REPRODUCTION OF THE MACKEREL ICEFISH (*CHAMPSOCEPHALUS GUNNARI*) AND ITS IMPLICATIONS FOR FISHERIES MANAGEMENT IN THE ATLANTIC SECTOR OF THE SOUTHERN OCEAN

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Abstract

Available information on key reproduction parameters of the mackerel icefish (*Champsocephalus gunnari*) has been reviewed and discussed in the light of existing conservation measures. Length at first spawning is approximately 25 cm around South Georgia and Kerguelen Islands, but approximately 35 cm around the South Orkney Islands and in the South Shetland Islands/Antarctic Peninsula region. Around South Georgia spawning takes place from March to May. Spawning around the South Orkney Islands and the South Shetland Islands probably occurs in June/July. Around South Georgia males start their spawning migration earlier than females. Fjords have been reported to be important spawning grounds. Fecundity is highest around South Georgia and Kerguelen but is decreasing towards higher latitudes.

Mesh size regulations presently in force offer very little protection to first spawners around South Georgia and juveniles and first spawners on the other South Atlantic fishing grounds. Spawning activities of *C. gunnari* and those of other exploited species could be best protected by the establishment of a permanent closed fishing season from 1 March to the end of each year's meeting of CCAMLR which is usually held in late October or early November.

Résumé

Les informations disponibles sur les paramètres clés de la reproduction du poisson des glaces (*Champsocephalus gunnari*) ont été examinées et discutées dans le contexte des mesures de conservation actuelles. La longueur au premier frai est d'environ 25 cm autour de la Géorgie du Sud et des îles Kerguelen, mais de 35 cm autour des îles Orcades du Sud et dans la région des îles Shetland du Sud et de la péninsule Antarctique. Autour de la Géorgie du Sud, le frai a lieu de mars à mai. Le frai, autour des îles Orcades du Sud et des îles Shetland du Sud, a probablement lieu aux mois de juin et juillet. Autour de la Géorgie du Sud, les mâles commencent leur migration de frai plus tôt que les femelles. Il a été signalé que les fjords sont des frayères importantes. La fécondité est au plus haut niveau autour de la Géorgie du Sud et des îles Kerguelen, mais diminue vers les latitudes plus élevées.

La réglementation sur la taille du maillage actuellement en vigueur n'offre que très peu de protection aux poissons qui se reproduisent pour la première fois autour de la Géorgie du Sud, et aux juvéniles et poissons frayant pour la première fois sur les autres lieux de pêche de l'Atlantique du Sud. Les activités de reproduction de *Champsocephalus gunnari* et d'autres espèces exploitées pourraient

être protégées au mieux par l'établissement d'une saison permanente de fermeture de pêche effective du 1er mars à la fin de chaque réunion annuelle de la CCAMLR, qui se tient, de coutume, fin octobre ou début novembre .

Резюме

В настоящей работе рассматривается и обсуждается в свете действующих Мер по сохранению имеющаяся информация о ключевых параметрах воспроизводства ледяной рыбы (*Champsocephalus gunnari*). В районах Южной Георгии и островов Кергелен длина при первом нересте приблизительно равняется 25 см, в то время как в районе Южных Оркнейских островов и районе Южных Шетландских островов/Антарктического полуострова она равняется 35 см. В районе Южной Георгии нерест происходит с марта по май. Нерест в районе Южных Оркнейских и Южных Шетландских островов, вероятно, происходит в июне/июле. В районе Южной Георгии нерестовая миграция самцов начинается раньше, чем нерестовая миграция самок. Имеются сведения о том, что фиорды являются важными нерестовыми участками. Плодовитость наиболее высока в районах Южной Георгии и островов Кергелен, но снижается на более высоких широтах.

Действующие в настоящее время меры по ограничению минимального размера ячеи не обеспечивают эффективной охраны впервые нерестующих особей в районе Южной Георгии, а также молоди и впервые нерестующих особей на других промысловых участках южной Атлантики. Самым эффективным методом обеспечения охраны нереста *C. gunnari* и прочих эксплуатируемых видов является введение постоянного закрытого сезона с 1 марта до окончания каждого ежегодного совещания АНТКОМа, которые обычно проводятся в конце октября - начале ноября.

Resumen

La información disponible acerca de los principales parámetros reproductivos del draco rayado (*Champsocephalus gunnari*) se ha examinado y debatido de acuerdo con las medidas de conservación existentes. El largo al primer desove es alrededor de 25 cm cerca de Georgia del Sur y las Islas Kerguelen, pero es alrededor de 35 cm cerca de las Islas Orcadas del Sur y en las Islas Shetland del Sur y la región de la Península Antártica. Cerca de Georgia del Sur el desove ocurre desde marzo a mayo. Alrededor de las Islas Orcadas del Sur y las Islas Shetlands del Sur es posible que ocurra alrededor de junio/julio. Cerca de Georgia del Sur, los machos comienzan su migración de desove antes que las hembras. Se ha observado que los fiordos son terrenos importantes para desove. La fecundidad es mayor alrededor de Georgia del Sur y Kerguelen pero disminuye hacia las latitudes más altas.

Reglamentos gobernando la abertura de la malla que están en vigor en este momento ofrecen muy poca protección a los desovadores alrededor de Georgia del Sur y a los reproductores juveniles y los de primer desove en los otros caladeros de pesca en el Atlántico Sur. Actividades de desove de *Champsocephalus gunnari* y de otras especies explotadas podrían ser protegidas más eficazmente estableciendo una temporada de veda de pesca permanente desde el 1° de marzo hasta el final de la reunión de CCRVMA cada año, la cual es generalmente conducida a fines de octubre o principios de noviembre.

1. INTRODUCTION

Since 1975/76 fishing in the Atlantic sector of the Southern Ocean has been mainly directed to the mackerel icefish (*Champsocephalus gunnari*). Catches were highest at about 240 000 tonnes, 220 000 tonnes and 100 000 tonnes in 1976/77 to 1977/78, 1982/83 to 1983/84 and 1986/87 to 1987/88 respectively. South Georgia has been the most important fishing ground for the species except in the seasons 1977/78 to 1979/80 when most of the catches were taken further south around the South Orkney Islands and in the South Shetland Islands/Antarctic Peninsula region.

Peak catches in the 1970s around South Georgia were based primarily on age classes 4 and 5 whereas catches in the 1980s consisted of age classes 2 and 3 (age class 2 being the recruiting age class). Since 1987/88 biomass estimates from the Virtual Population Analysis (VPA) indicate a downward trend. Assuming a mean level of recruitment and a fishing mortality of $F_{0.1}$ (0.25 to 0.3) spawning stock biomass could fall well below 100 000 tonnes in 1989/90 (CCAMLR, 1988b; Kock and Köster, 1989).

Since 1984 the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) established a number of conservation measures for the fish stocks around South Georgia (CCAMLR, 1988a, c) which were aimed either directly (mesh size regulations, closed season, TAC) at *C. gunnari* or should have some benefit for the species indirectly (closure of waters within 12 miles around the island). The prohibition of directed fishing of *C. gunnari* from 1 April to 30 September 1988 has been established specifically to protect spawning of the species. No such regulations exist for the other South Atlantic fishing grounds.

In its report of the annual meeting in 1988, CCAMLR asks the Scientific Committee to provide further advice on minimum mesh sizes to protect juvenile fish and on closed seasons for *C. gunnari* (CCAMLR, 1988c). In what follows, available information on key reproductive parameters (length at first spawning, spawning migration, spawning grounds, spawning time, fecundity) of *C. gunnari* has been reviewed. These parameters are discussed in the light of existing conservation measures and future implications for management of the species in compliance with Article II (3) of the Convention in the Atlantic sector of the Southern Ocean, in particular around South Georgia.

2. MATERIAL AND METHODS

Analysis was mostly based on published information. In addition some unpublished results of the Antarctic Expedition 1984/85 of the Federal Republic of Germany in South Georgia waters have been taken into account.

Maturity was determined either according to Everson's (1977) five point scale (Kock, unpublished) or Maier's (1908) eight point scale (Sosinski, 1985). Length at first spawning (see Kock, 1989) was estimated by fitting total length versus proportion of fish at maturity stages 3 to 5 (Kock) or 3 to 8 (Sosinksi) to a logistic equation (see Kock, 1989).

Potential or absolute fecundity was estimated by three different methods:

(i) All ova was washed out of the ovary and counted with an automatic egg counting device (e.g. Kock, 1979);

(ii) A weighed subsample of oocytes from an ovary was counted and then extrapolated to the entire ova (e.g. Sosinski, 1985); and

(iii) Sections of 0.9 to 2.9 g were taken from the central part of the right ovary. The proportion of the weight of the section to the weight of the entire ovary was used to extrapolate the number of oocytes in the subsample to that of the whole ovary (e.g. Lisovenko and Zakharov, 1988).

The following expressions are commonly used to describe the relationship between size and fecundity:

$F = a \cdot L^b$ (all authors, see Table 1)
$F = a + b \cdot W$ (Kock, Sosinski, Duhamel, see Table 1)
$F = a \cdot W^b$ (Lisovenko and co-authors, see Table 1).

3. RESULTS

3.1 Length at First Spawning

Length at first spawning L_{m50}, which corresponds to length at first maturity as determined by some authors (Kock, 1989) has been derived from data of Sosinski (1981 and 1985) and Kock (unpublished) (Table 1 and Figures 1 to 3). At South Georgia no significant difference in L_{m50} was apparent between the sexes nor between years (Figures 1 to 3). Length at first spawning of approximately 25 cm was similar in the late 1970s and 1985, in both cases after periods of heavy fishing.

Length at first spawning is much larger around the South Orkney Islands (Table 1). Data for the Elephant Island/South Shetland Islands region could not be fitted to a logistic curve (Sosinksi, 1985, Figure 10; Kock, 1989). However, there is evidence that L_{m50} is similar to that observed in the South Orkney Islands (Kock, 1989).

Spawning maturity curves for the population around South Georgia (Figures 1 to 3) were characterized by an asymmetrical shape, i.e. more juvenile individuals or fish with gonads in resting stage in the prespawning period (maturity stages 1 and 2 of the Everson scale) were present in the upper part of the curve than fish in prespawning condition (maturity stage 3) in its lower part. The difference between the theoretical (straight line) and the observed (dashed line) curve therefore represented the part of the population which was sexually mature but did not spawn in that particular season. An amount of specimens > 35 cm in the sample was too small to be representative. They have therefore been omitted here. Part of these specimens also had gonads in resting stage (i.e. were unlikely to spawn in the current season).

Although *C. gunnari* spawns annually, 15 to 25% of the population (both males and females) obviously do not spawn each year (Figures 1 to 3, shaded area) (see also Lisovenko and Silyanova, 1980; Sosinski, 1985, Figure 10). This is most likely the case also in the South Orkney Islands/South Shetland Islands region (Sosinski, 1985, Figure 10; Kock, 1989). The proportion of non-spawners cannot be assessed at present. In contrast to the populations in the Atlantic sector, *C. gunnari* around Kerguelen Islands obviously attains maturity within a very narrow length range (24 to 26 cm, Sosinski, 1985, Figure 10; Duhamel, 1987) and obviously spawns annually thereafter.

3.2 Spawning Migrations

No direct observation on spawning migrations (e.g. from tagging experiments) is available. The preponderance of fish in prespawning condition in coastal waters of South Georgia from March onwards points at a spawning migration to nearshore waters and fjords. In late March to mid April males outnumbered females in prespawning concentrations in

fjords (Table 2) which indicates that males start their spawning migration earlier than females (Kock, 1981; Anon, 1985). Prior to spawning, sex ratio was again approaching 1:1 (Table 2, Fortuna Bay).

No such information exists for the other South Atlantic populations.

An inshore movement for spawning has also been described for the population at Kerguelen (Duhamel, 1987). The Skif Bank population, however, does not carry out extensive spawning migrations but reproduces on the bank (Duhamel, 1987).

3.3 Spawning Grounds

Olsen (1955) was the first to describe the inshore waters of South Georgia as spawning grounds of *C. gunnari*. These observations have been confirmed by Kock (1981) who recorded the presence of dense prespawning aggregations of the species in the central (deeper) parts of Fortuna Bay, Cumberland Bay and Royal Bay in late March to mid April 1978. No prespawners have been observed in these areas in early February. However, spawning does take place on the shelf at 100 to 125 m depth (Permitin, 1973; Sosinksi, 1985), although its extent is not known. Larvae and 0-group fish have been mostly encountered in nearshore waters (Kock, 1981; Slosarczyk, 1983; North, 1987).

Spawning has also been recorded from the South Orkney shelf along depths over 600 m close to the bottom and from the Elephant Island shelf (Anon, 1985). However, Kock (1989) found little indication for extensive spawning on the Elephant Island shelf during a survey in May/June 1986.

Spawning grounds of the Kerguelen population are located at the 100 m depth contour in the northeastern part of the shelf. On Skif Bank *C. gunnari* spawn along the 200 m depth contour of the southern and western margin of the bank (Duhamel, 1987).

3.4 Spawning Time

Spawning at South Georgia occurs from March to May (Table 1) but may even start in February and extend to June. As commonly observed in many teleosts, bigger (= older) individuals reproduce earlier than first spawners (Lisovenko and Silyanova, 1980).

Spawning in the South Orkney Islands/South Shetland Islands region is later and takes place probably in June to July (CCAMLR, 1985; Kock, 1989).

Spawning of various populations in the Indian Ocean sectors occurs in remarkably different seasons (Table 1): May/June on Skif Bank and August to September at Kerguelen Islands and around Heard Island (Duhamel, 1987; Gerasimchook et al., 1987).

3.5 Fecundity

Fecundity of *C. gunnari* is well studied, in particular around South Georgia. Length/weight-fecundity relationships determined by various authors (Table 1), however, differ significantly from each other especially in the upper part of the curve (Figure 4). Fecundity estimates of Kock, Lisovenko and Silyanova and Sosinksi were based on material collected in 1976 to 1978 whereas Lisovenko and Zakharov refer to samples from 1983/84. The remarkable similarity of Kock's and Sosinski's results on one hand and those of Lisovenko and co-authors on the other hand indicates that methodological differences were most likely to be responsible for these differences but not year-to-year variations in

fecundity. Fecundity in the various populations obviously follows a latitudinal trend. Potential and relative fecundity were highest around Kerguelen and lowest around Elephant Island and the South Shetland Islands (Figure 5).

3.6 Discussion

Length at first spawning L_{m50} of *C. gunnari* around South Georgia has remained relatively constant between 1976 and 1985 although the population has undergone considerable fluctuations both in size and composition due to heavy fishing during that period. Estimates of L_{m50} of approximately 25 cm which do not differ significantly between sexes, originate from samples taken during prespawning period in January/February. Fish of this length are approximately 2.6 years old. They do not spawn, however, until April/May when they are of approximately 27 cm length and 2.9 years old.

Mesh size regulations have been widely used to establish a minimum size at first capture l_c. Its rationale is to prevent recruitment overfishing and to protect first spawners. Ideally l_c should exceed l_{m50} to some extent in order to allow fish to spawn at least once. Most often, however, l_c is less than L_{m50}.

A minimum mesh size of 80 mm for *C. gunnari* was among the first conservation measures which were introduced by CCAMLR in 1984 and came into force in 1985 (Conservation Measure 2/III). It was based on regulations which had been in use in the Soviet fishing fleet since 1980. Its scientific basis, however, remained unclear.

Preliminary mesh selectivity experiments resulted in a mean selectivity factor SF=3.01 for research vessel catches in the order of 0.5 tonnes/hour (Anon., 1988a). Minimum size at first capture (l_c=24 cm) would then correspond roughly to L_{m50}=25 cm. However, SF and l_c are most likely to be lower in commercial catches (> 1 to 1.5 tonnes/hour) (CCAMLR, 1988b). This demonstrates that present mesh size regulations do offer little, if any protection to first spawners around South Georgia. In fact, first spawners (i.e. primarily age class 2+) had always formed a substantial part of the annual catches (Kock and Köster, 1989, Figure 11) irrespective of the introduction of minimum mesh sizes in the Soviet fishing fleet since 1980.

Providing that most fish which escape through the meshes do survive, protection of first spawners could only be achieved by a substantial increase of minimum mesh size around South Georgia (e.g. to 110 or 120 mm).

Length at first spawning of 35 cm around the South Orkney Islands and the South Shetland Islands/Antarctic Peninsula region is much higher than around South Georgia although maximum length L_{m50} observed was similar in both regions (Kock, 1989; Table 2). Peak catches of 138 000 tonnes around the South Orkney Islands in 1977/78 were comprised almost entirely of juveniles of the very abundant 1973 and 1974 year classes (Kock and Köster, 1989). Catches of 57 000 tonnes around the South Orkney Islands and in the South Shetland Islands/Antarctic Peninsula region in the subsequent season obviously still consisted of juveniles and first spawners to a large extent (Kock and Köster, 1989, Figures 17 and 18). The two very abundant year classes, 1973 and 1974, were apparently already largely fished out before they were able to contribute significantly to the spawning stock biomass (SSB) of these two populations.

Catches on these two grounds dropped substantially after the 1978/79 season to a few thousand tonnes annually which were mostly taken around the South Orkney Islands. In some seasons these catches were almost entirely comprised of juveniles and first spawners (Kock and Köster, 1989, Figures 17 and 18).

It is evident that present minimum mesh sizes of 80 mm do offer very limited protection to the populations of *C. gunnari* around the South Orkney Islands and in the South Shetland Islands/Antarctic Peninsula region. Due to the large size of fish at first spawning, however, adequate protection of juveniles and first spawners could only be achieved by increasing minimum mesh sizes beyond those proposed for South Georgia (i.e. approximately 140 mm).

SSB and SSB/R (recruitment) calculations in VPA and Y/R (yield/recruitment) analyses are usually based on sexual maturity ogives. Although spawning of *C. gunnari* is likely to take place annually, our results indicate that part of the population(s) does not spawn each year. Present input parameters for VPA (CCAMLR, 1988b; Kock and Köster, 1989) may thus overestimate true SSB by 15 to 25%. It is recommended that in future maturity ogives should be based on spawning maturity instead of sexual maturity data.

Around South Georgia, spawning migration obviously commences in late February/early March. Males tend to migrate to coastal waters earlier than females. Consequently females may stay longer within the region of the fishery. It may thus be advisable to close the fishery from 1 March instead of 1 April onwards (Conservation Measure 10/VI).

Coastal spawning grounds, as far as they are known, seem to be well protected by the prohibition of fishing within 12 miles around South Georgia (Conservation Measure 1/III). Spawning on the shelf, however, should be protected as well. Taking into account that other commercially important species spawn in late autumn (*Notothenia rossii*, *Chaenocephalus aceratus* and *Pseudochaenichthys georgianus*) or in winter (*Notothenia gibberifrons*) it seems to be advisable to establish a closed fishing season for those species permanently during that period similar to the closed season which was established in 1988 by the Conservation Measure 10/VI. This closed season should preferably be extended from 1 March to the end of each year's meeting of CCAMLR which is usually held in late October or early November.

Potential fecundity of *C. gunnari* ranges from 1 500 to 30 000 eggs around South Georgia. It rarely exceeds 10 000 eggs in the other populations. Population fecundity around South Georgia is, however, much lower than suggested by the wide range of potential fecundity as the bulk of the population is formed by age classes 2 to 4. They do not produce more than approximately 1 500 to 7 000 eggs per fish.

Relative fecundity (i.e. egg production per gram of body weight) is highest around South Georgia (and Kerguelen Islands) but is decreasing in the waters of higher latitudes.

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Table 1: Reproductive parameters of *Champsocephalus gunnari*.

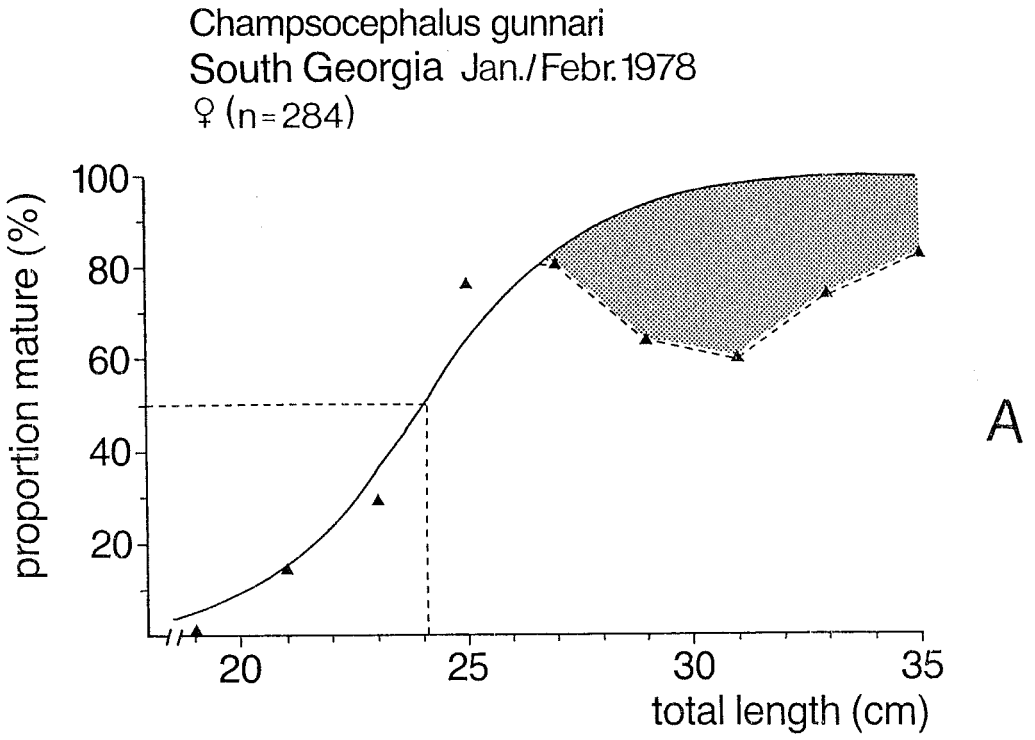
Locality	Spawning Time	$L_{m\ 50}$ (cm)	Year (s) of Investig.	Length range (cm)	Potential Fecundity Min	Potential Fecundity Max	Relative Fecundity	Fecundity in Relation to Length (cm)	Fecundity in Relation to Weight (g)	Source
South Georgia	March to May	21-26	1967	33-54	4050	23187	-	-	-	Permitin (1973)
		24.8	1976,1985	22-57	1564	31045	13.7-30.6	$F=0.1292 \cdot L^{3.0145}$	$F=383 + 17.9 \cdot W$	Kock (1979, 1981, Unpubl.)
		24.8	1976,1977 1979	22-51	1700	17338	-	$F=0.2223 \cdot L^{2.8882}$	$F=801 + 16.02 \cdot W$	Sosinski (1981, 1985)
		22-30	1965-1979	25-43	2208	11126	-	$F=1.54 \cdot L^{2.29}$	$F=189.6 \cdot W^{0.59}$	Lisovenko, Silyanova (1980)
		-	1984	22-58	1294	21932	-	$F=3.19 \cdot L^{2.08}$	$F=197.0 \cdot W^{0.58}$ *	Lisovenko, Zakharov (1988)
S. Orkney Islands	June to July	-	1967	43	-	8352	14	-	-	Permitin (1973)
		35.1	1979	31-44	5169	9889	-	$F=0.2574 \cdot L^{2.7744}$	$F=1753 + 10.4 \cdot W$	Sosinksi (1981, 1985)
Elephant Island	June to July	(35)	1981,1985 1986	34-50	3094	11664	8.0-16.7	$F=0.1216 \cdot L^{2.9177}$	$F=1523.1+8.55 \cdot W$	Kock (1989)
S.Shetland Islands	June to July (?)	(35)	1978	32-44	3388	9067	12.4-16.5	$F=0.0454 \cdot L^{3.2235}$	$F=128 + 14.45 \cdot W$	Kock (1982)
			1979	36-47	5710	11753	-	$F=3.774 \cdot L^{2.0487}$	-	Sosinski (1981, 1985)
Kerguelen	August to September		1975	26-38	2000	10645	-	$F=0.055 \cdot L^{3.9498}$	$F=57.14+21.42 \cdot W$	Sosinski (1981, 1985)
		25	1979-1984	26-37	2980	9060	24.2-45.4	$F=0.3027 \cdot L^{2.845}$	-	Duhamel (1987)
Skif Bank	May to June		1979-1984	25-25	1750	5220	17.9-29.2	$F=0.20 \cdot L^{2.869}$	-	Duhamel (1987)

* $F=1.97\ W^{0.58}$ in Lisovenko and Zakharov (1988).

Table 2: Sex ratio in prespawning concentrations of *Champsocephalus gunnari* on the shelf and in fjords of South Georgia (from Kock, 1981).

Date	Sex Ratio (%) F	M	Location
28/03/78	68.0	32.0	Shelf
30/03/78	70.6	29.4	Shelf
01/04/78	64.0	36.0	Shelf
12/04/76	60.4	39.6	Shelf
15/04/76	71.9	28.1	Shelf
15/04/76	69.8	30.2	Shelf
29/03/78	15.7	84.3	Cumberland W. Bay
02/04/78	25.8	74.2	Royal Bay
02/04/78	46.6	53.4	Fortuna Bay *

* A high gonadosomatic index (mostly > 20) indicates that fish are at prespawning state.



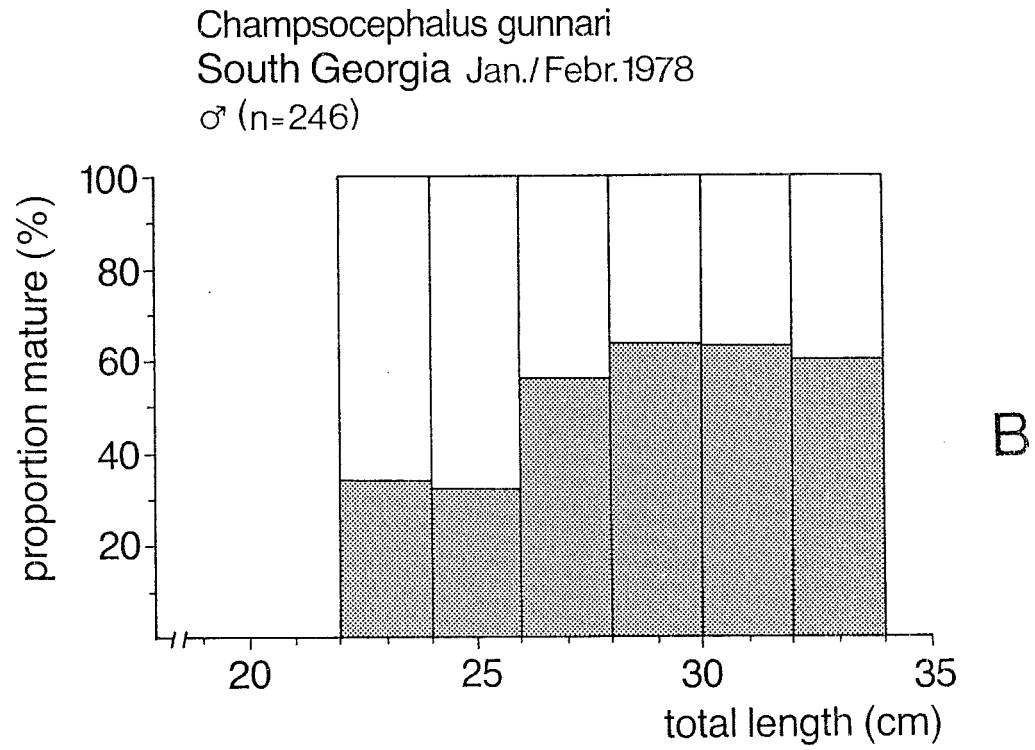


Figure 1: Spawning maturity curves for *Champsocephalus gunnari* around South Georgia in January/February 1978.

A: Females B: Males (Data could not be fitted to a logistic curve).

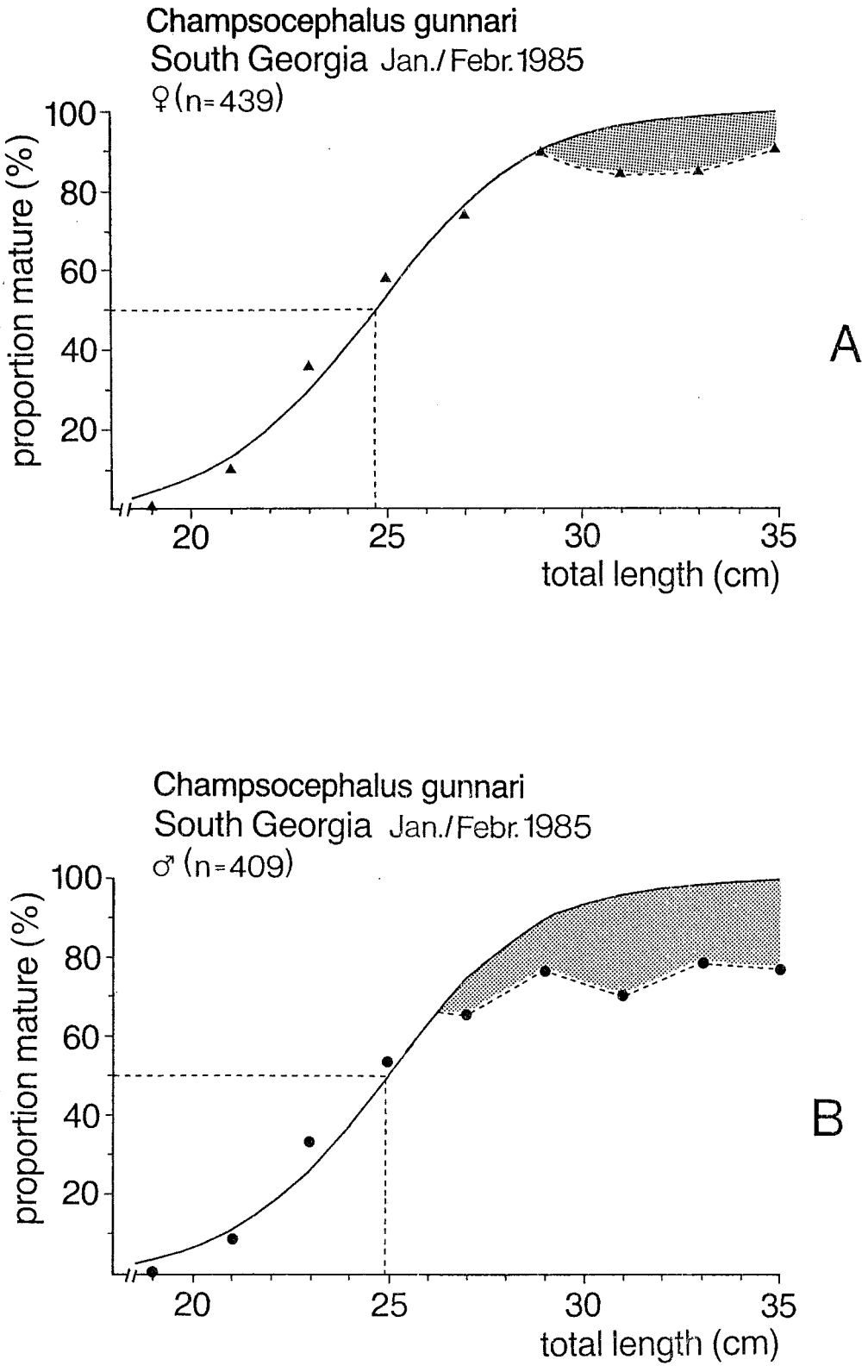


Figure 2: Spawning maturity curves for *Champsocephalus gunnari* around South Georgia in January/February 1985.

A: Females B: Males

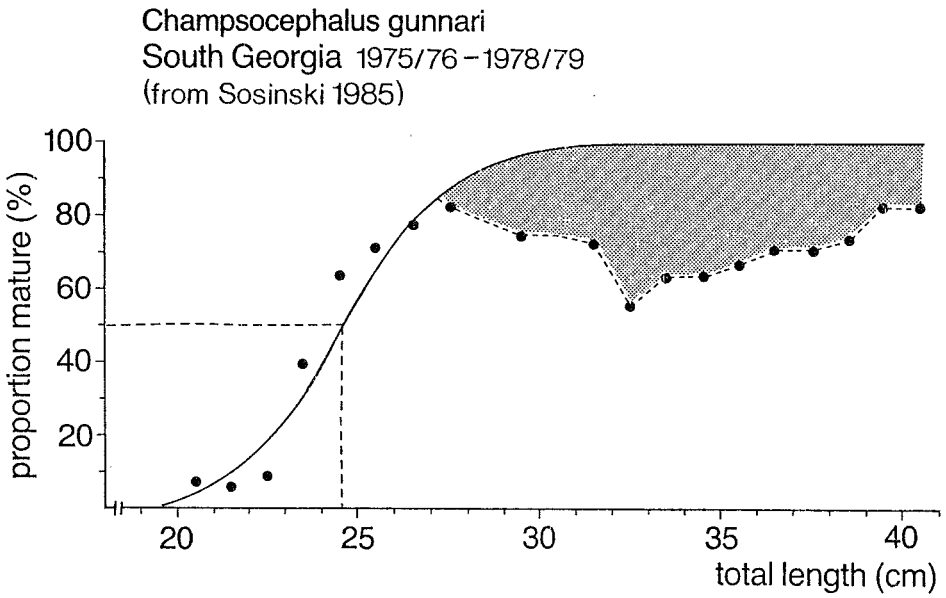


Figure 3: Spawning maturity curve for *Champsocephalus gunnari* (both sexes combined) around South Georgia in 1975/76 (from Sosinski, 1985).

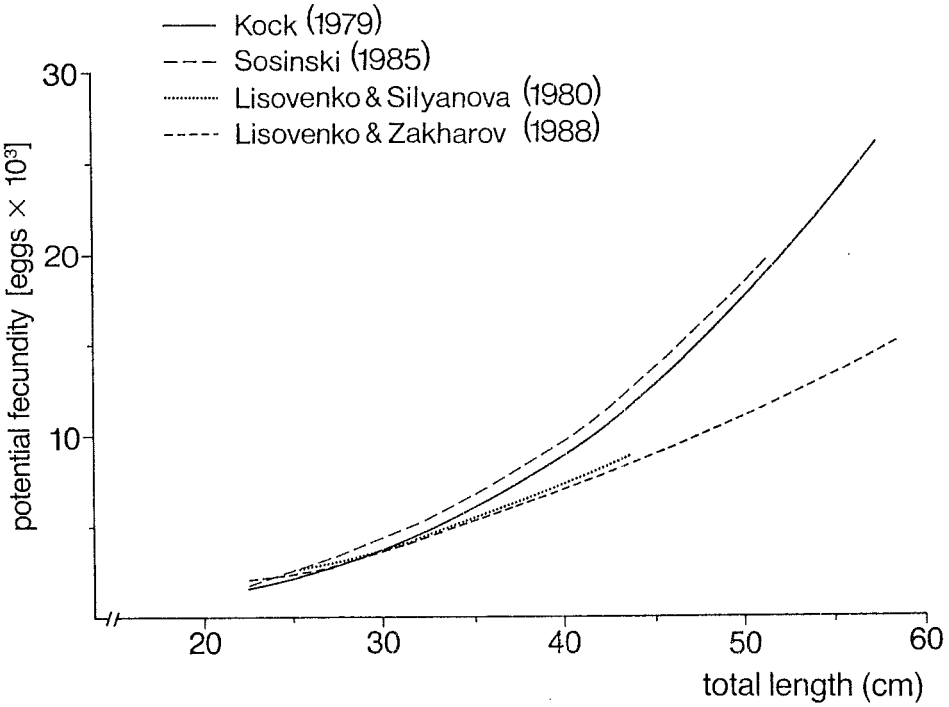
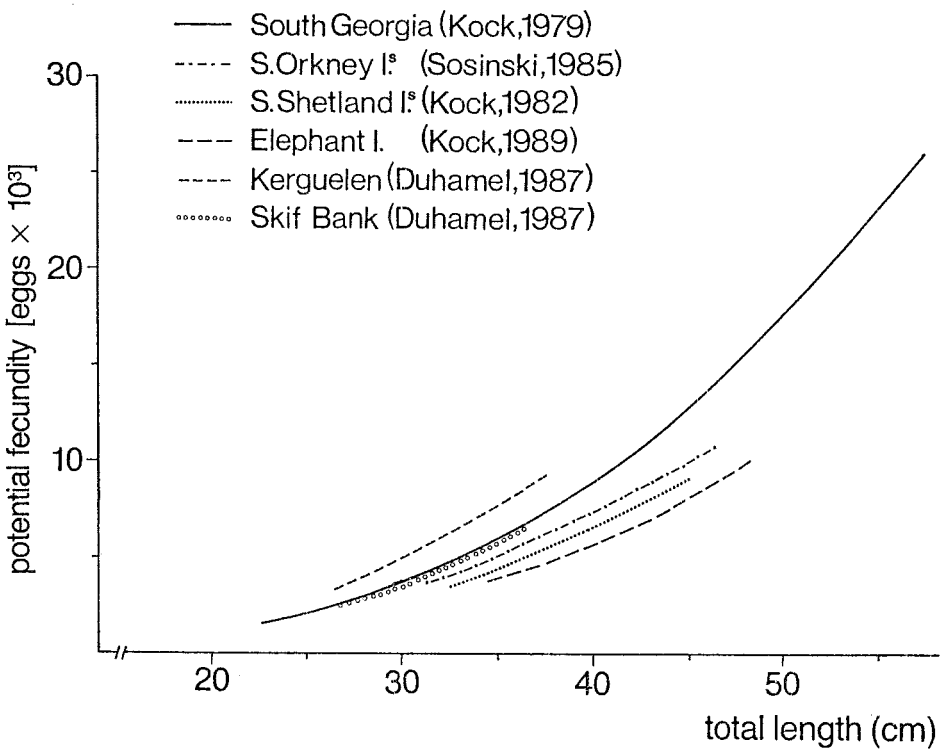


Figure 4: Length versus fecundity curves for *Champsocephalus gunnari* around South Georgia.



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