taxa are taken as by-catch – *C. gunnari, Channichthys rhinoceratus, Notothenia rossii, Lepidonotothen squamifrons* and deep-water skates, of which *Bathyraja eatoni* is the dominant species. In 1996, CCAMLR included in Conservation Measures 109/XV and 110/XV provisions aimed at protecting by-catch species in the course of these fisheries, such that

> 'if, .., the by-catch in any one haul of any of the species *Lepidonotothen squamifrons, Notothenia rossii, Channichthys rhinoceratus* or *Bathyraja* spp. exceeds 5% of the total catch by weight, the fishing vessel shall move to another fishing location at least 5 n miles distant. The fishing vessel shall not return to the location where the by–catch exceeded 5% for a period of at least five days.'

Neither of the two approaches indicated above makes a direct appraisal of the potential yield that could be tolerated by the by-catch species. As a result, the situation remains where the relative levels of by-catch may appear to be tolerable but there is still an over-exploitation of the by-catch species.

This paper aims to provide a preliminary assessment of whether the by-catches of *C. rhinoceratus, L. squamifrons* and deep-water skates (*Bathyraja* spp.) in the Heard Island commercial trawl fisheries may potentially affect the spawning biomass of the stocks of these species in the longer term. Two analyses were undertaken. First, estimates of long-term annual yield for each of *C. rhinoceratus, L. squamifrons* and skates were obtained using the methodologies currently in use by the CCAMLR Working Group on Fish Stock Assessment (WG-FSA). The second analysis examines the amount of each by-catch species caught in commercial operations targeted at different species. Both analyses are used to calculate catch levels and formulate general by-catch provisions for the Heard Island trawl fishery that aim (i) to avoid over-exploitation of these species and (ii) to prevent targeting of these species during trawl operations.

ASSESSMENTS OF YIELD

Catches from trawl fisheries around Heard Island contain three main by-catch taxa – *C. rhinoceratus, L. squamifrons* and skates. These species were monitored in three surveys from 1990 to 1993. The available research survey data and abundance estimates are presented in Williams and de la Mare (1995). The estimates of abundance are shown in Table 1.

Skates are usually treated by the fishery as a group of species because of the difficulty in their accurate identification. Such a grouping is retained in this analysis because skates in commercial trawls targeting *C. gunnari* (see below for details about the commercial operation and provision of data) are dominated by *B. eatoni* (>90%), compared to other types of trawling, notably prospecting, where *B. murrayi* and *B. irrasa* comprise a greater proportion of numbers and biomass (Table 2). Skates are not caught in appreciable numbers in trawls targeting *D. eleginoides* (see below).

Where possible, estimates of the biological characteristics of the stocks have been obtained from the research survey data. Proximate estimates were obtained from the literature for parameters that have not currently been estimated from Heard Island stocks.

These assessments follow the general procedure for evaluating precautionary catch limits according to the decision rules on escapement of spawning biomass and the probability of depletion of the spawning stock (see rationale discussed in detail below). The

Table 1: Taxa for which assessments are being undertaken. Estimates of abundance and coefficient of variation (CV) come from Williams and de la Mare (1995).

Species	Abundance Estimate (tonnes)	CV
C. rhinoceratus		
Autumn 1990	2 019	0.256
Summer 1992	2 766	0.308
Spring 1993	2 220	0.248
L. squamifrons		
Autumn 1990	2 846	0.418
Summer 1992	41 378	0.870
Spring 1993	335	0.392
Skates (*Bathyraja* spp.)		
Autum 1990	5 372	0.356
Summer 1992	10 507	0.212
Spring 1993	2 370	0.529

Table 2: Percent composition (by number and biomass) of skates caught in research trawls, commercial trawls during prospecting and commercial trawls targeting icefish in the vicinity of Heard Island.

Voyage	Total Skates		*B. eatoni*		*B. murrayi*		*B. irrasa*	
	N	kg	%N	%kg	%N	%kg	%N	%kg
Research – autumn 1990	172	222	56	76	42	19	1	5
Research – summer 1992	112	572	72	93	23	3	4	4
Research – spring 1993	44	95	68	67	16	3	16	30
Commercial – prospecting (1996/97)	422	886	33	56	40	9	27	35
Commercial – target icefish (1996/97)	154	545	90	96	8	1	1	3

Table 3: Estimates of von Bertalanffy growth parameters for *Channichthys rhinoceratus*, *Lepidonotothen squamifrons* and skates.

Parameter	*C. rhinoceratus*	*L. squamifrons*	Skates
t_0	0	0.1075	0
K	0.163	0.078	0.215
L_∞	583 mm	670 mm	1 050 mm

Table 4: Estimates of weight–length parameters for *Channichthys rhinoceratus* from three surveys at Heard Island between 1990 and 1993.

Parameter	*C. rhinoceratus*	*L. squamifrons*	Skates
a (kg)	5.142 E-10	2.934 E-9	1.468 E-9
b	3.398	3.240	3.214
n	2 561	1 042	246
r^2	0.95	0.97	0.97

generalised yield model (GYM) (Constable and de la Mare, 1996), Version 3.0, was used in these assessments.

Age and Growth Rates

Estimates of growth rates are currently unavailable for Heard Island.

Estimates of age for *C. rhinoceratus* given by Hureau (1966) were based on otoliths from only a few fish, with most fish (29 out of a total 34) being less than 400 mm in length and, by these estimates, less than 8 years old. The maximum age is uncertain because it is currently based on an estimate from one fish. Also, many fish greater than 475 mm were sampled in the summer survey of 1992 (see below). Nonetheless, until a current age/length relationship is obtained, the plus class for this species was assumed to include fish of ages 12 years and above. Values of L_∞ and K in a von Bertalanffy growth model were approximated from the data given in Hureau (1966) (t_0 was fixed at 0) using a least squares non-linear regression with the cited mean sizes at age weighted by the numbers at age. Ages less than 3 and greater than 9 years were excluded from the analysis due to low numbers of fish. L_∞ was estimated to be 583 mm and K estimated to be 0.163.

The values of the growth parameters for *C. rhinoceratus* are shown in Table 3, along with estimates for *L. squamifrons* published by Duhamel and Ozouf-Costaz (1985).

Very little information is available for skates. The best data available that give a size range similar to *B. eatoni*, the common skate in the Heard Island by-catch, are for *Raja clavata* in the North Sea. Estimates of the growth parameters were obtained from Brander and Palmer (1985).

Natural Mortality

Estimates of mortality for *L. squamifrons* were obtained from Sparre (1989), who gave a range of 0.1 to 0.3. For skates, the range of mortalities cited for *R. clavata* were between 0.1 and 0.3 (Ryland and Ajayi, 1984; Brander and Palmer, 1985).

Estimates of natural mortality were unavailable for *C. rhinoceratus*. The Beverton and Holt method (1956) was applied using the available data on mean lengths obtained from the research samples taken from 1990 to 1993 and

$$M = \frac{K(L_\infty - \bar{l})}{(\bar{l} - l')}$$

where l' is the length at which the fish are fully represented in the sample (considered to be 100 mm in the survey samples) and $\bar{l}$ is the mean length of fish greater than l'. $\bar{l}$ was calculated as the mean length of fish sampled in each survey with each length weighted by the respective swept area of the trawls. Values for $\bar{l}$ in the 1990, 1992 and 1993 surveys were 255 mm, 325 mm and 400 mm respectively. The values of M estimated for the 1990, 1992 and 1993 surveys were 0.34, 0.19 and 0.10 respectively. The range of M of 0.10 to 0.34 was used in the current projections.

Weight–length Relationship

The weight–length relationship was determined from available research survey data according to the model:

$$W = aL^b$$

where W is weight of fish (kg), L is the total length (mm) and a and b are the parameters of the equation. The models for the three species were fitted to all survey data using a quasi-Newton method. The estimates of parameters are shown in Table 4.

Characteristics of the Spawning Stocks

The assessment of yield is based on the status of the spawning stock. The data from the research surveys indicate that the spawning season is likely to be between February and April for *C. rhinoceratus* and November for *L. squamifrons*. General information in the literature suggests that skates may be summer spawners.

Data on maturity were available for Heard Island for *C. rhinoceratus* and *L. squamifrons*. The length at 50% maturity was determined using non-linear regression which gave values of 350 mm and 300 to 350 mm for these species

Table 5: Summary of recruitment information from Myers et al. (1993) for *Gadus morhua* and *Pollachius virens*. Stocks at approximately 50°N or higher and in the Atlantic Ocean.

Family	Species	Location	CV
Gadidae			
	Gadus morhua	Cod Celtic Sea	1.050
		Cod Faroe Plateau	0.636
		Cod Iceland	0.378
		Cod northeast Arctic	0.883
	Pollachius virens	Pollock or saithe Iceland	0.505
		Pollock or saithe northeast Arctic	0.462

respectively. The respective ranges over which maturity occurred were 210 to 490 mm and 185 to 475 mm. No data were available for skates. Brander (1981) indicates that *R. clavata* matures at approximately 8 years of age. This was used as the age of first maturity for skates at Heard Island.

Recruitment

The magnitude and variability in recruitment were unknown for these species. Estimates of recruitment variability were obtained from the literature. Table 5 gives a summary of recruitment coefficients of variation (CVs) (assuming no stock-recruitment relationship) from Myers et al. (1993) for the family Gadidae, members of which have similar life history characteristics to *C. rhinoceratus*, although *C. gunnari* have fewer larger yolky eggs. Stocks at approximately 50°N or higher and in the Atlantic Ocean were used as these were on latitudes similar to Heard Island. The range of CVs from Table 5 (0.3–1.0) is adopted for these trials for *C. rhinoceratus*.

Pollocks (*Pollachius virens*) were used as a proxy for *L. squamifrons* and skates, giving a range of CVs from 0.4 to 0.5. This is comparable with the CV of 0.442 for *D. eleginoides* at Heard Island (SC-CAMLR, 1996).

Fishing Season and Fishing Selectivity

The fishing season was assumed to be over the whole year. The size at which fish are selected by the fishery is mostly unknown. For *L. squamifrons*, the size of selection was taken as the smallest recorded in by-catch (170 mm) because few fish have been found in the by-catch in this area. The smallest *B. eatoni* in the commercial catch was greater than 200 mm. Thus, knife-edge selection at 200 mm was assumed for skates in these assessments.

For *C. rhinoceratus*, fishing selectivity was determined by examining the lengths of fish taken by the fishery in 1997. Fish are recruited to the fishery over the size range from 210 to 330 mm. Variation in the size at which 50% are recruited to the fishery was included (270–300 mm).

Assessment of Yield

The long-term annual yield for each species was determined as a proportion of the estimate of pre-exploitation biomass, γ, as used for determining precautionary catch limits for krill (SC-CAMLR, 1994 – paragraphs 5.18 to 5.26). This was necessary because no information was available on the actual magnitude of recruitment. In the case of these three taxa, three biomass estimates were available (see Table 1). These were used as the basis for three model projections for each species. The lowest precautionary catch level for each species provides the best indication of whether by-catch levels in the commercial fisheries around Heard Island may have an affect on these stocks.

The decision rules used to assess the precautionary limits were those used for prey species, i.e. that median escapement of the spawning stock at the end of 20 years of exploitation should be 75% of the pre-exploitation spawning biomass and that the probability of depletion below 0.2 of the median pre-exploitation spawning biomass be no greater than 0.1 over a 20-year period. The lowest γ satisfying these rules was determined for the three projections for each of the three species. The critical level of γ was finally determined by interpolation between two values near to the critical level.

The input parameters for the projections are shown in Table 6 and the results are shown in Table 7.

The 75% escapement rule is the binding rule for all three species in these assessments. Notably, the greatest variation occurred for *L. squamifrons*. The ranges of precautionary catch limits for each species are*:

C. rhinoceratus	62–87 tonnes
L. squamifrons	7–911 tonnes
Bathyraja spp. (skates)	50–210 tonnes

PROVISIONS FOR PROTECTING BY-CATCH SPECIES

Fishing operations in Division 58.5.2 in the 1996/97 season were of three types: prospecting for fishing grounds of *D. eleginoides*, targeting aggregations of *D. eleginoides*, and targeting aggregations of *C. gunnari*. Table 8 provides details of the catches of each of the main species caught on each of these voyages, including target species and the by-catch species discussed here. Clearly, the highest by-catch of the four species was taken when vessels were prospecting, as would be expected when fishing is conducted in a wide range of habitats. *C. rhinoceratus* and skates were a significant by-catch in the *C. gunnari* fishery, especially on Gunnari Ridge. Trawls targeting *D. eleginoides* concentrations had negligible by-catch. Note that the total by-catches for *C. rhinoceratus*, *L. squamifrons* and skates were 2.9, 4.0 and 5.5 tonnes respectively.

Table 8 also indicates the number of hauls in which each by-catch species comprised more than 5% of the catch, causing a triggering of the 5% rule in Conservation Measures 109/XV and 110/XV. Most instances occurred during prospecting, frequently causing the vessels to move a distance of five miles from the previous fishing site and at times making operations very difficult. In the *C. gunnari* fishery, *C. rhinoceratus* and skates triggered a number of instances, especially on Gunnari Ridge, until a midwater net was employed. There is only one occurrence of trawls targeted at *D. eleginoides* in which the 5% limit was exceeded.

The instances were subdivided into a number of classes to illustrate the type of voyage in which the rule is triggered, the triggering species and the amount of catch of a species involved. Also, the combined catch of all by-catch species was assessed for the number of times this would result in exceeding the 5% by-catch. Notably, a large majority of instances were caused by very small amounts of by-catch (Table 9). This occurs, especially in prospecting mode, when the catch of target species is low, and hence the amount of by-catch necessary to trigger the 5% rule is also very low. Most instances were caused by less than 100 kg of by-catch.

DISCUSSION

The estimates of long-term annual yields for *C. rhinoceratus*, *L. squamifrons* and skates were 62–87 tonnes, 7–911 tonnes and 50–210 tonnes respectively. Clearly, these estimates need to be refined by obtaining more data on the demography of these species from the local area. In addition, the paucity of data on skates generally suggests that these important by-catch species in both trawl and longline fisheries need to be given attention to determine more precisely their long-term annual yields. Despite this need for refinement, these results provide a useful preliminary examination of the potential for the fishery to exceed long-term sustainable annual yields. The by-catch of any of the species under consideration in 1997 did not exceed the lowest estimate of its yield. For *C. rhinoceratus*, *L. squamifrons* and skates (principally *B. eatoni*), total by-catch during the commercial activities in 1996/97 was approximately 5%, 58% and 11% of the respective lowest estimates of yield. While *L. squamifrons* had the highest proportion of yield taken, this species was the one for which the most information was available to make an assessment of yield. These results indicate that the current commercial trawl fisheries around Heard Island are unlikely to be negatively affecting these stocks. However, the estimates of yield should be used only as a guide to managing these species as a by-catch rather than as a means for establishing target fisheries for these species.

The by-catch provisions adopted by CCAMLR in 1996 were mostly invoked during prospecting for suitable commercial trawling grounds. However, these provisions may not be required to

* Note that the estimates of precautionary yield for *C. rhinoceratus* have been re-estimated since the original draft of this paper was submitted to WG-FSA (WG-FSA-97/30).

Table 6: Input parameters for projections of the GYM for three by-catch species at Heard Island*.

Category	Parameter	*C. rhinoceratus*	*L. squamifrons*	Skates
Age composition	Minimum age in stock	1	1	1
	Maximum age (plus class)	12	25	20
	Years in plus class	9	11	11
Times within year	Number of increments	360	360	360
Natural mortality	Mean annual M	0.10–0.34	0.1–0.3	0.1–0.3
Fishing mortality	Length when 50% of that size are recruited to fishery	270–300 mm	170 mm	200 mm
	Length range over which recruitment occurs	60 mm	0 mm	0 mm
	Reasonable upper bound for annual fishing mortality	5.0	5.0	5.0
	Tolerance (error) for determining fishing mortality in each year	1E–05	1E–05	1E–05
Fishing season		All year	All year	All year
von Bertalanffy growth	Time 0	0	0.1075	0
	L_∞	583 mm	670 mm	1 050 mm
	K	0.163	0.078	0.215
Weight–length ($W = aL^b$)	a	5.142E-10	2.934E-9	1.468E-9
	b	3.398	3.240	3.214
Spawning biomass	Length when 50% of that size are mature	350 mm	300–350 mm	
	Length range over which maturity occurs	280 mm	330 mm	
	Age of first maturity			8 years
	Increment in year when spawning occurs	1 March	1 November	1 March
	Number of increments in spawning season	1	1	1
Recruitment	Coefficient of variation	0.3–1.0	0.4–0.5	0.4–0.5
	Proportion of median SB_0 when depletion begins to occur	0.0	0.0	0.0
Total biomass	Date of biomass survey			
	Projection 1	1 May	1 May	1 May
	Projection 2	1 March	1 March	1 March
	Projection 3	1 November	1 November	1 November
	Coefficient of variation			
	Projection 1	0.256	0.418	0.356
	Projection 2	0.308	0.870	0.212
	Projection 3	0.248	0.392	0.529
	Coverage of survey	1	1	1
Simulation characteristics	Number of runs to test each catch level	1 001	1 001	1 001
	Replicates in formulating median SB_0 in each run	1 001	1 001	1 001
	Years to project stock before start of projections	1	1	1
	Vector of real catches for projecting over known catch period	0	0	0
	Number of years to project stock following known catch period	20	20	20
Decision rules	Proportion of median SB_0 considered to be level of depletion	0.2	0.2	0.2

* Note that the growth parameters and natural mortality for *C. rhinoceratus* have been re-estimated since the original draft of this paper was submitted to WG-FSA (WG-FSA-97/30).

Table 7: Results of assessments of critical-γ and the associated precautionary yields for each of three by-catch species at Heard Island using the GYM.

Species	Projection		γ 0.0	0.02	0.03	0.04	Critical γ	Yield (tonnes)
C. rhinoceratus	1	Escapement	1.012	0.840	0.757	0.670	0.031	62
		p (depletion)	0.000	0.000	0.000	0.009		
	2	Escapement	1.012	0.845	0.761	0.675	0.031	87
		p (depletion)	0.000	0.000	0.001	0.015		
	3	Escapement	1.012	0.837	0.751	0.665	0.030	67
		p (depletion)						
L. squamifrons	1	Escapement	0.998	0.756	0.641		0.021	60
		p (depletion)	0.000	0.002	0.027			
	2	Escapement	0.998	0.793	0.704		0.022	911
		p (depletion)	0.000	0.032	0.094			
	3	Escapement	0.998	0.754	0.636		0.020	7
		p (depletion)	0.000	0.002	0.025			
Skates	1	Escapement	0.993	0.748	0.628		0.020	107
		p (depletion)	0.000	0.000	0.019			
	2	Escapement	0.993	0.744	0.615		0.020	210
		p (depletion)	0.000	0.000	0.000			
	3	Escapement	0.996	0.756	0/643		0.021	50
		p (depletion)	0.000	0.008	0.054			

Table 8: Details for four voyages to Heard Island in 1997 with a total of seven commercial phases showing the type of voyage, the number of hauls, the catch of the target species, *Dissostichus eleginoides* or *Champsocephalus gunnari*, and the catch (kg) of four by-catch species. For each by-catch species, the number of hauls in which that species constituted more than 5% of the catch is given.

Phase	Type	No. of Hauls	*D. eleginoides* Catch (kg)	*C. gunnari* Catch (kg)	*C. rhinoceratus* Catch (kg)	Hauls with > 5%	*L. squamifrons* Catch (kg)	Hauls with > 5%	*N. rossii* Catch (kg)	Hauls with > 5%	Skates Catch (kg)	Hauls with > 5%
1	Prospecting	47	1 194	240	17	1	133	4	0	0	885	30
2	Prospecting	184	56 124	2 209	771	58	3 671	40	31	2	935	69
3	Prospecting	12	1 309	18	142	5	147	5	15	0	926	7
4	Target *D. eleginoides*	32	290 200	0	0	0	0	0	2	0	1 063	0
5	Target *D. eleginoides*	176	1 036 132	0	24	1	1	0	0	0	1 131	1
6	Target *C. gunnari*	25	808	126 720	1 375	7	78	1	2	0	546	4
7	Target *C. gunnari*	4	135	88 616	530	1	0	0	7	0	49	0
	Total	480	1 385 904	217 804	2 860		4 029		58		5 535	

Table 9: A subdivision of the instances triggering the 5% by-catch rule for each by-catch species in each type of commercial fishing activity. For each species, the number of catches in which it was greater than 5% of the catch is shown according to the amount of by-catch (kg) actually caught.

Activity	Trigger Species	Number of Instances Triggered by Catches of:					
		<5 kg	5–10 kg	10–20 kg	20–50 kg	50–100 kg	>100 kg
Prospecting	*C. rhinoceratus*	24	14	13	11	1	0
	L. squamifrons	25	7	5	2	5	5
	N. rossii	0	1	1	0	0	0
	Skates	23	28	30	17	4	3
	All above species	41	35	46	27	7	12
Target *D. eleginoides*	*C. rhinoceratus*	0	0	0	1	0	0
	L. squamifrons	0	0	0	0	0	0
	N. rossii	0	0	0	0	0	0
	Skates	0	0	0	0	0	1
	All above species	0	0	0	0	0	1
Target *C. gunnari*	*C. rhinoceratus*	1	0	1	1	1	4
	L. squamifrons	1	0	0	0	0	0
	N. rossii	0	0	0	0	0	0
	Skates	0	0	0	0	2	2
	All above species	2	0	1	0	0	8

keep the catches below long-term sustainable levels. The catch of *L. squamifrons* fell dramatically once commercial fishing grounds were found. Thus, the amount of this species caught during a season in which *C. gunnari* or *D. eleginoides* are targeted is likely to remain lower than the lowest estimate of yield (7 tonnes). For the other species, the by-catch is potentially larger on commercial fishing grounds, although given the catch levels for the target species, these catches are also not likely to exceed the long-term annual yield.

The basic role of the by-catch provisions is to protect the by-catch species from over-exploitation and from being targeted by commercial operations. To limit commercial operations to areas where the by-catch is no greater than 5% of the total catch, however, would exclude many areas from prospecting. In order to enable prospecting for commercial aggregations of *C. gunnari* or *D. eleginoides* while protecting the by-catch species from excessive fishing effort, the rules governing by-catch for the Heard Island area could be a combination of (i) limiting the total by-catch in a year to the estimates of long-term annual yield, (ii) allowing catches of by-catch species of up to 100 kg in any one haul and (iii) changing fishing grounds if any one of the by-catch species exceeds 100 kg and the total by-catch is greater than 5% of the total catch in a single haul.

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