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PRECAUTIONARY MEASURES FOR A NEW FISHERY ON *MARTIALIA HYADESI* (CEPHALOPODA, OMMASTREPHIDAE) IN THE SCOTIA SEA: AN ECOLOGICAL APPROACH

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Abstract

In anticipation of the development of a new fishery for the ommastrephid squid *Martialia hyadesi* in the Scotia Sea, this paper presents a revision of annual consumption of the species by higher predators and provides a brief review of information about the life cycle and distribution of the species obtained from research fishing and commercial catches. This species is eaten by seals, whales and seabirds, the latter being the most reliable source of consumption data because comprehensive sampling can be carried out during their breeding seasons. A conservative estimate for total annual consumption of *M. hyadesi* by higher predators in the Scotia Sea is 245 000 tonnes, with an upper estimate of 550 000 tonnes if less reliable data are included. *M. hyadesi* spawns between autumn and mid-summer with peak hatching in winter/spring. Its life span has not been established. Data from the CCAMLR Convention Area suggest that *M. hyadesi* may live for two years, but this may vary. In common with other ommastrephids, the species is probably semelparous. It is proposed that the timing and catches of the fishery should be highly conservative and set taking into account the timing of breeding and consumption rates of the most sensitive of the dependent species. Most Antarctic predators which have been studied consume relatively small and immature specimens of *M. hyadesi*. Fishing for *M. hyadesi* after the chick-rearing period of the most sensitive predator (grey-headed albatross) would minimise competition locally and ensure that the fishery only exploited the stock after escapement from most higher predator species. It would also allow seabird predation of the stock to be monitored prior to the fishing season as a way of assessing numbers of pre-recruits. Closing the fishery before recruitment of the next generation of squid would ensure availability of prey to higher predators during the following chick-rearing period. Preliminary data from a squid jigger which undertook research fishing around South Georgia in June 1996 provided the basis for determining realistic potential catch rates.

Résumé

Dans l'attente du développement d'une nouvelle pêcherie de l'Ommastrephidé *Martialia hyadesi* en mer du Scotia, l'auteur présente une révision de la consommation annuelle de cette espèce par les grands prédateurs et examine brièvement les informations provenant de campagnes de recherche et de captures commerciales sur le cycle biologique et la répartition de l'espèce. Cette espèce est la proie des phoques, des baleines et des oiseaux de mer, ces derniers produisant les données de consommation les plus fiables car il est possible d'effectuer un échantillonnage détaillé durant leurs périodes de reproduction. L'estimation modeste de la consommation annuelle totale de *M. hyadesi* en mer du Scotia par les grands prédateurs s'élève à 245 000 tonnes. Si l'on inclut des données moins fiables, l'estimation passe alors à 550 000 tonnes. Chez *M. hyadesi* le frai se produit entre l'automne et le milieu de l'été et l'éclosion atteint son maximum en hiver ou au printemps. Sa durée de vie n'est pas établie. Les données provenant de la zone de la Convention de la CCAMLR laissent entendre que *M. hyadesi* a une durée de vie de deux ans, mais cela peut varier. Comme les autres Ommastrephidés, l'espèce est probablement semelpare. Il est proposé de limiter l'ouverture de la pêche ainsi que les captures en tenant compte de la période de reproduction et des taux de consommation de l'espèce dépendante la plus sensible. La plupart des prédateurs de *M. hyadesi* ayant été étudiés se nourrissent de spécimens relativement petits et immatures. Pêcher *M. hyadesi* après la période d'élevage des jeunes du prédateur le plus sensible (l'albatros à tête grise) réduirait la concurrence sur le plan local et garantirait que le stock ne serait exploité que lorsqu'il aurait échappé à la plupart des espèces de grands prédateurs. Cela permettrait également de contrôler la prédation des oiseaux de mer sur le stock avant la saison de pêche de manière à évaluer le nombre de pré-recrues. Fermer la pêche avant le recrutement de la génération de calmar suivante laisserait aux grands prédateurs suffisamment de proies pour la période suivante d'élevage des jeunes. Les premières données d'un navire de pêche à la turlutte, menant une campagne de recherche autour de la Géorgie du Sud en juin 1996, servent de base à l'évaluation réaliste des taux de capture possibles.

Резюме

В преддверии дальнейшего развития промысла кальмара *Martialia hyadesi* в море Скотия в данной работе приводятся результаты исследования ежегодного потребления этого вида хищниками верхних звеньев трофической цепи, а также информация о его жизненном цикле и распределении, основанная на данных коммерческого и научно-исследовательского промысла. Данный вид является объектом питания тюленей, китов и морских птиц. В связи с возможностью брать пробы на протяжении всего периода размножения птиц, последние считаются самым надежным источником данных. По самым скромным оценкам общий объем потребления вида *M. hyadesi* в море Скотия составляет 245 000 т. Более реалистичная оценка этого параметра составляет 550 000 т. Нерестовый сезон данного вида приходится на период с начала весны до середины лета, а пик вылупления происходит зимой/весной. Хотя еще не определена продолжительность жизни *M. hyadesi*, данные из зоны действия Конвенции свидетельствуют о том, что в среднем она составляет два года. Вероятно, что, как и в случае других видов кальмаров, самки данного вида умирают после нереста. Приняв во внимание сроки сезона размножения и уровни потребления самых чувствительных зависимых видов, предлагаем ограничить сроки ведения промысла, а также общий допустимый вылов. Большинство изучавшихся видов-хищников питаются относительно небольшими и незрелыми экземплярами *M. hyadesi*. Ведение промысла *M. hyadesi* после периода выращивания птенцов наиболее чувствительного хищника (сероголового альбатроса) свело бы к минимуму конкуренцию в локальном масштабе и обеспечило бы эксплуатацию запаса только тогда, когда большинство видов-хищников верхних звеньев трофической цепи уже кормились бы за счет необлавливаемого резерва. Это также позволило бы проводить мониторинг потребления запаса морскими хищниками до начала промыслового сезона для оценки численности еще не поступивших в промысловый запас особей. Закрытие промысла до поступления следующего поколения кальмаров в промысловый запас обеспечило бы наличие пищи у хищников в последующий период выращивания птенцов. Предварительные данные одного судна, проводившего научно-исследовательский промысел в районе Южной Георгии, послужили основой для определения более реалистичных уровней потенциальной интенсивности лова.

Resumen

En vísperas del desarrollo de una nueva pesquería del calamar omastréfido *Martialia hyadesi* en el Mar de Escocia, este documento presenta un estudio del consumo anual de esta especie por depredadores mayores y una reseña sobre el ciclo de vida y distribución de la especie deducidos de la pesca de investigación y de las capturas comerciales. La especie es presa de focas, ballenas y aves marinas; éstas últimas constituyen la fuente de datos más fidedignos ya que se puede hacer un muestreo completo durante sus épocas de reproducción. Un calculo moderado del consumo anual total de *M. hyadesi* por los depredadores mayores en el Mar de Escocia es de 245 000 toneladas, con una estimación superior de 550 000 toneladas si se incluyen datos menos fidedignos. *M. hyadesi* desova entre el otoño y mediados del verano con el máximo de eclosiones en invierno/primavera. No se ha determinado su ciclo de vida. Los datos del Area de la Convención de la CCRVMA sugieren que *M. hyadesi* puede vivir hasta dos años, pero esto puede variar. La especie probablemente comparte una característica común con otros omastréfidos: la muerte después del desove. Se propone que tanto la época de explotación como las capturas mismas se establezcan con cautela tomando en cuenta la época de reproducción y la tasa de consumo de la especie más dependiente. La mayoría de los depredadores antárticos estudiados se alimentan de ejemplares pequeños e inmaduros de *M. hyadesi*. Si la pesca de *M. hyadesi* se aplaza hasta después del período de cría del depredador más susceptible (albatros de cabeza gris) se reduciría al mínimo la competencia a nivel local y se aseguraría que la pesca se dirija sólo al stock que ha escapado de la mayor especie dependiente. También permitiría estudiar la depredación de las aves marinas en el stock antes de la temporada de pesca, como una manera de evaluar el número de prereclutas. El cierre de la pesca antes del reclutamiento de la próxima generación de calamares aseguraría la disponibilidad de la presa para los depredadores mayores en la próxima época de cría de polluelos. Los datos preliminares, obtenidos de un barco potero que efectuó estudios alrededor de Georgia del Sur en junio de 1996, proporcionaron la base para determinar realísticamente las posibles tasas de captura.

Keywords: fishery, precautionary measures, predator consumption, Scotia Sea, squid, CCAMLR

INTRODUCTION

As annual catches of *Illex argentinus* in the southwest Atlantic have diminished and world demand for ommastrephid squid has increased in recent years (Josupeit, 1995), operators of distant-water fleets in the region have become interested in exploiting new resources. The oceanic/slope ommastrephid squid *Martialia hyadesi* has been an occasional, and generally small, catch in the *I. argentinus* fishery since its inception, with a larger catch taken near the Falkland/Malvinas Islands in 1986 and 1995. This has increased commercial interest in this species, which is widely distributed in the sub-Antarctic Scotia Sea and is the most likely candidate among the Antarctic squid for commercial exploitation in the near future (Rodhouse, 1990).

Data from higher predators breeding at South Georgia show that *M. hyadesi* is, at least seasonally, an important component of the diet of several species and a minor component of many more. Data from predators provide the only insight into the size of the stock (Rodhouse et al., 1993), although fishery and research activities over the last decade have provided some information on the biology of the species (Rodhouse, 1991; Rodhouse et al., 1992c, 1994, 1996; Rodhouse and White, 1995). This paper updates estimates of predator consumption of *M. hyadesi* in the Scotia Sea and presents a conservative scheme for: (i) commercial harvesting at a rate proportional to the predator take; and (ii) timing the fishing season to avoid direct competition with what is perceived to be the most sensitive predator species.

FISHERY AND RESEARCH DATA

Data on *M. hyadesi* from fishing and research vessels in the Scotia Sea and on the Patagonian Shelf edge are summarised in Table 1. A large

Table 1: Summary fishery and research data on *M. hyadesi* from the Scotia Sea and the Patagonian Shelf edge.

Fishing Activity	Annual Catch (tonnes x 10^3)	ML mm: Mode	ML mm: Range	Maturity Status (M)	Maturity Status (F)	Sampling Month	Sample Size
Japanese jigger fishery Patagonian Shelf edge 1986	26	270	230–330	II–IV	II–III	March	288
Japanese jigger trials APFZ 1989	0.008	240	170–290	II–III	II	February	108
BAS research cruise APFZ 1994 (JR06)	<0.001	210	161–248 (506 n = 1)	II	II (III n = 1)	February	12
FICZ 1995	5.8	295	240–390	IV–V	II–III	May	336
BAS research cruise 1996 APFZ (JR11)	<0.001	220	170–290	II–III	II	February	208
Korean jigger trials South Georgia 1996 (CCAMLR scientific fishery)	0.053	298	212–370	IV–V	II–III	June	862

catch of *M. hyadesi* was taken near the Patagonian Shelf edge in 1986, prior to the establishment of the Falklands Interim Conservation and Management Zone (FICZ), and a total of some 26 000 tonnes was landed in Japan in that year (Rodhouse, 1991).

In February 1989 two Japanese squid jiggers carried out an exploratory survey in the vicinity of South Georgia, Shag Rocks and at the Antarctic Polar Frontal Zone (APFZ) west of South Georgia, and caught about 8 tonnes, all at the APFZ (Rodhouse, 1991).

In February 1994 a research cruise by the British Antarctic Survey (BAS) tracked satellite-tagged predators (grey-headed albatrosses feeding chicks at Bird Island, South Georgia) to the APFZ north of South Georgia. *M. hyadesi* were sampled with a pelagic trawl and the distribution of the squid related to a mesoscale oceanographic feature (a putative warm-core ring) at the APFZ (Rodhouse et al., 1996).

M. hyadesi is regularly caught in the FICZ but usually in very much smaller quantities than the dominant species, *I. argentinus*. In 1995 unusually large numbers of *M. hyadesi* were caught by the *I. argentinus* jigging fleet in the FICZ (González et al., 1997). A total of some 5 800 tonnes was reported compared with about 60 000 tonnes of *I. argentinus*.

In February 1996 another BAS research cruise at South Georgia tracked satellite-tagged grey-headed albatrosses to the APFZ and sampled the *M. hyadesi* population during an interdisciplinary cruise to study in detail the relationship between the squid community and mesoscale oceanography of the APFZ (Rodhouse, unpublished data).

In June 1996 a Korean-registered squid jigger (*Ihn Sung 101*) carried out research fishing in the vicinity of South Georgia with a catch limit set by CCAMLR. A total of approximately 50 tonnes of *M. hyadesi* was caught north of the South Georgia shelf (González and Rodhouse, 1996).

Fishery and research samples reveal some simple trends of size and maturity stage. All measurements were made on samples taken from the catch by scientists/observers prior to commercial grading. Modal mantle length (ML) of squid caught on the Patagonian Shelf edge and FICZ was in the range 230 to 390 mm and squid were larger and more mature in May than in March (Table 1). At the APFZ, where all samples have been collected in February, ML was in the range 161 to 290 mm, with the exception of a single large specimen of 506 mm taken by the 1994 BAS research cruise. The modal ML of the South Georgia specimens collected in June 1996 was 290 mm, about 80 mm longer than those from the APFZ, and collected four months earlier in waters to the north (Table 1). Males were generally at a more advanced maturity stage than females in both samples and they were more mature in samples taken later in the year; ranging from stage II (Lipinski, 1979) at the APFZ in February to stage V (fully mature) at South Georgia in June. Females were never more mature than stage II, except the single large specimen caught by BAS in 1994 which was at stage III.

A study of molecular genetic markers (allozymes) in samples from the APFZ and the Patagonian Shelf edge (Brierley et al., 1993) has indicated that *M. hyadesi* in the south Atlantic possibly subsumes a cryptic species and that there are probably reproductively isolated stocks in the region that overlap outside their spawning areas.

There are few catch-per-unit-effort data for *M. hyadesi* in the Scotia Sea other than those obtained during the *Ihn Sung 101* research fishery in June 1996 (González and Rodhouse, 1996). However, this trial indicated the potential commercial viability of a *M. hyadesi* fishery. The mean daily catch rate of the *Ihn Sung 101* in June 1996 was 7.5 ± 6.1 tonnes (Table 2) but if the catch rate on the first day of fishing is ignored, on the assumption that the vessel had not found the main concentration of squid, the mean catch rate was 8.6 ± 5.8 tonnes per day.

LIFE CYCLE AND DISTRIBUTION OF *MARTIALIA HYADESI*

Back-calculated hatching dates of a small sub-sample of adult squid that were aged from samples taken on the Patagonian Shelf edge and at the APFZ suggest that spawning takes place between autumn and mid-summer with most squid hatching in winter/spring (Rodhouse et al., 1994). The spawning area is unknown but a few small juveniles have been sampled on the shelf near the Falkland/Malvinas Islands (Rodhouse et al., 1992b), suggesting that at least some spawning occurs near the southern edge of the Patagonian Shelf.

Table 2: Daily catch rate of the Korean-registered squid jigger *Ihn Sung 101* fishing for *M. hyadesi* at South Georgia in June 1996.

Date of Drift	Number of Lines with 25 Jigs Each	Hours Fishing	Gross Catch (tonnes)	Catch Rate (tonnes per hour)
17/18 June	96	11.0	0.5	0.05
18/19 June	96	17.5	9.8	0.56
19/20 June	96	14.0	1.2	0.09
20/21 June	96	14.0	5.4	0.39
21/22 June	96	16.5	9.8	0.59
22/23 June	96	17.0	7.0	0.41
23/24 June	96	14.0	18.5	1.32
Total	–	104.0	52.2	–
Mean ±SD	96	14.8 ± 2.3	7.5 ± 6.1	0.49 ± 0.42

Specimens from samples in Table 1 which were aged by counting daily growth increments in statoliths were up to one year old (Rodhouse, 1991; Rodhouse et al., 1994). Given the early maturity stage of these squid there is some basis for concluding that they have a life cycle of more than one year. Given the highly seasonal environment of the south Atlantic it is unlikely that life cycle falls between one and two years as this infers that the spawning season would alternate between generations.

A small sample of squid (six males and six females) from the 1996 winter research fishery at South Georgia were aged (González and Rodhouse, unpublished data). Mean age was 325 days (range 310–360) and hatch dates were back-calculated to have been in July/August. Although the males were mature (IV–V), all the females were stage II. It seems likely that these female squid would not have matured during the winter in which they were caught and that they would probably not have been ready to spawn until up to a year later.

The implication of the above is that *M. hyadesi* has a two-year life cycle. However, Arkhipkin and Silvanovich (in press) have found a small number of large mature females of only one year old in the South Atlantic. *M. hyadesi*, in common with other ommastrephids, probably has a very plastic life cycle with variability in growth and maturation rate over its range. However, because recent information (González and Rodhouse, unpublished data) for *M. hyadesi* in the CCAMLR Convention Area suggests a two-year life cycle for the purpose of drawing up precautionary measures for the CCAMLR Convention Area, the tentative assumption of a two-year life cycle, including the egg stage, is made here.

It is a safe assumption that *M. hyadesi*, in common with all the better-known ommastrephid squid, is semelparous. There are no data on the second year of the life cycle and little or no predation on the species during its second year has been recorded or inferred.

Distribution in the Scotia Sea and elsewhere is linked to the APFZ (O'Sullivan et al., 1983; Rodhouse and Yeatman, 1990; Piatowski et al., 1991). This circumpolar feature is a narrow band of ocean between the Polar Front and the sub-Antarctic Front which expands northwards in a loop in the Southwest Atlantic where the Falkland/Malvinas Current diverges from the Antarctic Circumpolar Current (ACC) (Figure 1). Most records of *M. hyadesi* are from within, or close to the APFZ. By analogy with populations of other ommastrephid squid we can speculate that: (i) spawning occurs somewhere in the northwest part of the Scotia Sea; (ii) eggs and paralarvae are carried eastwards by the prevailing ACC system; (iii) there are feeding grounds where high concentrations of prey are located; and (iv) there is a counter-current spawning migration. However, most information on ommastrephid life cycles comes from shelf species and even these broad assumptions need to be tested carefully for *M. hyadesi*. Predation and fishing activity are probably located in the feeding areas but knowledge is very limited.

MARTIALIA HYADESI DATA COLLECTED FROM PREDATORS

Seabirds

Annual consumption of *M. hyadesi* in the Scotia Sea by eight species of seabird is given in Table 3 together with information about the chick-rearing

Table 3: Estimated consumption of *M. hyadesi* by seabird predators in the Scotia Sea (see text for literature sources).

Predator Species	Annual Consumption (tonnes x 10^3)	Chick-rearing Season	ML mm: Mode	ML mm: Range	Sampling Months	% Total Squid (*M. hyadesi*)	% Total Diet (*M. hyadesi*)
Diomedea chrysostoma (grey-headed albatross)	14.2–18.7	Dec–May	198	172–279	Jan–Jun	67–77	25–54
D. melanophrys (black-browed albatross)	3.5	Jan–May	217	190–276	Feb	73–77	17–24
D. exulans (wandering albatross)	0.04–0.06	Mar–Dec	257	205–361	May–Nov	2	0.8
Phoebetria palpebrata (light-mantled sooty albatross)	0.02	Jan–May	220	no data	Jan–May	1	0.5
Procellaria aequinoctialis (white-chinned petrel)	74.6	Jan–Mar	179	120–245	Jan–Mar	52	10
Macronectes giganteus (southern giant petrel)	0.3	Jan–May	192	no data	Jan–May	15	0.3
M. halli (northern giant petrel)	0.006	Nov–Mar	184	no data	Nov–Mar	1	0.01
Eudyptes chrysolophus (macaroni penguin)	4.0	Dec–Mar	198	160–264	Feb	96	0.1

period, size of squid consumed, the months when samples have been collected and the importance of *M. hyadesi* in the diet of each species. Consumption estimates for albatrosses and giant petrels are from Rodhouse et al. (1993) and for white-chinned petrels from Croxall et al. (1995). The period of chick rearing for each species is taken from Croxall (1984) and details of *M. hyadesi* in the diet of flying seabirds are taken from Thomas (1982), Hunter (1983), Rodhouse et al. (1987), Rodhouse et al. (1990), Rodhouse and Prince (1993) and Croxall et al. (1995). Thomas (1982) and Hunter (1983) identified ommastrephids in the diet of light-mantled sooty albatrosses and giant petrels as *Todarodes* spp. but these are now known to be *M. hyadesi*. The estimate for macaroni penguins was obtained from the estimate of total consumption by the species in the Scotia Sea (Croxall et al., 1985). Of this an estimated 0.1% of biomass consumed is *M. hyadesi* (K. Reid, unpublished data).

Estimates of consumption of cephalopods by seabirds are the most reliable of all the predator data because they are collected from regurgitations of adults returning to feed the chicks (most species) or from chicks on the nest immediately after being fed (light-mantled sooty albatross and giant petrels). The proportion of squid in the overall diet can also be determined accurately by analysis of these regurgitations; these estimates do not take account of potential biases due to differential digestion of fish, squid and crustaceans, nor of disproportionate accumulation of identifiable squid hard parts.

Seals

Studies of seals and whales have relied on stomach contents of dead specimens, scats from seals and stomach lavaging of seals that may not have fed for some considerable time. The potential biases in these data are evident and likely to be substantially greater than those applying to the data from seabirds.

Annual consumption of *M. hyadesi* by two species of seal is given in Table 4, together with information about the period when all seals are foraging at sea, size of squid consumed, months when samples have been collected and importance of *M. hyadesi* in the diet of each species.

The estimate of 308 000 tonnes consumed by southern elephant seals (Rodhouse et al., 1993) was based on the suggestion that, when feeding in pelagic habitats, 75% of biomass consumed is squid (Laws, 1977). The limited evidence available supports the view that southern elephant seals feed primarily on squid when at sea (Rodhouse et al., 1992a). However, because of the uncertainties, including differential digestion rates of fish and squid, attached to estimating the proportion of squid in the diet, an alternative, more conservative, estimate of 25% is also used in Table 4 to estimate *M. hyadesi* consumption by southern elephant seals.

In a two-year study (1992–1993) of the diet of male Antarctic fur seals during winter, only 1.3 % of scats contained cephalopod remains, none of which was *M. hyadesi* (Reid, 1995). In four years of study (1991–1994) of scats collected from breeding female Antarctic fur seals, cephalopods occurred in 5%; again no *M. hyadesi* was found (Reid and Arnould, 1996). However, *M. hyadesi* did occur in one of 55 scats collected in June 1983 (North, 1996). Notwithstanding the lack of data on the diet of females outside the breeding season, it would appear that *M. hyadesi* is a rare component of the diet of Antarctic fur seals. It is perhaps most likely to be encountered when feeding on myctophids, which form a small but important component of the diet of females during the latter part of the lactation period (Reid and Arnould, 1996). It would, however, seem unrealistic to assume that *M. hyadesi* forms more than 0.1 % of the diet of Antarctic fur seals. However, given the biomass of Antarctic fur seals in the Scotia Sea, this apparently trivial consumption by individuals may amount to a substantial quantity at the population level.

Whales

Estimates of annual consumption of *M. hyadesi* by three species of whale are given in Table 5 together with information, where available, about the size of squid consumed, months when samples have been collected and estimated importance of *M. hyadesi* in the diet.

The estimate for sperm whale consumption is taken from Rodhouse et al. (1993) but this is tentative for reasons discussed therein. The data for southern bottlenose whales are taken from the population estimate and combined with the estimate of squid consumption, given by Kasamatsu and Joyce (1995). They give a total estimate for the Antarctic and break down the encounter rate in their surveys by 20° intervals of longitude. The estimate for consumption in the Scotia Sea was made here by taking the

Table 4: Estimated consumption of *M. hyadesi* by seal predators in the Scotia Sea (see text for literature sources).

Predator Species	Annual Consumption (tonnes x 10^3)	Months Spent Foraging at Sea	ML mm: Mode	ML mm: Range	Sampling Months	% Total Squid (*M. hyadesi*)	% Total Diet (*M. hyadesi*)
Mirounga leonina (southern elephant seal) 75% diet squid	308.0	Jun–Aug	271	193–426	Nov–Feb	17.5	13
M. leonina (southern elephant seal) 25% diet squid	77.0	Jun–Aug	271	19–426	Nov–Feb	17.5	4.4
Arctocephalus gazella (Antarctic fur seal)	<15.7	all year	175	158–183	all year	15–20	0–1

Table 5: Estimated consumption of *M. hyadesi* by whale predators in the Scotia Sea (see text for literature sources).

Predator Species	Annual Consumption (tonnes x 10^3)	ML mm: Mode	ML mm: Range	Sampling Months	% Total Squid (*M. hyadesi*)	% Total Diet (*M. hyadesi*)
Physeter catodon (sperm whale)	<3.3?	no data	no data	Oct–Mar	<2	<2
Hyperoodon planifrons (southern bottlenose whale)	73.7	226	176–258	Nov	0–2.7	2.7
Globicephala melaena (long-finned pilot whale)	<48.0	no data	no data	no data	no data	no data

proportion of the total encounters made between 20 and 70°W. The proportion of squid attributable to *M. hyadesi* is taken from Slip et al. (1995) who found that *M. hyadesi* comprised 2.7% of the squid mass represented by beaks in the stomach of a single stranded southern bottlenose whale at Heard Island. Given the composition of the cephalopod fauna and the fact that southern bottlenose whales feed almost exclusively on squid, it is not implausible that *M. hyadesi* forms at least a similar small proportion of the diet of the species in the Scotia Sea. The only other data on the diet of this species are from two specimens from South Africa (Sekiguchi et al., 1993) and one specimen from Tierra del Fuego (Clarke, 1986). In terms of squid beak numbers, the diet was dominated by cranchiids in each of these specimens.

The data for long-finned pilot whales are taken from population estimates given by Kasamatsu and Joyce (1995). Whale population size and estimated squid consumption for the Scotia Sea was derived in the same way as for southern bottlenose whales. There are no data on diet of long-finned pilot whales in the Antarctic but elsewhere they are known to feed almost exclusively on squid and in the Faroe Islands the diet is dominated by the ommastrephid *Todarodes sagittatus* when available (Desportes and Mouritsen, 1993). Because long-finned pilot whales feed almost exclusively on ommastrephids in the north Atlantic, 100% of the squid diet in the Scotia Sea might be *M. hyadesi*. However, because of the lack of information, long-finned pilot whales have been excluded when making a conservative estimate of total consumption here.

APPROACHES TO MANAGING A *MARTIALIA HYADESI* FISHERY

Catch Limits

The data in Tables 3 to 5 indicate that a reasonable, conservative estimate of annual predator consumption of *M. hyadesi* in the Scotia Sea is about 245 000 tonnes. This is based on all seabird data, a conservative estimate for consumption by southern elephant seals, best estimates for Antarctic fur seals, sperm whales and long-finned pilot whales but excluding southern bottlenose whales. A higher estimate of about 550 000 tonnes annually, the total of all consumption data in the tables, is based on several major assumptions and is only included here to indicate the context of the conservative estimate.

Reported fishery catches of *M. hyadesi* have usually amounted to only a few tonnes annually. In some years, however, notably 1986, 1990 and 1995, more substantial catches of up to 26 000 tonnes have been made (González et al., 1997). *M. hyadesi* has a different appearance and possesses a stronger collagen tunic beneath the skin of the mantle than *I. argentinus*. This requires different processing methods, so it is unlikely to be confused aboard fishing vessels or in markets. In consequence the unreported catch is unlikely to be large.

Article II of the CCAMLR Convention requires that stocks are managed on the principle that harvesting should not reduce stocks below a level that compromises the maintenance of stable ecological relationships between harvested, dependent and related populations. Additionally, CCAMLR places more stringent conditions on new fisheries, especially in respect of proposed fishing methods and catch levels and the likelihood of effects on dependent or associated species (e.g. Conservation Measure 31/X: see CCAMLR, 1993). Data on predator consumption of *M. hyadesi*, presented in Tables 2 to 4, provide a conservative indication of its production level. The problem is to estimate the proportion of this that could be harvested in accordance with Article II because there is no way of estimating the proportional escapement from predators. For the squid population to remain stable there must be sufficient escapement of squid to complete the life cycle and spawn. It is likely that the predators take a relatively small proportion of the total *M. hyadesi* population. Seabirds, in particular, can only exploit that proportion of the stock – given that it is a jet-propelled species with a depth range that must span at least the upper 200 m of the ocean – that is available at, or near, the surface. As a starting point for a new fishery it is therefore probably safe, particularly in the context of Article II, to assume that a catch of 10% of the most conservative estimate of predator consumption would have little impact on the squid stock. This would be some 25 000 tonnes, a quantity similar to the commercial catch taken on the Patagonian Shelf edge in 1986 (Rodhouse, 1991). This approach is not without precedent, a similar argument having been made in relation to predator consumption as a basis for indicating a precautionary catch level for *Euphausia superba* (Everson and de la Mare, 1996) and forms one of the approaches currently under consideration by CCAMLR (see CCAMLR, 1995, p. 51). However, it is important to consider the impact of this level of exploitation on what might be the most sensitive species of squid-dependent predator.

Restrictions on Fishing Season

The data in Tables 1 to 3 indicate that the predator species which is most likely to be sensitive to competition from a commercial fishery is the grey-headed albatross. This is because although total consumption is relatively low, *M. hyadesi* comprises the highest proportion of squid diet and total diet in this predator. The most sensitive period of the year is probably the chick-rearing period, December to May, when the foraging range of parent birds is limited by the maximum feeding interval that a chick can sustain.

The safest strategy for fishery management would therefore be to delay opening the fishery until June, when the grey-headed albatrosses have completed rearing their chicks, and to close the fishery from September to May. In the June to August period, when it is proposed that the fishery would be open, *M. hyadesi* are entering the presumed second year of their life cycle. The data in Tables 1 to 3 suggest that few predators at South Georgia feed on *M. hyadesi* once they have reached this size and age. This strategy would therefore minimise direct competition between the fishery and the most sensitive predators at the time of exploitation.

The remaining problem is that over-exploitation could reduce the size of the spawning stock with longer-term effects for predators. Holding the fishery closed until after the breeding season of grey-headed albatrosses would allow breeding success to be monitored prior to opening the fishery and would allow the possibility of keeping the fishery closed, or reducing fishing effort, in response to any reduction in breeding success that could be attributed to decline in the *M. hyadesi* stock. For example, a reduced proportion of *M. hyadesi* in the grey-headed albatross diet, associated with a reduction in breeding success, might provide a prior warning.

It is also necessary to close the fishery prior to the appearance of the next generation of squid. The best timing of this cannot be judged with the limited information currently available, but as a precaution, a closing date from late August until the following June would avoid exploitation of <1-year-old squid.

This scheme for managing a *M. hyadesi* fishery taking into account the species' life cycle and predation by grey-headed albatrosses, is illustrated in Figure 2.

DISCUSSION

M. hyadesi apparently differs from other species of squid currently exploited by commercial fisheries in that at least some squid may have a two-year life cycle, including the egg stage. However, no squid more than one year old have been examined so, until more data are available, much doubt exists about the details of the latter half of the life cycle. Growth, maturation, feeding ecology and migrations during the period when it is proposed to harvest the population are poorly understood. The only information about spawning locality and timing comes from a few observations of juveniles and, by inference, from growth records in the statoliths of adult squid.

In contrast, the role of *M. hyadesi* in the diet of higher predators in the Scotia Sea is reasonably well studied. Methods for assessing and managing ommastrephid fisheries elsewhere have been developed (Beddington et al., 1990; Rosenberg et al., 1990) but these are not applicable at the start of a new fishery because there are no data on which to base an estimate of recruitment strength prior to the start of fishing. Such methods have also been developed on the Patagonian Shelf for species that are probably less important in the diet of higher predators than *M. hyadesi* is in the Scotia Sea.

The ecological approach to managing a new *M. hyadesi* fishery outlined here is intended to be a precautionary guide for management at the outset of exploitation. Any new fishery will need to be monitored carefully, and these guidelines updated, once the characteristics of the fishery, the life cycle and stock structure of *M. hyadesi* in the Scotia Sea are better understood. Whether the life span of *M. hyadesi* is one or two years, the precautionary measures proposed here would remain applicable to a new fishery in the CCAMLR Convention Area. However, rational management of the developed fishery would require the question of life span to be resolved. The data accruing from a fishery, whose size is controlled in the manner outlined in this paper, would allow improved assessments to be made.

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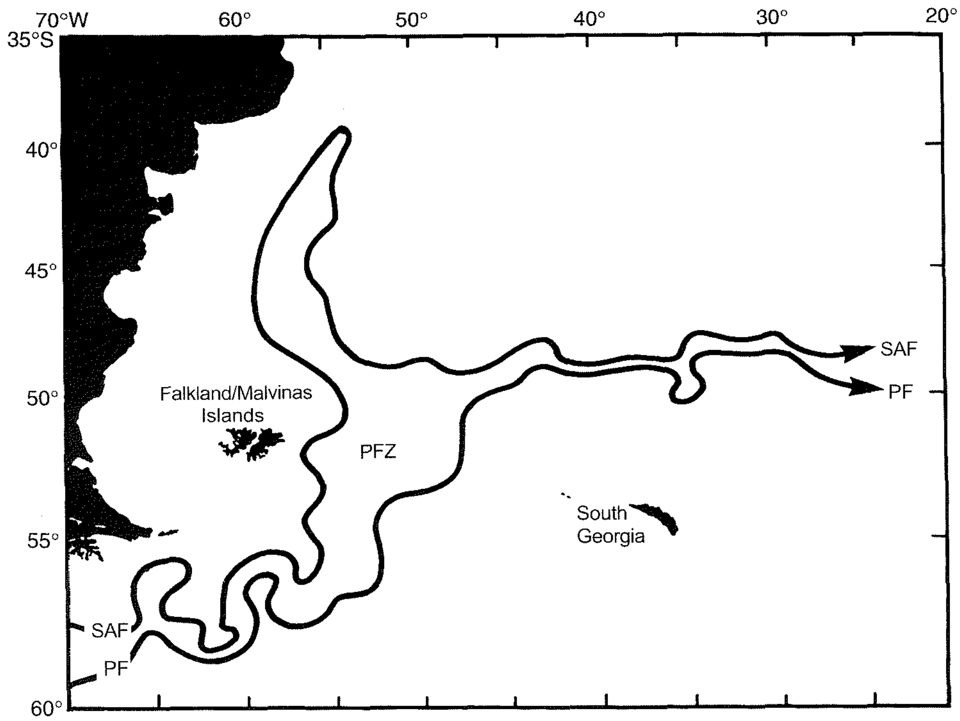

Figure 1: Map of the Scotia Sea showing position of the Antarctic Polar Frontal Zone in relation to the Falkland/Malvinas Islands, the Patagonian Shelf and South Georgia. PF: Polar Front; SAF: sub-Antarctic Front; PFZ: Polar Frontal Zone (arrows indicate direction of the Antarctic Circumpolar Current).

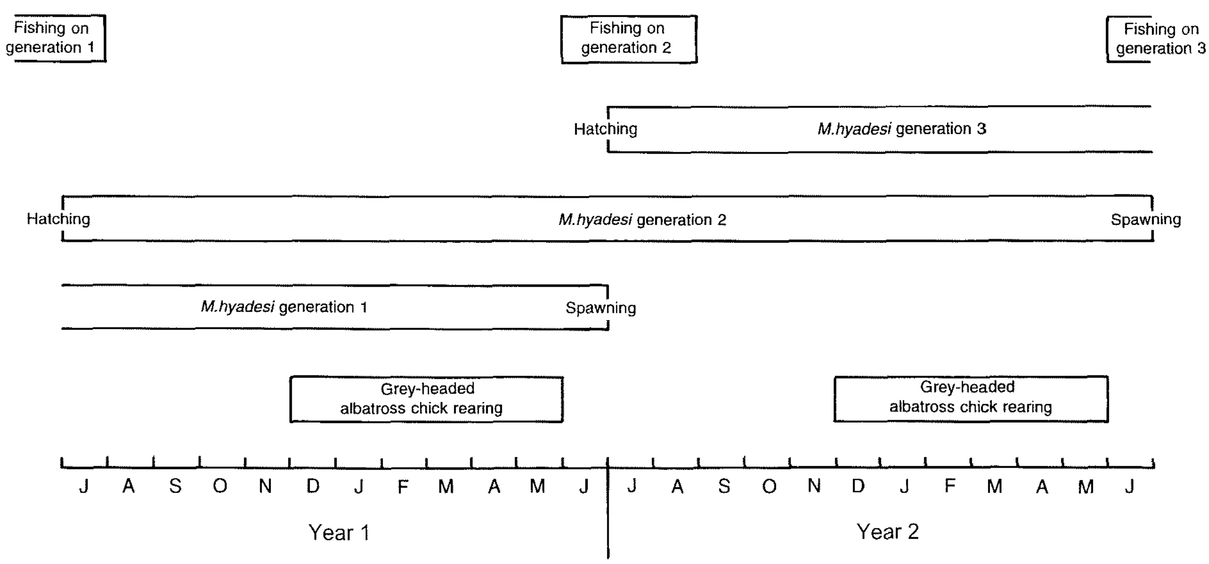

Figure 2: Schematic life cycle of *M. hyadesi* showing presumed spawning time, grey-headed albatross chick–rearing period and proposed fishing season.

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