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Józef SOSIŃSKI[1], *Jacek SZLAKOWSKI*[2]

Stock monitoring and biology

BIOLOGICAL CHARACTERISTICS AND BIOMASS ESTIMATES OF THE FISH STOCKS ON THE SOUTH GEORGIA SHELF IN THE 1986/87–1988/89 SEASONS

CHARAKTERYSTYKA BIOLOGICZNA I OCENA BIOMASY STADIÓW RYB SZELFU GEORGII POŁUDNIOWEJ W SEZONACH 1986/87–1988/89

[1] Sea Fisheries Institute, Gdynia
[2] Department of Biological Resources of Sea, Academy of Agriculture Szczecin

The fish species on the South Georgia shelf were sampled in the 1986/87–1988/89 fishing seasons, during three RV "Profesor Siedlecki" cruises. The biological structure of fish stocks, the length-frequency and age distributions during the period of study are described. The biomass of fish stocks was estimated by the "Swept Area Method".

INTRODUCTION

Large scale commercial exploitation of fish stocks around South Georgia (FAO statistical subarea 48.3) began at the end of the 1960s. In the 1969/70 fishing season (split year, with the fishing season running from July through to the end of following June) it started with catches of nearly 400 000 tonnes of *Notothenia rossii marmorata* and just over 100.000 tonnes in 1970/71. In the following fishing seasons catches of this species were decreasing and in 1988 the stock size was estimated to be less than 5% of its pristine level (Kock and Köster 1989). The rapid depletion of the *N. rossii marmorata* stock was a serious sign that the Antarctic fish resources were limited and vulnerable to heavy exploitation. The overfishing of *N. rossii marmorata* stock caused the fishery shifts to other species, *Champsocephalus gunnari*. Since 1980/81 it has become the target species in the fishery around South Georgia, although the annual catches have exhibited large fluctuations, mostly due to variations in year class strength (Mucha and Ślósarczyk 1988, Kock and Köster 1989).

To stop the decline and overfishing of fish stocks, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), adopted several conservation

measures and introduced a catch reporting system. In 1984 commercial fishing was prohibited within 12 nautical miles of South Georgia and mesh regulation was introduced with a minimum mesh size 120 mm for *N. rossii* and *Dissostichus eleginoides*, and 80 mm for other species. In 1985 direct fishing on *N. rossii marmorata* around South Georgia was prohibited, and in 1987 the total catch of *C. gunnari* around South Georgia was limited to 35.000 tonnes for the 1987/88 season. From 1 April until 1 October 1988 direct fishing for five important species, *Ch. gunnari, Chaenocephalus aceratus, Pseudochaenichthys georgianus, N. rossii marmorata* and *N. gibberifrons* was prohibited, also between 4 November 1988 and 20 November 1989. For the 1989/90 season the total catch of *Ch. gunnari* around South Georgia was limited to 8.000 tonnes and direct fishing on *Ch. aceratus, Ps. georgianus, N. gibberifrons* and *N. squamifrons* was prohibited. The use of bottom trawls in the direct fishery for *Ch. gunnari* was also prohibited. Closed seasons between 20 November 1989 and 15 January 1990 and between 4 April and 4 November 1990 were established (Anon. 1989, Hureau and Ślósarczyk 1990).

Polish ichthyological research in Antarctica has started since 1976 (Linkowski and Rembiszewski 1978) and commercial exploitation since 1977 (Sosiński and Skóra 1984). From the very beginning the Sea Fisheries Institute at Gdynia (SFI) has carried out the monitoring studies of fish stocks off South Georgia. During the 1986/87–1988/89 fishing seasons SFI undertook three cruises to the South Georgia fishing grounds in an attempt to assess the standing stock biomass and population structure of fish species. In the 1986/87 and 1987/88 fishing seasons research were carried out jointly by Sea Fisheries Institute with the Northeast Fisheries Center, National Marine Fisheries Service, NOAA, USA (Sosiński and Skóra 1987, 1988, Mucha 1989). In the 1988/89 fishing season they were conducted in collaboration with Imperial College of Science and Technology, University of London, UK (Parkes et al. 1989, Sosiński 1990).

The purpose of this paper is to review the results of three RV "Profesor Siedlecki" surveys and provide information on population structure and biomass estimates of the main fish species at South Georgia shelf.

MATERIALS AND METHODS

The materials for the present study were collected during three cruises of the Polish RV "Profesor Siedlecki" in December 1986, December 1987 to January 1988, and in February 1989. The survey area was divided into 3 depth strata and 22 grid squares according to Everson (1984); stratum 1: 50–150 m, stratum 2: 150–250 m and stratum 3: 250–500 m. Trawl stations were randomly located within depth strata with roughly equal numbers of stations within each grid square. The number of station per stratum/grid was in proportion to its seabed area. Areas known to be unsuitable for bottom trawling, to the south of the island, were avoided whenever possible.

The RV "Profesor Siedlecki" made 109 successful tows in the 1986/87 fishing season survey, 128 in 1987/88 and 55 in 1988/89. All tows were of usually 30 minutes duration, timed from completion of warp out to commencement of hauling. The trawl speed was 3.5 knots. The trawl net was a P 32/36 otter bottom trawl with a 80 mm mesh codend and 40 mm fine mesh liner. The horizontal net opening was 17.5 m and vertical opening 4.5 m.

Depending on the size of catch, the weight of the entire or representative, random, sub-sample of catch was recorded. The catch was sorted and identified to the species level according to Fischer and Hureau (1985). Then the number and weight of each fish species were determined. Further analyses were made for five dominant species, three channichthyids: *Champsocephalus gunnari, Chaenocephalus aceratus, Pseudochaenichthys georgianus,* and two notothenids: *Notothenia gibberifrons* and *N. rossii marmorata.* The representative, random sample of fish (or all) of each species were taken for ichthyological analyses. The fish were measured (total length TL) to 1 cm below and weighed to 10 grams, small specimens to 1 gram. Sex, maturity (in Everson's scale) and stomach fullness (in five degree scale) were determined. Otoliths and scales for age determination were collected.

To express biomass distribution, the catch weights were standardized to 30 minutes trawling time and to 1 km^2 swept area. The biomass of fish was estimated by the "Swept Area Method" (Saville 1977, Mucha 1984) following the formula: $B = \frac{CPUE \times A}{q}$, where:

B = biomass of a given fish species (tonnes),

CPUE = catch per unit of effort (kg/km^2, kg/30 minutes),

A = area of seabed covered during survey (km^2),

q = a constant, referred to in this paper as catchability coefficient (q = 1).

RESULTS

Species composition

A total of 32 fish species belonging to 15 families were identified during the whole period of research (Tab. 1), but during each cruise only 24 species occurred. Three families accounted for 30–41% of all species: *Notothenidae* (8–9 species), *Channichthyidae* (3 species) and *Myctophidae* (1–5 species).

Four species, *Champsocephalus gunnari, Chaenocephalus aceratus, Pseudochaenichthys georgianus* and *Notothenia gibberifrons* constituted the bulk of catches, being found at nearly all stations. *Notothenia rossii marmorata,* formerly the most abundant and commercially important species of the area, occurred sporadically, in small numbers. Two other notothenids, *Notothenia squamifrons* and *Dissostichus eleginoides,* were rarely present in the catches, though large concentrations of the former were

Table 1

Species composition of bottom trawl catches during RV "Profesor Siedlecki" surveys in the 1986/87–1988/89 fishing seasons with weight share in % of the main species

Species	1986/87	1987/88	1988/89
RAJIDAE			
Raja georgiana	++	++	++
ARTEDIDRACONIDAE			
Artedidraco mirus	++	++	++
BATHYDRACONIDAE			
Parachaenichthys georgianus	++	++	++
Psilodraco breviceps	+	+	+
BATHYLAGIDAE			
Bathylagus spp.	+	–	–
BOTHIDAE			
Mancopsetta maculata antarctica	++	++	++
CHANNICHTHYIDAE			
Champsocephalus gunnari	44.5	11.7	39.1
Chaenocephalus aceratus	9.8	6.6	10.7
Pseudochaenichthys georgianus	4.8	21.4	18.7
CENTROLOPHIDAE			
Pseudoicichthys australis	–	+	–
GEMPYLIDAE			
Paradiplospinus gracilis	–	+	–
HARPAGIFERIDAE			
Harpagifer georgianus	–	+	–
LIPARIDIDAE			
Careproctus spp.	+	–	–
Paraliparis spp.	+	+	+
MURAENOLEPIDAE			
Muraenolepis spp.	++	++	++
MYCTOPHIDAE			
Electrona antarctica	+	–	–
Electrona calsbergi	–	–	+
Gymnoscopelus nicholsi	+	+	++
Krefftichthys anderssoni	–	–	+
Protomyctophum bolini	–	–	+
Protomyctophum choriodon	–	–	+
NOTOTHENIDAE			
Dissostichus eleginoides	1.1	43.3	0.9
Notothenia angustifrons	–	+	–
Notothenia gibberifrons	16.4	9.9	18.0
Notothenia kempi	+	+	+
Notothenia rossii marmorata	0.6	2.5	3.5
Notothenia squamifrons	18.4	0.5	0.4
Nototheniops larseni	++	++	++
Nototheniops nudifrons	++	++	++
Pagothenia hansoni	++	++	++
PARALEPIDIDAE			
Notolepis coatsi	+	–	–
ZOARCIDAE			
Melanostigma gelatinosum	+	+	+
Total catch (in kgs)	36681	28075	6757

++ "regular" species

+ "ocassional" species

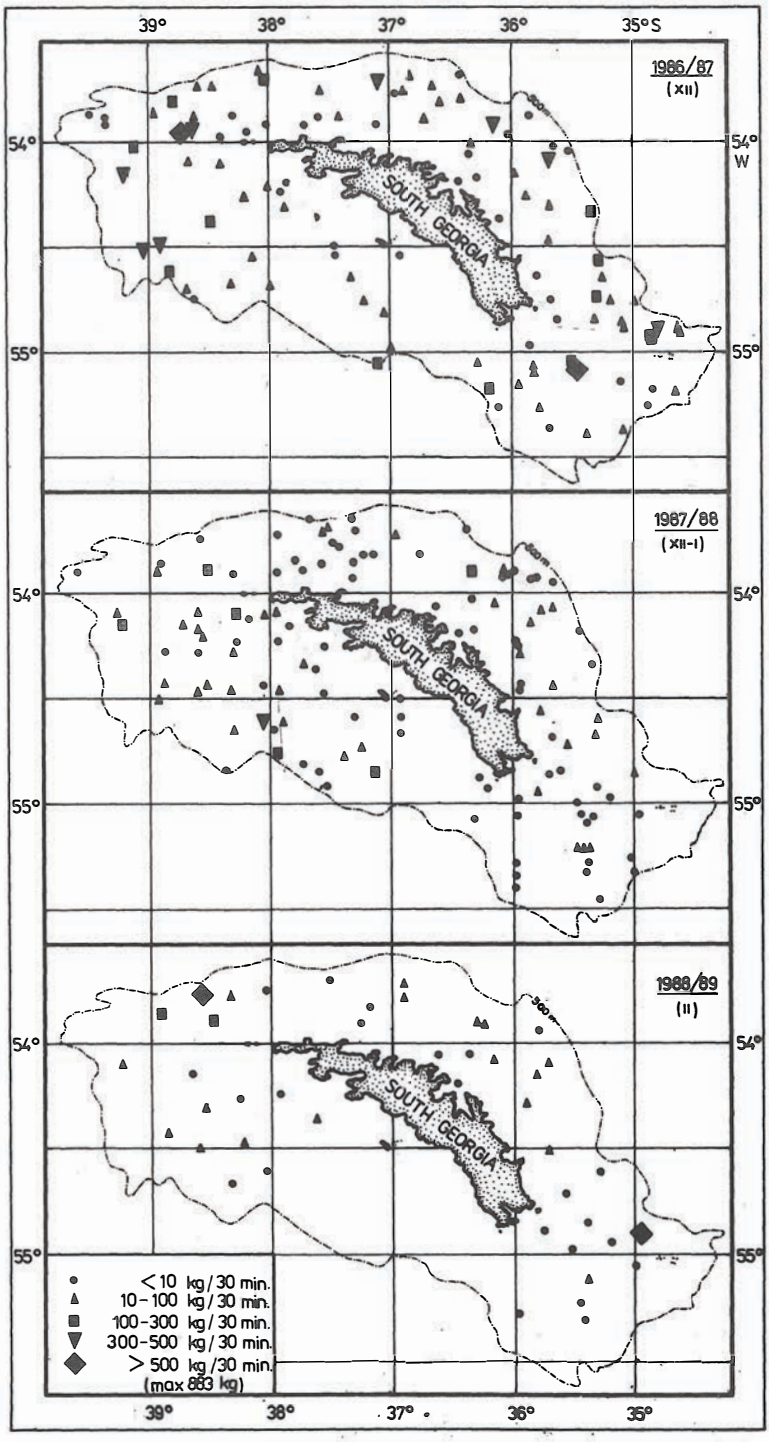

Fig. 1. Catches of *Champsocephalus gunnari* around South Georgia in the 1986/87–1988/89 RV "Profesor Siedlecki" surveys (in kg/30 minutes)

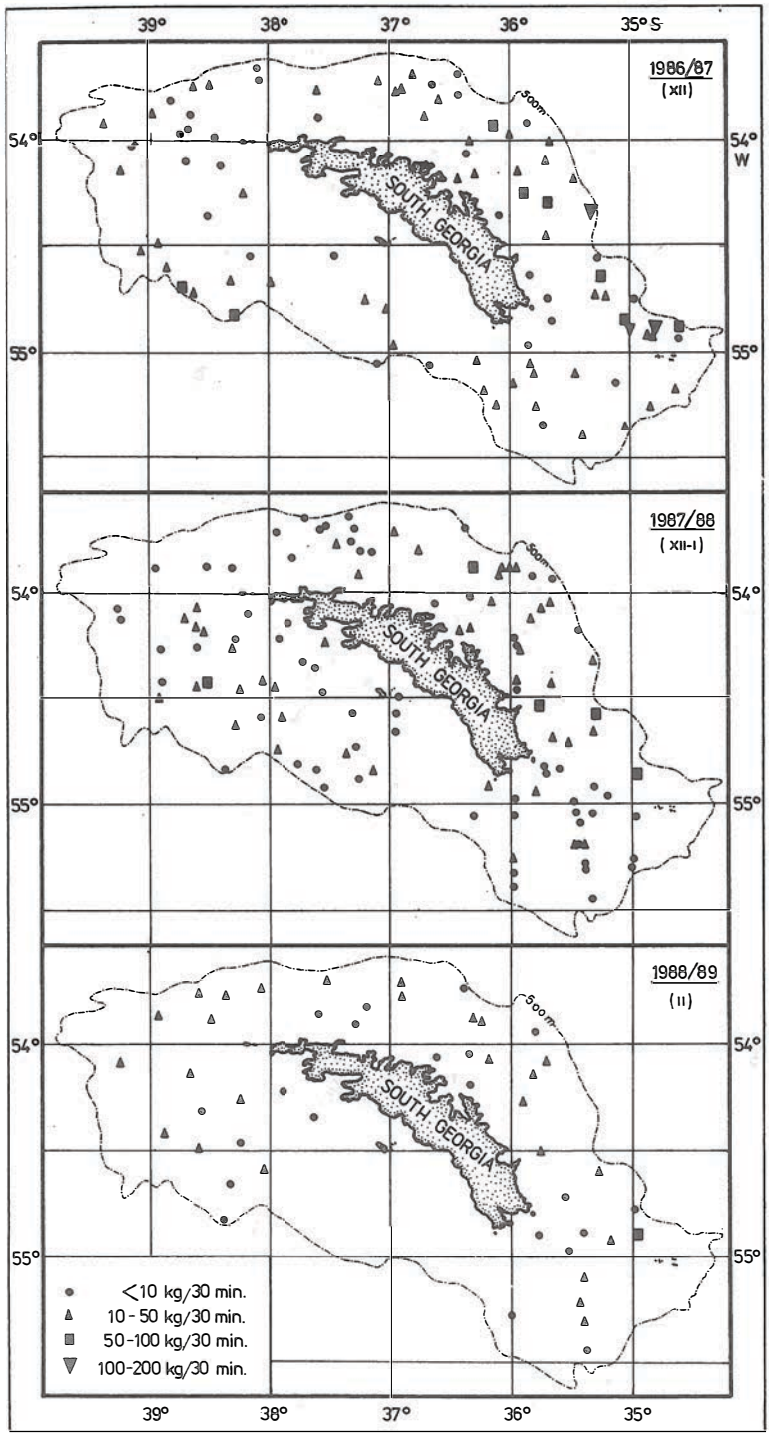

Fig. 2. Catches *Chaenocephalus aceratus* around South Georgia in the 1986/87–1988/89 RV "Profesor Siedlecki" surveys (in kg/30 minutes)

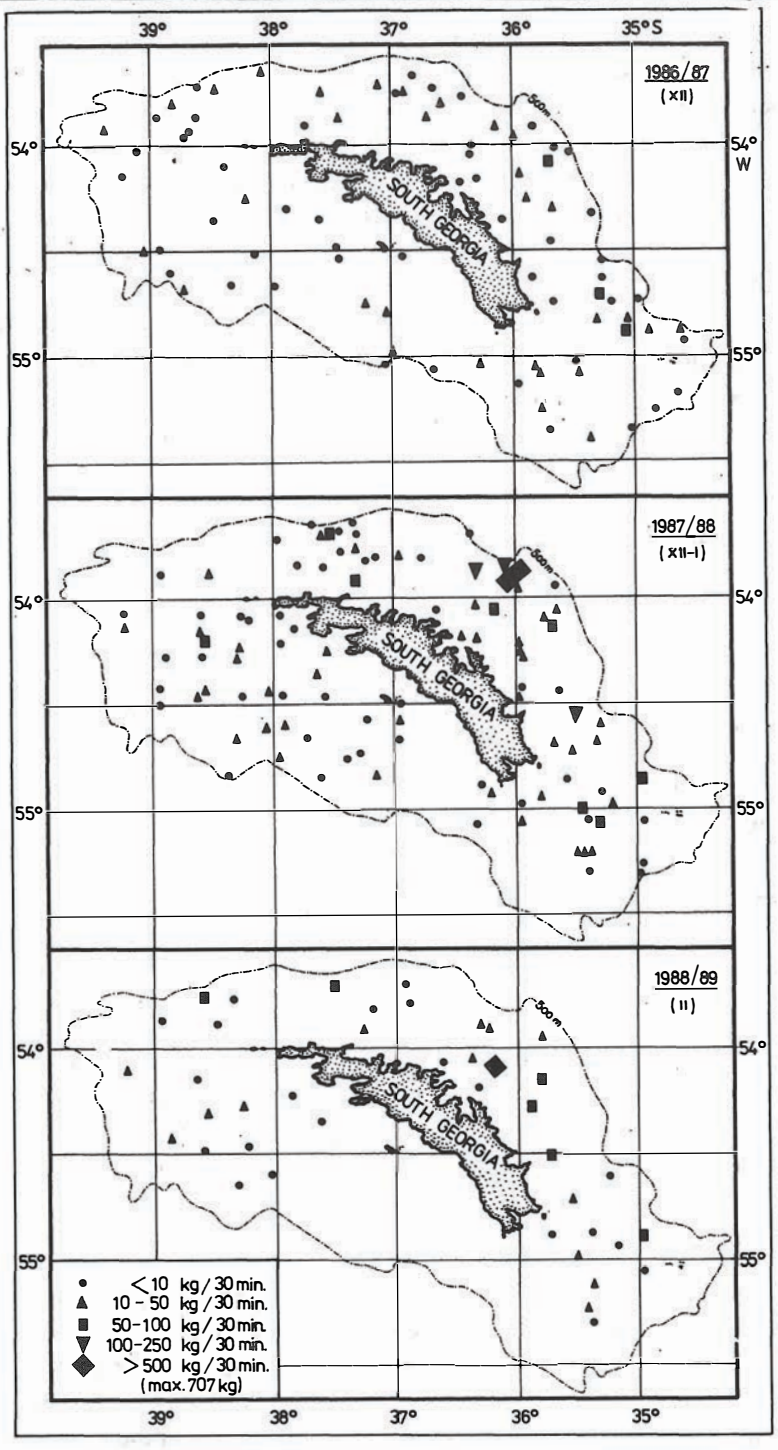

Fig. 3. Catches of *Pseudochaenichthys georgianus* around South Georgia in the 1986/87–1988/89 RV "Profesor Siedlecki" surveys (in kg/30 minutes)

found in 1986/87, and of the latter in the 1987/88 season. A group of nine species occurred regularity in the catches, sometimes constituting a significant by-catch. To these species, considered as "regular", belonged (in decreasing order of abundance): *Notothenios larseni, N. nudifrons, Muraenolepis* spp. *Parachaenichthys georgianus, Gymnoscopelus nicholsi, Pagothenia hansoni, Raja georgiana, Artedidraco mirus* and *Mancopsetta maculata antarctica.* The remaining species from *Bathylagidae, Centrolophidae, Gempylidae, Harpagiferidae, Liparididae, Paralepididae, Zaorcidae, Psilodraco breviceps, Notothenia angustifrons* and to some extent *N. kempi,* occurred rarely in the catches, usually as single specimens (only *P. breviceps* and *N. kempi* were sometimes more abundant), and were considered to be "occasionals". These species are distributed either in shallower (e.g. *Harpagifer georgianus* and *N. angustifrons*) or deeper (e.g. *N. kempi*) water, or are predominantly pelagic (the rest of listed species). Besides, the South Georgia ichthyofauna is predominated by species belonging to the *Notothenioidei* suborder, and the other species (not taking here *Myctophidae* into consideration), are rarely taken in the bottom trawl catches.

CPUE and biomass distribution

Evaluations were carried out for the following species: *Champsocephalus gunnari, Chaenocephalus aceratus, Pseudochaenichthys georgianus, Notothenia gibberifrons* and *N. rossii marmorata.*

Champsocephalus gunnari. Abundant species, widespread evenly on the shelf, occurred in 80–97% of the tows. The highest catch rates were located in the depth stratum 150–250 m (Tab. 2) and to the west and to the east of the island (Fig. 1). Catches were usually less than 100 kg/min, with a nearly equal share of the catches less than 10 kg/30 min and 10–100 kg/30 min. Large concentrations, over 500 kg/30 min, were recorded only twice, in the 1986/87 and 1988/89 seasons, with the maximum catch rate 883 kg/30 min in 1988/89.

Chaenocephalus aceratus. Abundant species, evenly distributed over the shelf, occurred in 82–87% of the tows. Catches in general were less than 50 kg/30 min, with a nearly equal share of the catches less than 10 kg/30 min and 10–50 kg/30 min (Fig. 2). Some smaller concentrations, ranging 50–100 and 100–200 kg/30 min, were recorded along the northeast side of the island in the 1986/87 and 1987/88 seasons. This species was more abundant in the depth stratum 150–250 m (Tab. 2).

Pseudochaenichthys georgianus. Abundant species, evently distributed over the shelf, occurred in 74–80% of the tows. Catches of *Ps. georgianus* were small, generally in deeper waters, 150–500 m, usually did not exceed 50 kg/30 min (Fig. 3, tab. 2). The largest, single concentrations of *Ps. georgianus* with catch rates ranging 518–707 kg/30 min were found in the 1987/88 and 1988/89 seasons north of the island.

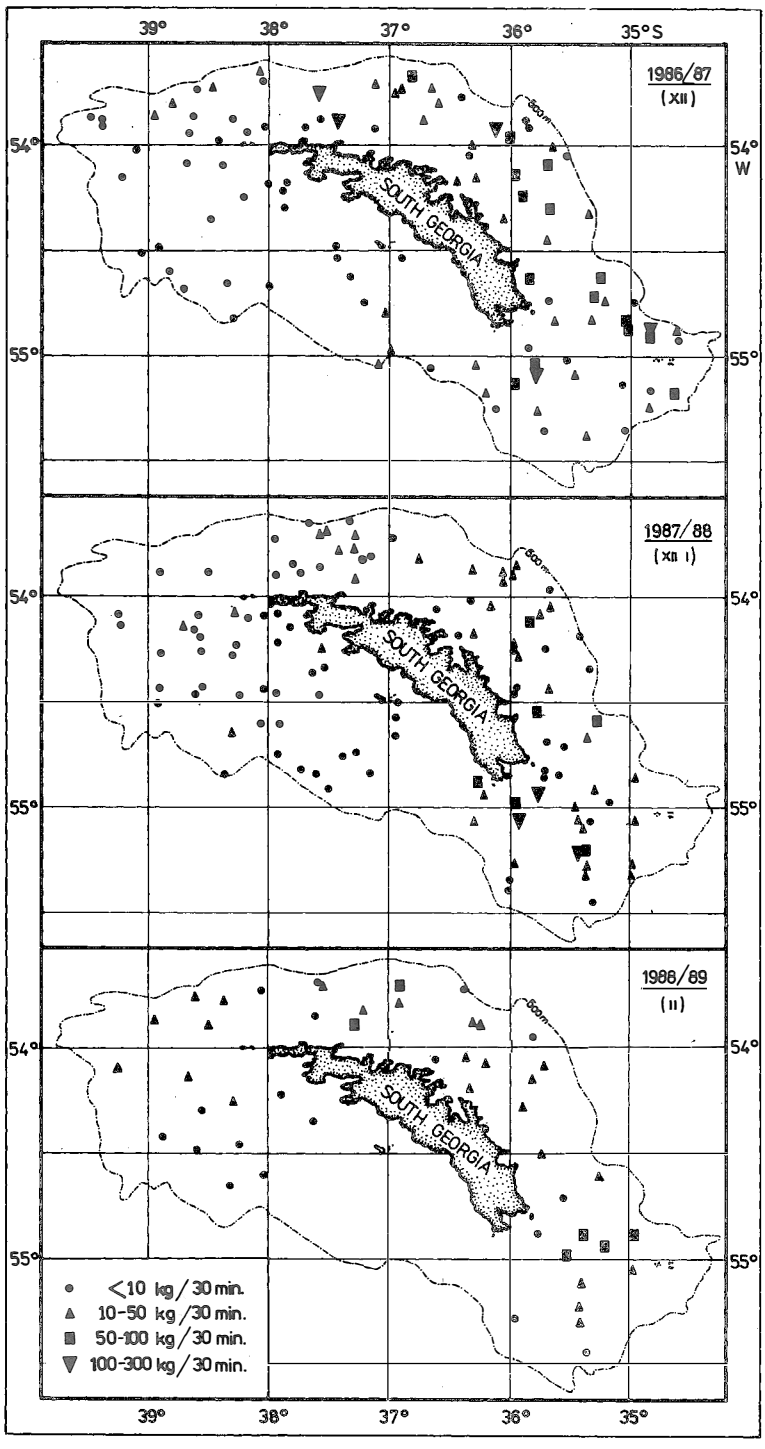

Fig. 4. Catches of *Notothenia gibberifrons* around South Georgia in the 1986/87–1988/89 RV "Profesor Siedlecki" surveys (in kg/30 minutes)

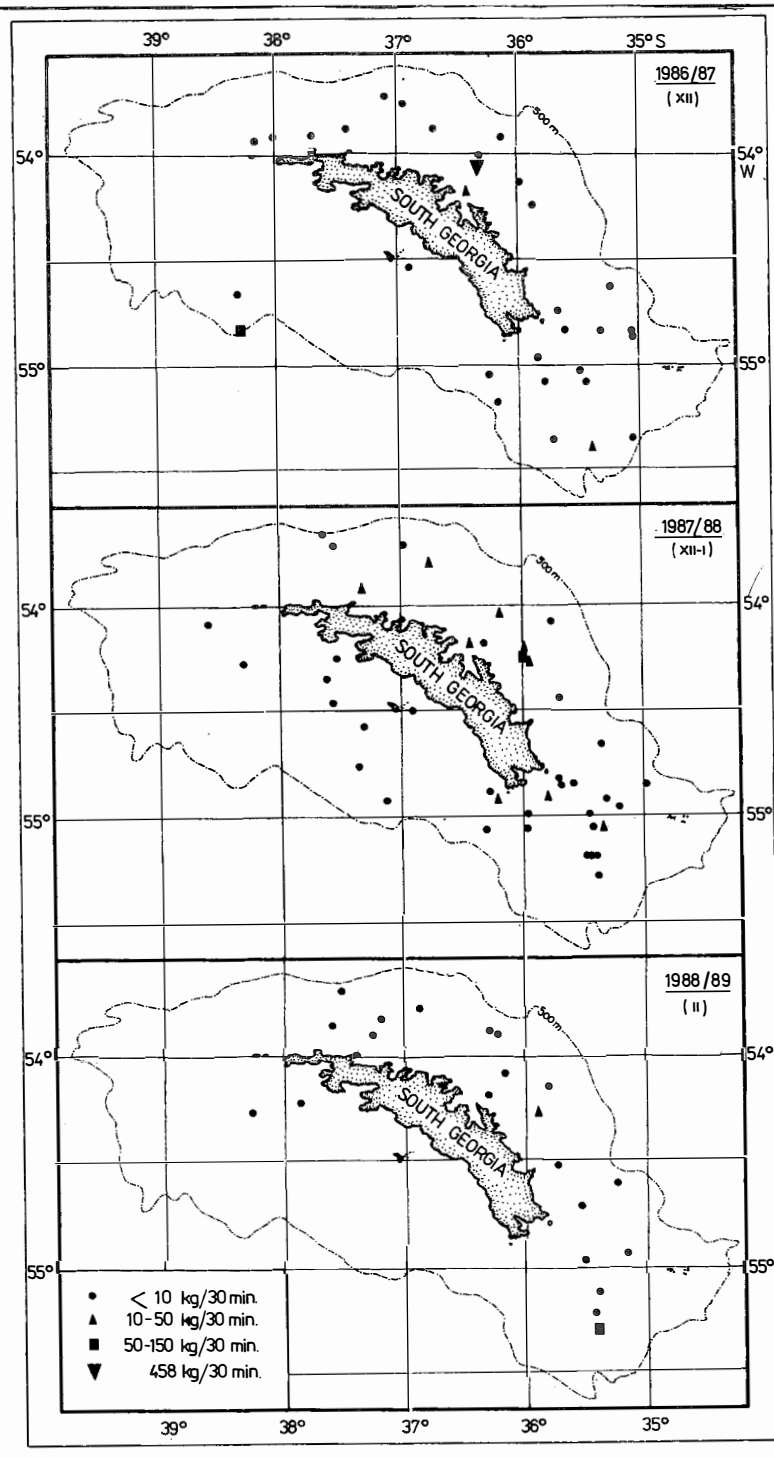

Fig. 5. Catches of *Notothenia rossii marmorata* around South Georgia in the 1986/87–1988/89 RV "Profesor Siedlecki" surveys (in kg/30 minutes)

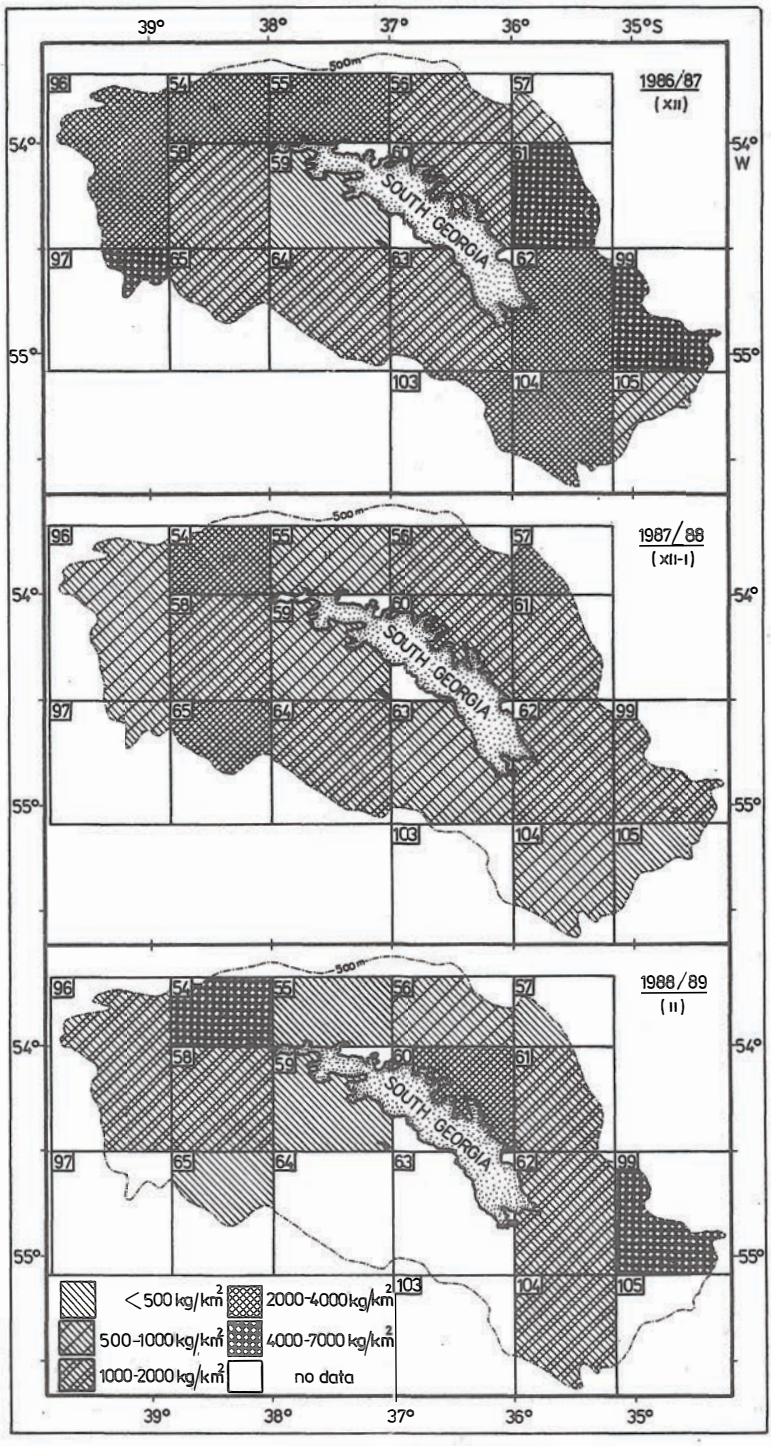

Fig. 6. Biomass distribution of the main demersal species on the South Georgia shelf in the 1986/87–1988/89 RV "Profesor Siedlecki" surveys per statistical subdivision (in kg/km^2)

Notothenia gibberifrons. It was the dominant species of notothenids, occurred in 87–94% of the tows. This species was evently distributed over the whole shelf in all depth strata, although it was more abundant in shallower waters, 50–250 m in depth (Fig. 4, Tab. 2). No area of particularly high concentrations of this species were located, however generally larger concentrations were found north and southeast of the island. The catches on the grounds west and southwest of the island were generally less than 10 kg/30 min.

Notothenia rossii marmorata. This species occurred sporadically in the catches, in 28–38% of the tows, also as a by-catch, occasionally formed single larger hauls (Fig. 5). Catches of *N. rossii marmorata* were small, usually did not exceed 10 kg/30 min (Tab. 2). The largest catch was 458 kg/30 min in 1986/87 opposite the Cumberland Bay.

The biomass density varied between 102 and 6463 kg/km^2 per statistical subdivision during the whole period of study (Fig. 6, Tab. 3). Biomas densities differed considerably in depth strata (Tab. 3). The highest mean biomass density, more than 2000 kg/km^2, was found in depth stratum 150–250 m, where the highest catch rates of the main species were recorded (Tab. 2). Except for the 1986/87 survey the second depth stratum with the highest mean biomass density was depth stratum 50–150 m, The uneven spatial biomass distribution per statistical subdivision over the whole shelf area was recorded. Slightly larger biomass densities occurred along the northwest, north and northeast side of the island (Fig. 6). The estimated biomass densities in subdivisions are directly related, and in fact, strongly influenced by high catch rates of fish in these subdivisions and its seabed areas. In 1987/88, when no particular large concentrations of fish were found (apart from *Ch. gunnari* in subdivision 65 and *Ps. georgianus* in 57), the biomass density distribution was relatively stable (Fig. 6, Tab. 3). In 1986/87 the highest biomass densities, over 4000 kg/km^2, were found in subdivisions 61, 97 and 99, and in range 2000–4000 kg/m^2, in subdivision 54, 55, 62, 96, 103 and 104 (Tab. 3, Fig. 6), where large concentrations of *Ch. gunnari* (subdivisions 54, 55, 61, 62, 96, 97, 99, 104), *Ch. aceratus* (subdivisions 61, 99), *Ps. georgianus* (subdivisions 61, 62) and *N. gibberifrons* (subdivisions 55, 61, 62, 99, 104) occurred (Fig. 1–4). In 1988/89 the highest biomass densities were recorded in subdivisions 99, 54 and 60, where large concentrations of *Ch. gunnari* (subdivisions 99 and 54) and *Ps. georgianus* (subdivision 60) occurred (Fig. 1, 3, 6).

BIOMASS OF THE MOST ABUNDANT SPECIES

The biomass estimates of the most abundant species are shown in Table 4. These five species comprised 79–90% of the total biomass estimates from each of the three cruises. The three channichthyids species made up 65–69%, with *Ch. gunnari* 37–50% share alone. This species made up about 53–77% of the biomass of the channichthyids.

Table 2

Mean CPUE (in kg/30 minutes of standardized tow and kg/km^2) of the main species in the bottom trawl catches during RV "Profesor Siedlecki" surveys in the 1986/87–1988/89 fishing seasons

Season	Stratum [m]	MEAN CPUE									
		kg/30 min					kg/km^2				
		Fish species					Fish species				
		Ch. gunnari	Ch. aceratus	Ps. georgianus	N. gibberifrons	N. rossii marmorata	Ch. gunnari	Ch. aceratus	Ps. georgianus	N. gibberifrons	N. rossii marmorata
1986/87	50–150	99	9	6	34	2	779	70	53	237	14
	150–250	336	68	26	115	1	2059	352	222	366	70
	250–500	74	40	17	49	9	649	243	155	405	37
	50–500	235	51	20	86	3	1463	267	171	347	50
1987/88	50–150	11	11	23	42	5	132	104	182	232	39
	150–250	72	35	129	46	15	980	289	445	308	63
	250–500	7	9	14	7	1	62	76	84	95	43
	50–500	44	24	80	37	9	558	193	295	237	53
1988/89	50–150	43	23	15	53	3	350	178	111	411	28
	150–250	159	35	38	46	14	1293	287	335	338	157
	250–500	6	10	88	29	1	34	65	501	228	5
	50–500	94	26	45	43	8	780	209	325	328	92

Table 3

Biomass distribution of five main species on the South Georgia shelf per statistical subdivision and depth stratum in the 1986/87–1988/89 seasons (in kg/km^2)

Square	1986/87	1987/88	1988/89
1	2	3	4
54	3102	2196	6060
55	2938	546	490
56	1392	1908	729
57	700	2363	350
58	1241	1336	1076
59	102	566	484
60	1545	1429	3003
61	4714	1936	1834
62	2312	1948	1396
63	1016	726	–

continued tab. 3

1	2	3	4
64	1466	1005	–
65	1339	3835	213
96	3154	904	1342
97	5667	696	–
99	5092	1197	6463
103	2612	–	–
104	3644	736	1261
105	731	296	–
Stratum [m]			
50–150	1154	690	1078
150–250	3068	2086	2410
250–500	1490	360	834

Table 4

Estimated fish biomass on the South Georgia shelf by the Swept Area Method in the 1986/87–1988/89 seasons (in tonnes)

Species	1986/87	1987/88	1988/89
	Seabed covered area (km^2)		
	32329	32116	26742
Champsocephalus gunnari	47312	17913	20847
Chaenocephalus aceratus	8628	6209	5589
Pseudochaenichthys georgianus	5520	9461	8697
Notothenia gibberifrons	11234	7621	8762
Notothenia rossii marmorata	1634	1699	2455
Other species	19949	5740	5183
Total biomass	94277	48643	51533

Among *Nototheniidae,* the species with the highest biomass estimates were *N. gibberifrons* (12–17%) and *N. rossii marmorata* (2–5%). Two other species of this family, having potentially, secondary commercial importance, *N. squamifrons* and *D. eleginoides,* were not usually abundant (except for *N. squamifrons* in the 1986/87 season and *D. eleginoides* in the 1987/88 season), so estimates of their biomass were low and were placed in the "Other" fish category. The biomass estimate for *N. squamifrons* in the 1986/87 season, due to two unexpectedly large catch rates, 5226 and 1438 kg/30 min, in

subdivision 65 at depth stratum 250–500 m, reached 13950 tonnes, that means 15% of the total biomass estimate. In the remaining subdivisions this species occurred sporadically, and in two following research its biomass estimates did not exceed 1%. Similarly, in the 1987/88 season, two large catch rates, 9977 and 1993 kg/60 min, of *D. eleginoides* in subdivision 57 at depth stratum 250–500 m, were recorded. These data, due to their distortion of the *D. eleginoides* results at South Georgia, were not incorporated into the biomass estimate of this species. 65–69% of the total biomass of the demersal fish on the South Georgia shelf made up channichthyids and 21–30% notothenids (of notothenids having commercial importance). The other species (excluding *N. squamifrons* and *D. eleginoides*) were very low in abundance and totalled less than 10% of total biomass estimates.

STOCK STRUCTURE

For five of the dominant species the stock structure was analyzed.

Champsocephalus gunnari. In the 1986/87 season the length distribution of fish ranged from 9 to 57 cm. In the catches predominated fish from length range 20–32 cm with modal length at 26 cm (Fig. 7). The mean length of fish was 25.8 cm. Most of fish, 95%, belonged to age groups II and III, with age group II predominance (58% of fish by numbers). The share of juveniles (age group I) in the catches was small, only 2%, but immature fish composed as many as 50% of all examined fish by numbers. In the 1987/88 season fish length ranged from 4 to 57 cm. In the length distribution dominated three length ranges: 11–18 cm, 21–27 cm and 28–40 cm with modes at 16, 23 and 32 cm representing fish from age groups I–III. The mean lenght of fish was 27.4 cm. Juveniles, newly recruited fish, 4–18 cm long (age group I), constituted 14% of examined fish by numbers. Immature fish made up as much as 32% of the catches. The rest of fish had gonads mostly at maturity stage 2. Feeding intensity of fish was low. In the 1988/89 season the length distribution ranged from 13 to 59 cm, with three length ranges dominated: 16–18 cm (15.9% of fish by numbers), 23–27 cm (36.8%), 34–37 cm (12.6%) and modes at 17, 25 and 37 cm. The mean length of fish was 26.7 cm. In the age distribution dominated young fish from age groups I–III, with age group II share reaching 50%. Sexually immature juveniles made up 39% of the catches. Over 60% of examined fish were mature specimens, with gonads at maturity stage 2 and 3. Feeding intensity of fish was low, 43% of fish had empty stomachs.

The stock of *Ch. gunnari* was strongly rejuvenated, in 1986/87 length-frequency distribution formed single peak with mode at 26 cm, to which belonged fish mostly from age group II and III, and practically no recruitment occurred. In the two following seasons strong recruitment and growth progression were observed. In the length-frequency distribution three distinctive peaks were discerned, and modal class progres-

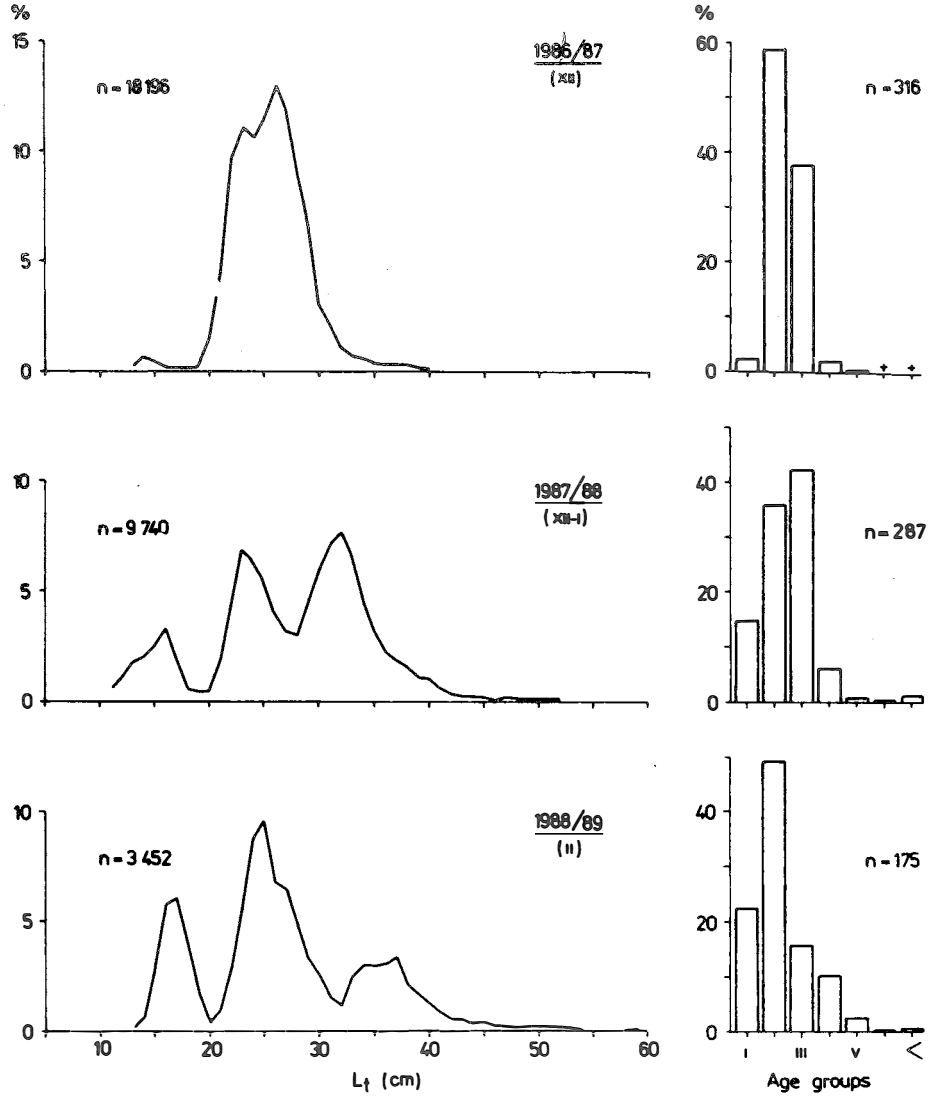

Fig. 7. Length-frequency and age distributions of *Champsocephalus gunnari* around South Georgia in the 1986/87–1988/89 RV "Profesor Siedlecki" surveys

sion beginning since 1986/87 was easily followed through. Somehow different situation in the age distribution occurred. In the 1986/87–1987/88 seasons a strong year class 1984/85 (age group II and III respectively) predominated in the catches. However, in 1988/89 a substantial decline of this year class occurred, just as a 1985/86 year class, and a 1983/84 year class in 1987/88 (Fig. 7). The age distribution indicated a substantial decline in number of fish over age group III.

Chaenocephalus aceratus. In the 1986/87season fish length ranged from 13 to 72 cm (Fig. 8). The mean length of fish was 35.0 cm. In the polymodal length distribution modes at 15, 25, 34, 42–44, 57 and 60 cm were easily discerned. The first four modes corresponded well to age groups I–IV, after which the distribution became less clear. 44% of the examined fish belonged to length range 22–29 cm, age group II. Juvenile fish, 13–37 cm in length, predominated in the catches (67% by numbers). Over 80% of fish had empty stomachs. In the 1987/88 season fish length ranged from 11 to 71 cm. The mean length of fish was 37.7 cm. The length distribution was polymodal like in previous season, but only three length ranges, 15–18 cm, 22–27 cm and 29–37 cm with modes at 16, 25 and 32 cm were easily discerned. These three modes corresponded well to age groups I–III, with the age group III share 37% (by numbers). The length distri-

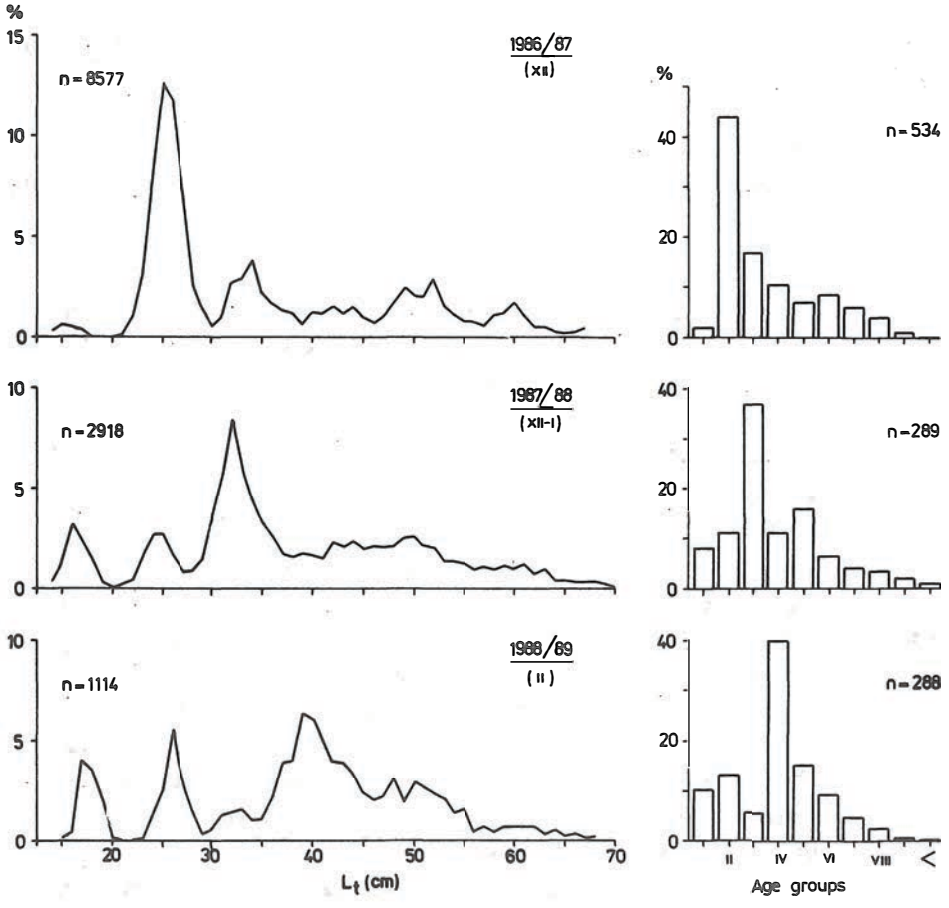

Fig. 8. Length-frequency and age distribution of *Chaenocephalus aceratus* around South Georgia in the 1986/87–1988/89 RV "Profesor Siedlecki" surveys

bution of larger fish, over 40 cm in length was rather uniform, with a small mode at 50 cm. The share of immature fish in the catches fell down to 28%, compared with 68% of mature fish with gonads at maturity stage 2. Due to regurgitation of stomach contents in the net most of fish (80%) had empty stomachs. In the 1988/89 season the length distribution ranged from 15 to 73 cm with discernible modes at 17, 26, 33, 39, 48 and 50 cm. The mean length of fish was 39.9 cm. The first four modes corresponded well to age groups I–IV, after which the distinctions became less clear. Larger fish, over 35 cm in length consisted 73% of the catches by numbers. The age composition of *Ch. aceratus* was predominated by age group IV with 40% share. 30% of the examined fish had gonads at maturity stage 1 and 60% at maturity stage 2. 88% of fish had empty stomachs.

The stock of *Ch. aceratus* was recruited in the 1986/87–1988/89 seasons by juvenile, immature fish, belonging to age groups I and II (Fig. 8). The year class 1984 (age group II in 1986/87) was especially numerous and predominated in the RV "Profesor Siedlecki" research catches in three following seasons. A progression of dominating length ranges, modal lengths and age groups through the length-frequency and age distributions of *Ch. aceratus* occurred (Fig. 8). The most easily discerned was progression of fish from length range 22–29 cm, with mode at 25 cm, belonging to age group II in 1986/87. In 1987/88 they belonged to length range 29–37 cm with modal length 32 cm and age group III, and in 1988/89 to length range 35–45 cm with mode at 39 cm and age group IV.

Pseudochaenichthys georgianus. In the 1986/87 season the length distribution ranged from 6 to 55 cm, with the dominant length ranges 30–38 cm with modal length 35 cm, and 44–52 cm with two modes, 48–49 cm and 51 cm (Fig. 9). Large fish, over 44 cm in length constituted 30% of the catches by numbers. The mean length of fish was 38.8 cm. In the age distribution of *Ps. georgianus* age groups II and III constitsuted 76% of fish, with 53% share age group II. Nearly 48% of fish were immature, mostly from length range 30–38 cm, and 44% were mature, with gonads at maturity stage 2. In the 1987/88 season fish length ranged from 8 to 57 cm and 89% of fish belonged to the length range 41–53 cm with modal length at 44 cm. The mean length of fish was 43.4 cm. In the age composition predominated age group III, with 72% share. Due to growth of fish more fish than in previous season were mature (70%), with gonads at maturity stage 2. The share of immature fish fell down to 26%. Feeding intensity of fish was low, more than 56% of fish had empty stomachs. In the 1988/89 season the length distribution ranged from 18 to 59 cm. In the catches dominated large fish, 80% of the examined fish belonged to the length range 45–52 cm with mode at 48–50 cm. The mean length of fish was 45.9 cm. Two age groups, III and IV, made up 83% of the age composition. 89% of fish were mature, 40% with gonads at maturity stage 2 and 45% with gonads at maturity stage 3. Comparing to the previous surveys the number of immature fish fell down to 11%. 50% of fish had empty stomachs, feeding intensity of the rest was low.

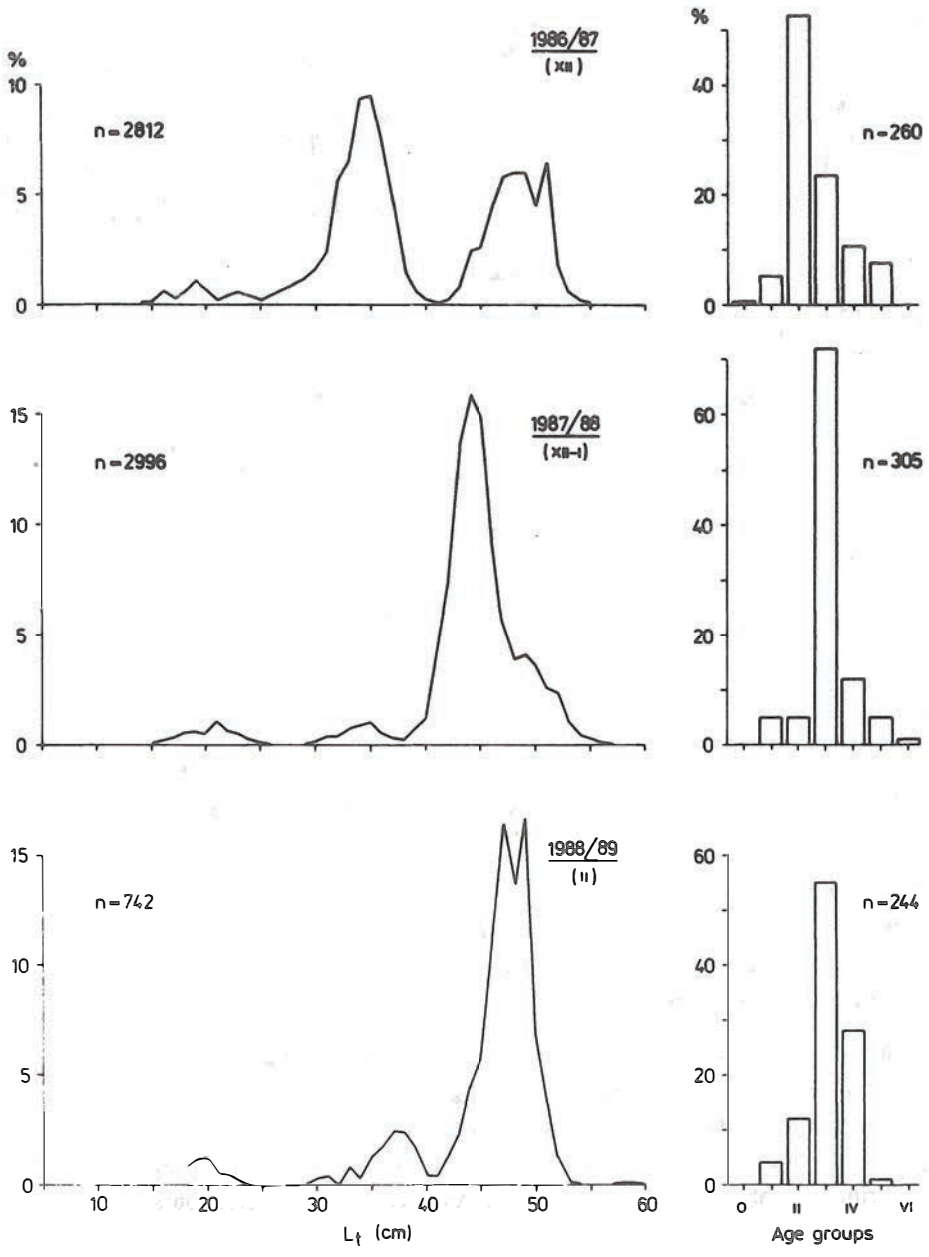

Fig. 9. Length-frequency and age distribution of *Pseudochaenichthys georgianus* around South Georgia in the 1986/87–1988/89 RV "Profesor Siedlecki" surveys

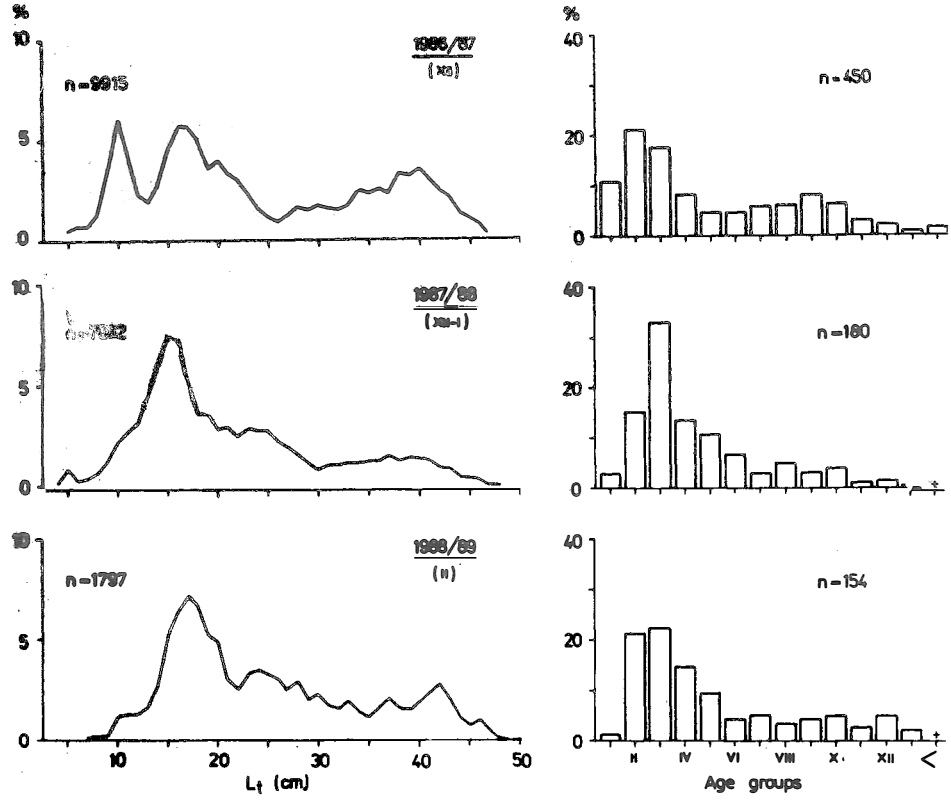

Fig. 10. Length-frequency and age distributions of *Notothenia gibberifrons* around South Georgia in the 1986/87–1988/89 RV "Profesor Siedlecki" surveys

No substantial changes in the length-frequency and age distributions of *Ps. georgianus* in the whole period of study were observed (even if a strong recruitment in 1986/87 occurred), however an increase of the mean length of fish and share of larger, mature fish in the catches is noteworthy.

Notothenia gibberifrons. In the 1986/87 season the length distribution ranged from 5 to 51 cm, with three dominant length ranges, 8–12 cm, 14–25 cm, 27–46 cm and modal lengths 10, 16 and 40 cm (Fig. 10). The mean length of fish was 24.6 cm. To the length range 9–27 cm belonged juveniles and over 30 cm in length mature fish. The age distribution ranged from age group I to XVII but predominated (56% by numbers) young, immature fish, from age groups I–IV. 37% of fish had gonads at maturity stage 2. Feeding intensity of fish was moderate, 54% of fish had stomachs filled in 2–4 degree. In the 1987/88 season the length distribution ranged from 3 to 51 cm. Predominated small fish, from length range 10–20 cm, with modal length 15 cm, so the mean length of fish, 21.5 cm, was lower than in previous season. In the age distribution the share

of young fish, from age groups I–IV, had grown, compared with previous season, to 64%. The fish belonging to age group III made up 33% of the catches by numbers. The share of age groups II and IV was 15 and 13% respectively. 60% of the examined fish were immature. Feeding intensity was low, 40% of fish had empty stomachs. In the 1988/89 season fish length ranged from 7 to 50 cm with the mean length 25.0 cm. Similarly like in two previous surveys in the catches predominated small, immature fish. The share of larger fish, over 35 cm in length was small (21%). In the length distribution dominated three length ranges, 14–22 cm with mode at 17 cm (44% of fish by numbers), 23–39 cm (37% of fish) and 40–43 cm with mode at 42 cm (9%). Fish from

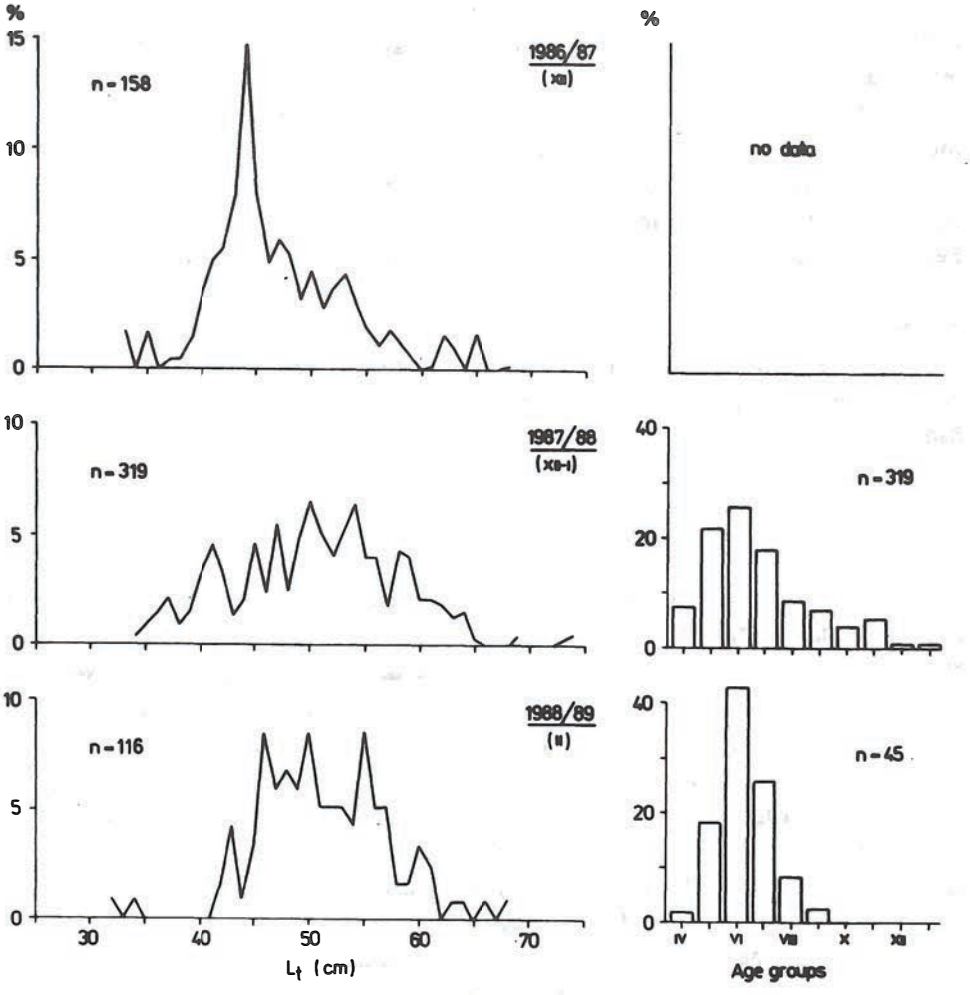

Fig. 11. Length-frequency and age distribution of *Notothenia rossii marmorata* around South Georgia in the 1986/87–1988/89 RV "Profesor Siedlecki" surveys

age groups II–IV constituted 58% of the catches. 64% of the examined fish were immature and 33% had gonads at maturity stage 2. Feeding intensity of fish was moderate, 52% of fish had stomachs filled in stage 2–4, and only 15% had empty stomachs.

The stock of *N. gibberifrons* was strongly rejuvenated, the share of immature fish ranged in succeeding seasons from 56 to 64%, but recruitment was only observed in 1986/87. In the two following seasons a slow increase of the size of fish was observed (even if a drop of the mean length of fish in 1987/88 occurred, partly connected with the decrease of share of larger fish, 33–45 cm in length, in the catches), due to a growth progression of fish from dominating length range, 8–25 cm, age group I–IV in 1986/87.

Notothenia rossii marmorata. In the 1986/87 season the length distribution ranged from 27 to 68 cm, with modal length 44 cm and the mean length 47.7 cm (Fig. 11). In the catches predominated fish from length range 39–55 cm. All the examined fish were mature, with gonads at maturity stage 2 (44%) and 3 (56%). Feeding intensity of fish was high, 58% had stomachs filled in 3–4 degree and 23% in 2 degree. In the following season the length distribution ranged from 34 to 74 cm, with the mean length 50.2 cm. Predominated fish from length range 45–58 cm and age groups V–VII. 95% of the examined fish were mature specimens, with gonads mostly at maturity stage 2. Feeding intensity of fish was low. In the 1988/89 season fish length ranged from 32 to 68 cm, with mean length 51.4 cm. Modes were impossible to distinguish, 75% of caught fish belonged to length range 46–57 cm. The examined fish were IV–IX years old, with the bulk of fish V–VII years old. All examined fish were mature, with gonads in equal share at maturity stage 2 and 3. Feeding intensity of fish was moderate, 55% of fish had stomachs filled in 2–4 degree.

DISCUSSION

There have been a number of attempts to estimate the biomass of fish stocks off South Georgia with the Swept Area Method (Kock 1981, 1986, Mucha 1984, Ślósarczyk et al. 1985, Balguerias et al. 1987, Mucha and Ślósarczyk 1988). These estimates yielded acceptable results but in most cases are incomparable with each other because of some differences in the methods used (e.g. type of gear used), the sources of information serving for estimates (research or commercial catches), subdivisions and seabed area covered during survey. The present study isbased on the results from the surveys of RV "Profesor Siedlecki". The surveys were conducted in three consecutive fishing seasons, 1986/87–1988/89, applying one type of gear, one method of fishing, covering similar station localizations and seabed area.

Since 1976/77 the mackerel icefish, *Champsocephalus gunnari,* has been a principal species in the fishery around South Georgia. Due to heavy fishery, high fishing mortality and large variations in year class strength, the catches have fluctuated

Table 5

Biomass estimates of the main fish species off South Georgia, calculated using the Swept Area Method in the 1975/76–1988/89 seasons (in tonnes)

Season	FISH SPECIES					Source
	Ch. gunnari	Ch. aceratus	Ps. georgianus	N. gibberifrons	N. rossii marmorata	
1975/76	141469	18719	36401	40094	35682	Kock et al. 1985
1976/77	226606	7595	23210	22339	37928	Ślósarczyk et al. 1985
1976/77	110212	3684	11291	10909	18979	Mucha & Ślósarczyk 1988[1]
1977/78	34713	18399	31057	20100	9326	Kock et al. 1985
1977/78	2372	5192	39703	19989	5606	Ślósarczyk et al. 1985
1977/78	1297	2934	25017	10285	3507	Mucha & Ślósarczyk 1988
1978/79	1152	4047	4192	5984	1421	Ślósarczyk et al. 1985
1979/80						
1980/81	88414	7720	8717	13693	2327	Ślósarczyk et al. 1985
1980/81	77306	4550	5202	8896	1661	Mucha & Ślósarczyk 1988
1981/82	46192	10013	16940	25801	34284	Ślósarczyk et al. 1985
1981/82	17268	3721	6199	9739	12888	Mucha & Ślósarczyk 1988
1982/83						
1983/84	15575	8170	24452	4427	964	Mucha & Ślósarczyk 1988
1984/85	15821	11542	8134	15762	12718	Kock 1986
1984/85	2699	14415	15088	11337	29065	Mucha & Ślósarczyk 1988
1985/86	27476	10667	9806	11141	3483	Mucha & Ślósarczyk 1988
1986/87	151293	2659	2010	3252	11471	Balguerias et al. 1987[2]
1986/87	80341	18576	–	11356	312	Mucha & Ślósarczyk 1988
1986/87	47312	8628	5520	11234	1634	This paper
1987/88	17913	6209	9461	7621	1699	This paper
1988/89	20847	5589	8697	8762	2455	This paper

[1] Commercial fishery data, northeastern fishery grounds, subdivisions 56, 57, 60–62.

[2] Semipelagic trawl

strongly, and the stock of *Ch. gunnari* has undergone considerable changes in biological structures (strong rejuvenation) and stock size. In the course of the fishery the mean length and age of fish has declined considerably and the fishery has depended on the recruiting year class, attaining the first maturity (Kock 1985, 1986, 1991, Sosiński 1985, Ślósarczyk et al. 1985, Mucha and Ślósarczyk 1988). Within the past fishing seasons several periods with high biomass of *Ch. gunnari* resulting in stock size recovery were observed (Tab. 5) (Mucha and Ślósarczyk 1988, Kock and Kōster 1989, Kock 1991). However, not only the direct impact of the fishery may cause the variability

of the stock size of *Ch. gunnari,* the natural reasons may play a role as well. It has been found that a part of the population of *Ch. gunnari* at South Georgia does not spawn each year (Sosiński 1985, Kock and Kellermann 1991). This, and possibly a higher natural mortality, may be caused by the low krill abundance at the island. Besides, according to Kock and Kōster (1989), recruitment of *Ch. gunnari* is less affected by the decline of the spawning stock size. During the RV "Profesor Siedlecki" surveys young fish, from age groups I–III predominated in the catches. The share of immature fish in the catches was high, ranging 32–50% by numbers, in spite of the mean lengths of fish (25.8–27.4 cm) were above the length at first maturity L_{50}, equal 24 cm for *Ch. gunnari* at South Georgia (Sosiński 1985), or the length at first spawning, 25 cm (Kock and Kellermann 1991: Fig. 4). A slight increase in the average fish size was observed and the length-frequency distribution which had been composed of one peak in 1986/87 became to polymodal, with three distinctive peaks in 1988/89. However, the catches were usually made up only of two age groups, II and III. In 1987/88 and 1988/89, when strong recruitment occurred, the share of fish from age group I had grown siginificantly in the catches (Fig. 1). The age distribution in 1988/89 had a more stable structure compared with the two previous seasons, but a substantial decline of the share of fish over age group III in the catches indicates high mortality. With respect to the biomass estimates of *Ch. gunnari* the highest value, 47.000 tonnes was obtained for the 1986/87 season. In the next two seasons more than a twofold decrease of biomass was recorded (Tab. 4). In the 1986/87 season three independent biomass estimates of *Ch. gunnari* at South Georgia were available (Balguerias et al. 1987, Mucha and Ślósarczyk 1988, RV "Profesor Siedlecki" survey – this paper) (Tab. 5). The highest result, 151.000 tonnes, assumed as valid by the CCAMLR Working Group on Fish Stock Assessment (Kock and Kōster 1989), was estimated during the Spanish survey, when a high-opening semipelagic trawl was used. Such type of trawl gives larger, and probably more realistic biomass estimates of *Ch. gunnari,* as the species tends to keep in the water column above the bottom. Also catches of *Ch. gunnari* reported in the 1986/87–1988/89 seasons (1986/87–71.151 tonnes, 1987/88–34.619, 1988/89 – 21.359, Anon. 1991) were well above, or close, to the biomass estimated in the RV "Profesor Siedlecki" surveys. A trial biomass estimate of *Ch. gunnari* by the Swept Area Method using a mid-water trawl suggested a conversion factor of 2.5–3.0 to adjust biomass estimates from bottom trawl surveys (Ślósarczyk et al. 1985, Mucha and Ślósarczyk 1988). Thus, such adjustment makes estimates more reliable, but their application to management decisions should be treated with caution. The accuracy of biomass estimations of *Ch. aceratus, Ps. georgianus* and *N. gibberifrons,* species with more even distribution and benthic ways of life, are more precise in bottom trawl surveys (Mucha 1984, Ślósarczyk et al. 1985).

These three abundant species, *Ch. aceratus, Ps. georgianus* and *N. gibberifrons,* are regular by-catch species (Tab. 1) and were important in one season or another but could not support a commercial fishery on their own.

The general pattern of growth and exploitation of *Ch. aceratus* in the 1976/77–1987/88 seasons is well shown by Kompowski (1990a, b) and supplemented with recent data and VPA analysis by Kock (1991). The South Georgia stock of *Ch. aceratus* has been under the constant impact of the fishery since the mid of 1970's. The pressure of the fishery caused considerable reduction of larger, mature fish, over 55–60 cm in length (mostly females), and, at the same time, significant in some seasons the by-catch of immature specimens less than 34 cm in length. The biomass of *Ch. aceratus* stock was reduced to about 40% of its initial 1975/76 level (Kock 1986). According to Kompowski (1990a) the stock size of *Ch. aceratus* fluctuates depending on the strength of the year classes recruiting into the stock, and Kock (1991) stated that an almost linear stock-recruitment, relationship in *Ch. aceratus* was apparent from VPA analysis. Results from the 1986/87–1988/89 surveys indicate an increase in the mean length of fish and occurrence of the recruitment, but still only one, the strong 1984 year class (age group IV in 1988/89) predominated in the catches (Fig. 8). The increase in the mean length of fish, ranging from 35.0 to 39.9 cm in succeeding seasons, accompanied by a decline in the share of immature fish (from 67 to 30%) and an increase of larger fish, over 35 cm in length (from 35 to 73%) in the catches, is particularly important as a sign of an increase in the mature part of the stock. Especially, that according to Kock (1981) the length at sexual maturity (L_{50}) is for *Ch. aceratus* males and females 46.3 and 46.8 cm respectively, whereas Kock and Kellermann (1991: Fig. 4) report the length at first spawning at about 46 cm for males and as much as about 57 cm for females. Kompowski (1990b) reports a much smaller L_{50}, 35 cm for both sexes. However, the observed increase in the proportion of larger fish in the stock was not apparent from biomass estimates. The biomass estimates were less optimistic, showing the opposite trend, a decline (Tab. 4). The 1986/87 season was the last one considered by Mucha and Ślósarczyk (1988) with their biomass calculations being based on commercial data brought forward (Tab. 5). According to them, the stock of *Ch. aceratus* was improving, having reached a biomass level over 18.000 tonnes (compared with 8.600 tonnes from the RV "Profesor Siedlecki" survey), and therefore limitation of the catches of this species was not necessary. Also Kock (1991) indicates the possibility of the *Ch. aceratus* stock size increase.

Similarly, the biomass of *Ps. georgianus* in the mid of 1980s wa equal to only about 25% of its 1975/76–1977/78 levels (Tab. 5) (Kock 1986), although the length-frequency distributions did not exhibit substantial changes (Kock 1991). At the beginning of the exploitation, large fish, over 45 cm in length, from age groups V–XII occurred in the catches (Mucha 1980, Ślósarczyk et al. 1985). In the course of the fishery the average length of fish had decreased, and smaller, younger fish (from age groups II–IV) appeared in the catches, but the size distribution did not differ greatly. In the RV "Profesor Siedlecki" catches, except in the 1986/87 survey, when smaller fish, from length range 30–38 cm, were numerous, dominated large fish, over 41 cm in length,

(Fig. 9). Due to the length progression, the mean length of fish examined in the 1988/89 season, 45.9 cm, was above the length at first spawning, equal about 43 cm (Kock and Kellermann 1991: Fig. 4). The biomass estimates for *Ps. georgianus,* even with a rather low value in 1986/87, indicate a substantial decline in stock biomass compared to 1975/76–1977/78, but a relatively stable biomass level during the 1980s (Tab. 4 and 5).

N. gibberifrons is a third by-catch species influenced by the fishery. According to Mucha and Ślósarczyk (1988), basing on the commercial catches, this species is characterized by stable biomass density and relatively stable biomass estimates. They did not see the need for limitation of the catches of this species, contrary to Kock (1986, 1991) who reported a substantial decline in the stock biomass (Tab. 5). The biomass of *N. gibberifrons* estimated in the 1986/87 survey was similar to the estimate of Mucha and Ślósarczyk (1988) for the same season (Tab. 5). The subsequent decline and increase of the biomass in the two following seasons probably reflected the changes in the stock structure, rejuvenation in 1987/88, and slight increase of the average size of fish in 1988/89 (Fig. 10). Even if biomass estimates differed, the changes in biological structure of the stock, decrease of mean length and increase in the catches the share of smaller fish, were reported since the end of the 1970s (Skóra 1980). In the RV "Profesor Siedlecki" catches predominated small, less than 30 cm in length, immature fish (Fig. 10). The mean lengths of examined fish ranged 21.5–25.0 cm in succeeding seasons, and were much below the length at first maturity (L_{50}) – 37.5 cm (Kompowski 1983) or the length at first spawning – 34 cm (Kock and Kellermann 1991: Fig. 4). Mucha and Ślósarczyk (1988) reported for the 1985/86 season the mean length of fish at 38 cm, compared with 24.6 cm in the 1986/87 RV "Profesor Siedlecki" survey. However, the differences in length-frequency distributions and mean lengths between data from research surveys and commercial fishery, are to some extent affected by closing for the fishery shallow water grounds (50–150 m depth), within 12 miles around South Georgia, where smaller fish predominate.

The estimated biomass of *N. rossii marmorata,* ranging 1634–2455 tonnes (Tab. 4), showed decline, comparing to previous data (Tab. 5). The patchy, uneven distribution of this species over the shelf, in relation to the smaller number of hauls in which *N. rossii marmorata* occurred (Fig. 5) has considerable influence on the stock size estimates. Length-frequency and age distributions (Fig. 11) were comparable to those from 1974/75–1985/86 (Ślósarczyk et al. 1985, Kock 1991). The history of exploitation of this remarkable, severely affected by the fishery species, has focused much attention and analysis. In the very recent review, Kock (1991) stated that the stock size could double from the present level, 3–5% of its pristine stock size (Kock and Kōster 1989) by 1995/96, if recruitment remains at the present level (or even allowing its 50% reduction) but catches (or rather by-catches) stay well below 1000 tonnes (now 300–600 tonnes).

Although the fish stock biomass estimates based on commercial data (Mucha 1984, Mucha and Ślósarczyk 1988) usually differed from research data (Kock 1986, Kock and Kōster 1989, this paper), the changes in the biological characteristics of the fish stocks at South Georgia were obvious. The mean length and age of caught fish has decreased, and the share of immature fish in the catches has increased. The mean length of fish which occurred in the RV "Profesor Siedlecki" catches were close, or even smaller than the length at sexual maturity (L_{50}) or length at first spawning. Similar observations were reported both from commercial and research catches since the end of the 1970s (Kock 1985, Sosiński 1985, Ślósarczyk et al. 1985, Kock 1986, 1991). However, if a slow increase of the mean length of fish and size progression, observed during the 1986/87–1988/89 research would remain in progress in the following seasons, it could be a promising indication of the beginning of the slow recovery of fish stocks. Also the conservation measures established by CCAMLR to protect fish stocks at South Georgia, as discussed by Kock (1985, 1986, 1991) in a series of papers, and by Kock and Kōster (1989), should secure this process.

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Józef SOSIŃSKI, Jacek SZLAKOWSKI

CHARAKTERYSTYKA BIOLOGICZNA I OCENA BIOMASY STAD RYB SZELFU GEORGII POŁUDNIOWEJ W SEZONACH 1986/87–1988/89

STRESZCZENIE

Podczas trzech kolejnych rejsów RV "Profesor Siedlecki" w sezonach 1986/87–1988/89, na łowiskach Georgii Południowej (Antarktyka) badano stan zasobów ryb. W połowach odnotowano obecność 32 gatunków ryb,

należących do 15 rodzin (Tab. 1). Do gatunków mających znaczenie użytkowe należały: kergulena *Champsocephalus gunnari*, borel *Chaenocephalus aceratus*, georgianka *Pseudochaenichthys georgianus* i nototenia żółta *Notothenia gibberifrons*. W połowach rzadko, i w niewielkich ilościach występowała także nototenia marmurkowa *Notothenia rossii marmorata*, podstawowy niegdyś gatunek w połowach przemysłowych na szelfie Georgii Południowej (Tab. 2–5, Fig. 1–6). Zmiany w strukturze biologicznej stad ryb czterech gatunków ryb użytkowych wskazują na postępujące ich odmłodzenie, związane z uzupełnianiem stad przemysłowych przez ryby młodociane (Fig. 7–10). Obserwowane uzupełnienie nie skompensowało jeszcze ubytków z lat poprzednich wywołanych silną presją rybołówstwa, a także przyczynami naturalnymi, powodującymi znaczne wahania obfitości pokoleń (czynniki hydrologiczne, obecność lub brak skupisk kryla). Jednakże, wobec praktycznego zamknięcia łowisk Georgii Południowej dla rybołówstwa, można oczekiwać powolnej odbudowy stad ryb. Brak jest jednak, pomimo podjęcia środków ochronnych, oznak odbudowy stada nototenii marmurkowej (Fig. 11). Jego biomasa utrzymuje się nadal na bardzo niskim poziomie (Tab. 5).

Authors' addreses:

doc. dr hab. Józef Sosiński
Sea Fisheries Institute
ul. Kołłątaja 1
81-332 Gdynia
Polska (POLAND)
mgr inż. Jacek Szlakowski
Department of Biological Resources of Sea
ul. Kazimierza Królewicza 4
71-550 Szczecin
Polska (POLAND)

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