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State of mackerel icefish (*Champsocephalus gunnari* Lonnberg, 1905) stock from South Georgia area based on Polish biological investigations in 1975–1992

ABSTRACT: Results of Polish biological investigations and surveys on the state of mackerel icefish (*Champsocephalus gunnari* Lonnberg, 1905) stock served to undertake an attempt at an independent estimation of some of its biological parameters as well as at the assessment of its biomass and fishing mortality during 1975/76–1991/92 fishing seasons with virtual population analysis (VPA) method (using MAFFVPA programme). Laurec-Shepherd and hybrid methods were applied for the VPA tuning. Von Bertalanffy equation parameters were estimated and compared with those published earlier. $F_{0.1}$ and F_{max} values were assessed using Beverton and Holt model and Thompson and Bell method. Based on data from available literature the coefficient of natural mortality (M) was assumed to be 0.5. VPA results indicate that the total stock biomass (TSB) during the last 1991/92 season amounted to 34,818 tonnes and was approximately 10 times lower than in 1975/76 season. Spawning stock biomass (SSB) declined to a minimum of 7,396 tonnes in 1989/90 season. The assessment results point out to the recruitment as a major factor contributing to the stock fluctuations.

Key words: Antarctic, South Georgia, mackerel icefish, assessment, biomass.

Introduction

In the Atlantic sector of Antarctica one of the most important fisheries areas is the South Georgia shelf (Fig. 1). Polish investigations of fish resources of that area started in 1976 (Rakusa-Suszczewski 1978, Linkowski and Rembiszewski 1978), while Polish fishing vessels began their commercial operations in January 1977 (Sosiński and Kuranty 1979). The whole period of the fishing activity has been accompanied by continuous monitoring of the exploited commercial species stocks state. One of the most important commercial species in that area with respect to the size of the stock biomass is mackerel icefih (*Champsocephalus gunnari* Lonnberg, 1905).

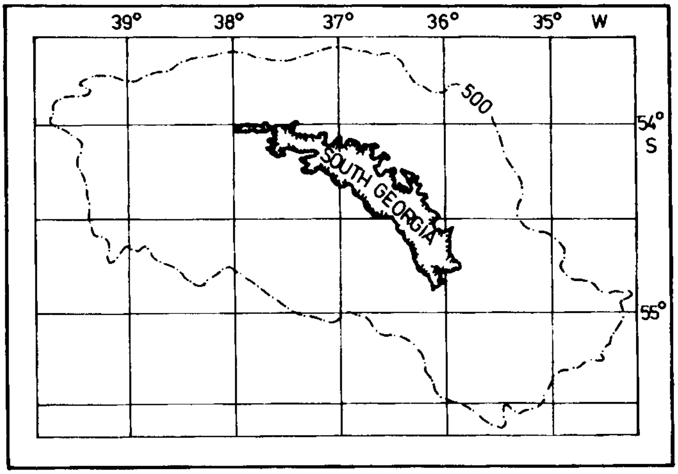


Fig. 1. South Georgia and its shelf.

This work is aimed at an assessment of the stock state changes as well as its biomass fluctuations based on results of Polish biological investigations of that species.

Material and methods

The published (Sosiński 1981, 1985a, 1985b, 1990, Ślósarczyk et al. 1984, Mucha and Ślósarczyk 1988, Sosiński and Szlakowski 1992) and unpublished (Cielniaszek, Szlakowski and Traczyk, unpubl.; Cielniaszek and Szlakowski, unpubl.) results of Polish biological and fisheries investigations on mackerel icefish from the South Georgia stock have been used. International catch statistics on icefish originate from the Statistical Bulletin of CCAMLR (Anon. 1990, 1993). Statistics of Polish icefish catches and Polish fishing vessels catch rates of that species were derived from Statlant A and B forms available from the Sea Fisheries Institute in Gdynia, as well as from unpublished data.

Biological and fishing data were collected both from Polish commercial fishing vessels cruises attended by a research team of the Sea Fisheries Institute in Gdynia as well as during surveys conducted from the Sea Fisheries Institute Research vessel R/V "Profesor Siedlecki" and from the British owned R/V "Hill Cove" and R/V "Falklands Protector".

The survey data were gathered during the following research cruises:

— R/V "Profesor Siedlecki" in 1975/76, 1978/79, 1986/87, 1987/88, 1988/89. Cruises in 1986/87 and 1987/88 were carried out jointly with the Northeast Fisheries Center (National Marine Fisheries Service, NOAA), Woods Hole, USA;

— R/V "Hill Cove" in 1989/90;
— R/V "Falklands Protector" in 1990/91 and 1991/92.

Cruises in 1988/89—1991/92 were conducted in collaboration with Imperial College of Science and Technology, University of London, UK.

Commercial fishery data originated from Polish Deep Sea Fishing Company "Dalmor" vessels: M/T "Gemini" in 1976/77 and 1977/78; M/T "Rekin" in 1976/77; M/T "Sirius" in 1977/78 and 1978/79; M/T "Libra" in 1980/81; M/T "Neptun" in 1981/82; M/T "Taurus" in 1983/84 and M/T "Carina" in 1985/86.

The biological data collection based on random sampling procedures comprised length (total, to one centimeter below) measurements and detailed biological analysis. Age was determined from otoliths. The transition date from one age group to another was set on 1 July. The resulting length distributions, mean weights and age — length keys calculated on year basis were used to convert total international catches, Polish catches, Polish commercial CPUE and swept area biomass estimates into numbers. Length-weight relationship was determined and mean weights at lengths were calculated. They were used subsequently to estimate overall annual mean weights by multiplying the weights and frequencies in each length-class in successive years. Since no biological data on icefish were collected by Poland both in 1979/80 and 1982/83 — the lacking age distributions have been estimated from USSR length distributions shown in Kock (1991) and applying Polish age-length key of 1983/84.

Von Bertalanffy growth function parameters were calculated with FISHPARM program using mean length at age from 1983/84 — 1988/89 seasons. Yield per recruit, $F_{0.1}$ and F_{max} were calculated both using Thompson and Bell method (Ricker 1985) as well as applying Beverton and Holt (1957) model. The latter served as a basis for ploting yield isoplethes.

Fishing mortality, total and spawning stock biomass changes in 1975/76 — 1991/92 were estimated using virtual population analysis (VPA). Tuning was conducted with Laurec-Shepherd and hybrid (Pope and Shepherd 1985) methods. It was decided to use two fleets for tuning: Polish catch — effort data and swept area biomass estimates (Tab. I). Since both sets were lacking data in some years (but not necessarily the same) they had to be completed using the existing information from the other set or on basis of the total catch changes. In few other instances the data in a set had to be corrected due to their departure from an expected trend seen in two other sets of data. The thumb rule accepted in this procedure was to increase or decrease the uncertain value by 75% of the change observed in one of the two other sets (Tab. I).

Separable VPA was attempted but not being able to find a rational to choose between different sets of selection factors the approach has been abandoned. Accordingly further calculations of yield per recruit with

Table I

Data on mackerel icefish catches, CPUE and swept area biomass estimates used for assessment.

Fishing season	International catches	Polish catches	Share of Polish catches	Polish commercial CPUE	Survey CPUE	CPUE estimates used for tuning	Swept area biomass estimates	Biomass estimates used for tuning
	(tonnes)	(tonnes)	(%)	(t/d)	(t/h)	(t/d)	(tonnes)	(tonnes)
1975/76	12290	5	0.04	–	0.167	1.9	–	49.8
1976/77	93400	3185	3.41	10.8	–	10.8	226.6	226.6
1977/78	7557	2069	27.38	1.2	–	1.2	2.4	25.2
1978/79	641	110	17.16	0.3	–	0.3	1.2	12.2
1979/80	7592	753	9.92	1.1	–	1.1	–	25.3
1980/81	29384	9166	31.19	8.9	–	8.9	88.4	88.4
1981/82	46311	4446	9.60	11.6	–	11.6	46.2	46.2
1982/83	128194	13	0.01	–	–	24.1	–	127.9
1983/84	79997	8098	10.12	15.2	–	15.2	41.3	41.3
1984/85	14148	389	2.75	0.6	–	3.6	–	9.8
1985/86	11107	2506	22.56	12.8	–	12.8	27.5	27.5
1986/87	71151	2236	3.14	23.2	0.313	23.2	47.3	47.3
1987/88	34619	787	2.27	8.1	0.044	8.1	17.9	17.9
1988/89	21359	2.6	0.01	–	0.094	13	20.8	20.8
1989/90	8087	523	6.47	37.1	0.437	37.1	40.3	40.3
1990/91	40	40	–	–	0.079	4.6	15.2	15.2
1991/92	5.3	5.3	–	–	0.144	6.3	28.1	28.1

Note: in 1990/91 and 1991/92 survey catches only

Thompson and Bell method as well as catch projections were conducted applying the selection curve obtained from the tuning with Laurec—Shepherd and hybrid methods.

Following the published estimates of natural mortality (M) for mackerel icefish (Frolkina and Dorovskikh 1990) a mean level of 0.5 was assumed in all calculations.

The VPA analysis was carried out with the MAFFVPA programme developed by the UK Ministry of Agriculture, Fisheries and Foods (MAFF). Calculations of yield per recruit (Thompson and Bell model) were conducted with the YR programme received from CCAMLR commission.

Results

Stock abundance indices

— Catches and catch per unit of effort

The annual (by so called southern hemisphere split year beginning in July, called further in text — seasons) icefish mackerel catch from the South Georgia shelf from 1970/71 to 1975/76 has not exceeded 10,000 tonnes a year (Kock 1991). After that time until 1991/92 three periods of the catches raise and decline have been recorded (Tab. I). In 1976/77 the catch increased threefolds up to 93,400 tonnes and next sharply decreased in the 1978/79 season to only 641 tonnes. The maximum catch level of 128,194 tonnes was reached in 1982/83. In years to follow the catches began to decline to 11,107 tonnes in 1985/86, however, raised again to 71,151 tonnes in 1986/87. A continuous decline in the following years down to 8,087 tonnes in 1989/90 has ended with a moratorium announced for seasons 1990/91 and 1991/92.

Polish fishing fleet catch changes matched approximately with the trends observed in the total international catches (Tab. I). In seasons 1976/77 and 1977/78 Polish catches totalled 3,185 and 2,069 tonnes. The declining trend continued during the next 2 years followed by a period of a substantial catch increase during 1980/81, 1981/82 and 1983/84 to the maximum of 9,166 tonnes in the former and of 8,089 tonnes in the latter case. Unfortunately, due to the Polish fishing fleet withdrawal form South Georgia area in the best hitherto recorded international fishing season 1982/83 — the Polish icefish catch in that year amounted only to 13 tonnes. During 1985/86 and 1986/87 icefish catches by Polish fishing vessels have increased, however, again to 2,506 and 2,236 tonnes, respectively. The low level of Polish icefish catches in 1984/85 as well as in 1987/88 resulted again from a decision of fishing enterprises involved not to deploy their vessels in the area.

The Polish mackerel icefish fishery in the South Georgia shelf has been carried out by few types of factory and freezing trawlers fishing with both bottom and pelagic trawls. Bulk of the vessels constituted factory trawlers B-15 and B-22 types belonging to tonnage class 2000 – 3000 GRT. The mean icefish catch per unit of effort (CPUE) expressed in tonnes per day of that tonnage class during the successive seasons is shown in Tab. I. A substantial degree of conformity between the observed CPUE trends and the swept area biomass estimates of that stock implied their application as a set of abundance indices. The lacking CPUE data in some years has been supplemented with CPUE's calculated on basis of the relative changes of CPUE resulting from research catches or from the changes observed in the total catches.

The highest mean CPUE of 37.1 t/day was recorded in 1989/90 followed by 23.2 t/day in 1986/87. The very low mean CPUE at the level of 0.3 to 1.2 t/day were observed between 1976/77 – 1979/80 and in 1984/85.

— Swept area biomass estimates

Standing stock biomass of icefish in the South Georgia area was estimated with swept area method using commercial fishing and survey data (Ślósarczyk et al. 1984, Mucha and Ślósarczyk 1988, Sosiński and Szlakowski 1992, and unpublished reports by Cielniaszek, Szlakowski and Traczyk, and Cielniaszek and Szlakowski). The estimates ranged from 226,606 tonnes in the first 1976/77

Table II

Estimates of standing stock biomass with swept area method in 1976/77–1991/92 seasons and Polish or joint Polish-USA and

Season	Month	Vessel	Type of data	All species trawlable biomass	*Ch. gunnari* trawlable biomass	Share of *Ch. gunnari* biomass
				(tons)	(tons)	(%)
1976/77	Jan.–May	M.T. "GEMINI"	commercial	323703	226606	70.0
1977/78	Dec.–Apr.	M.T. "GEMINI"	commercial	72862	2372	3.3
1978/79	Dec.–Mar.	R.V. "PROF. SIEDLECKI"	survey	20452	1152	5.6
1979/80	–	–	–	–	–	–
1980/81	Oct.–Feb.	M.T. "LIBRA"	commercial	123368	88414	71.7
1981/82	Nov.–Feb.	M.T. "NEPTUN"	commercial	133230	46192	34.7
1982/83	–	–	–	–	–	–
1983/84	Nov.–Jan.	M.T. "TAURUS"	commercial	156000	41300	26.5
1984/85	–	–	–	–	–	–
1985/86	Nov.–Jan.	M.T. "CARINA"	commercial	66132	22476	41.5
1986/87	December	R.V. "PROF. SIEDLECKI"	survey	94277	47312	50.7
1987/88	Dec.–Jan.	R.V. "PROF. SIEDLECKI"	survey	48643	17913	36.8
1988/89	February	R.V. "PROF. SIEDLECKI"	survey	51533	20847	40.5
1989/90	January	M.T. "HILL COVE"	survey	63159	40289	63.8
1990/91	Jan.–Feb.	M.T. "FALKLANDS PROT."	survey	69090	15205	22.0
1991/92	January	M.T. "FALKLANDS PROT."	survey	95710	28099	29.4

season to 28,099 tonnes in the last 1991/92 season considered (Tab. II). The lowest estimates of 2,372 tonnes and 1,152 tonnes have resulted from Polish commercial vessel data of 1977/78 and 1978/79, respectively.

Assumption of 100% catchability of bottom trawls for icefish biomass estimation, uneven area and depth coverage both during commercial and research vessels fishing operations, the influence of a single large catch on the final estimate as well as differences in vertical opening of trawls used may cast some doubts on precision of the relative and absolute biomass estimates (Tab. II), at least in some years (Ślósarczyk et al. 1985). The uncertainties specifically refer to the swept area estimates resulting from M/T "Gemini" and R/V "Profesor Siedlecki" surveys in 1977/78 and 1978/79 fishing seasons when extremely low biomass estimates have been obtained. More pelagic occurrence of icefish shoals observed in these years could be responsible for the underestimation (Ślósarczyk et al., op.cit.). Combined with small vertical opening of the commercial trawls used it could lead to a considerably decreased catchability of bottom trawls compared to pelagic ones. On the other hand an overestimation of the icefish biomass, e.g. in 1976/77 season (and may be in other years), was also possible due to the tactics of the commercial vessel to maintain within the area of highest fish concentration.

of makcerel icefish off South Georgia
based on Polish commercial fishery data,
Polish – British survey results.

Ch. gunnari biomass mean density	Total area covered by survey	Depth range	Number of hauls	Gear type	Horizontal opening of trawl	Average trawling speed	Source
36.6	6194	150 – 500	277	P-36/39	24.0	3.80	Ślósarczyk et al. 1984
0.3	8164	150 – 500	243	P-32/36	17.5	3.80	Ślósarczyk et al. 1984
0.2	5471	150 – 500	36	P-26/32	17.0	4.25	Ślósarczyk et al. 1984
–	–	–	–	–	–	–	–
7.9	11196	50 – 500	507	P-32/36	17.5	3.60	Ślósarczyk et al. 1984
9.8	4722	50 – 500	298	P-32/36	17.5	3.70	Ślósarczyk et al. 1984
–	–	–	–	–	–	–	–
3.4	12150	50 – 500	–	P-32/36	17.5	–	Ślósarczyk et al. 1984
–	–	–	–	–	–	–	–
4.3	6434	50 – 500	232	P-32/36	17.5	3.20	Mucha and Ślósarczyk 1988
1.5	32329	50 – 500	109	P-32/36	17.5	3.50	Sosiński and Szlakowski 1992
0.8	23116	50 – 500	128	P-32/36	17.5	3.50	Sosiński and Szlakowski 1992
0.8	26742	50 – 500	55	P-32/36	17.5	3.50	Sosiński and Szlakowski 1992
1.3	29933	50 – 500	59	120 feet	20.0	3.75	Cielniaszek et al., unpubl.
0.5	28082	50 – 500	73	120 feet	20.0	3.50	Cielniaszek and Szlakowski, unp.
1.0	27482	50 – 500	74	120 feet	20.0	3.50	Cielniaszek and Szlakowski, unp.

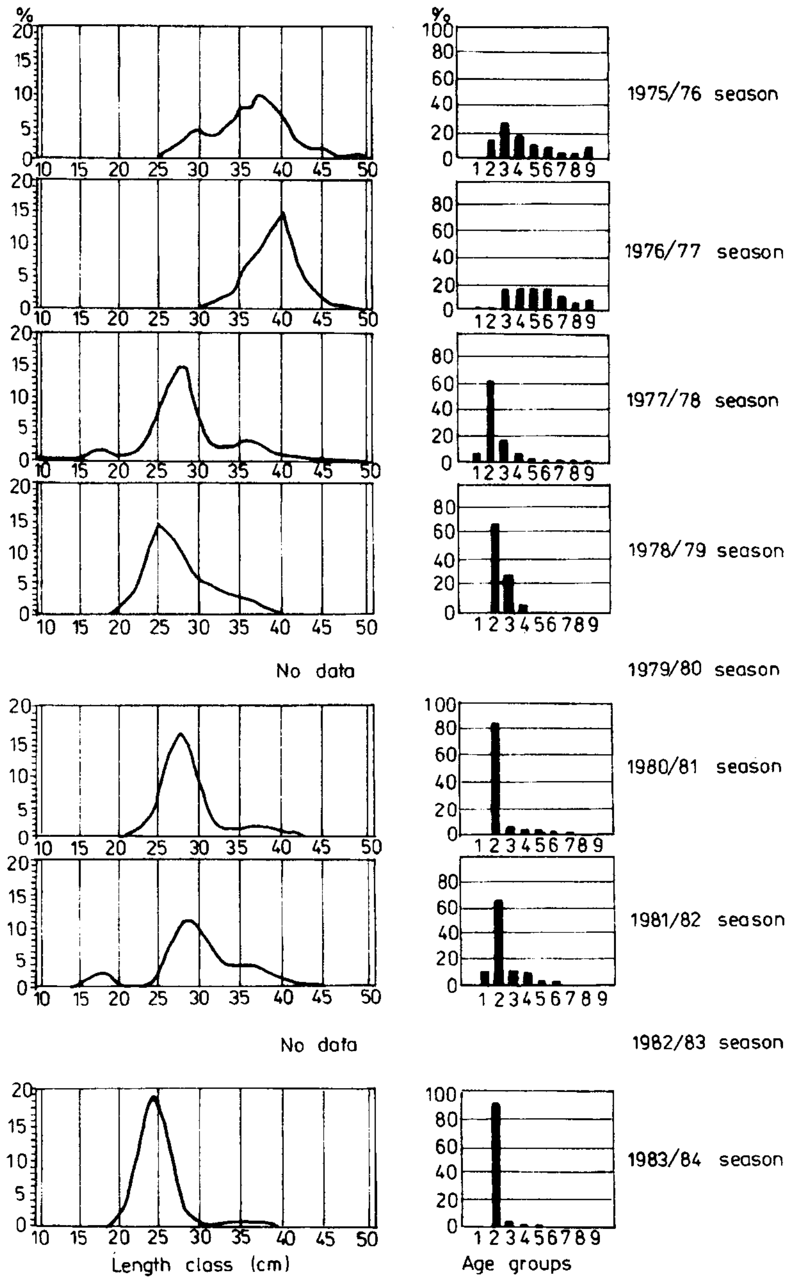
Comparison of biomass estimates made with swept area method during the whole period in question with trends observed in total catches and commercial CPUE shows, however, that in general their trends match quite well (Tab. I).

The lacking swept area biomass estimates in 1979/80, 1982/83 and 1984/85, similarly to procedures followed in case of lacking CPUE data, have been calculated on the basis of relative changes in total catches or commercial CPUE's. In addition, using the same approach, the standing stock biomass estimates considered to be underestimates in 1977/78 and 1978/79 were corrected.

— Age and length distribution changes

The share of successive age groups in the stock, reflected to an extent also by the length distribution curve, depends on a number of biotic and abiotic factors. Mackerel icefish taken during 1975/76 to 1991/92 fishing seasons ranged from 10 to 60 cm in length and from 1 to 9 years in age. Only inconspicuous number of fish were older.

The composition of the exploited icefish stock in respect to length and age is presented in Fig. 2. In fishing seasons 1975/76 and 1976/77 the fishery was based on the so called accumulated stock consisting of a considerable number of year-classes. High intensity of the exploitation resulted in a decline of the stock of fish belonging to older age groups. Starting from 1977/78 until 1983/84



fishing season the fishery concentrated mainly on 2 years old fish recruiting to the exploited part of the stock. The total catch and catch rates have depended on the abundance of year-classes entering the exploited stock and at the same time creating the very stock. The year-classes recruiting to the stock as age

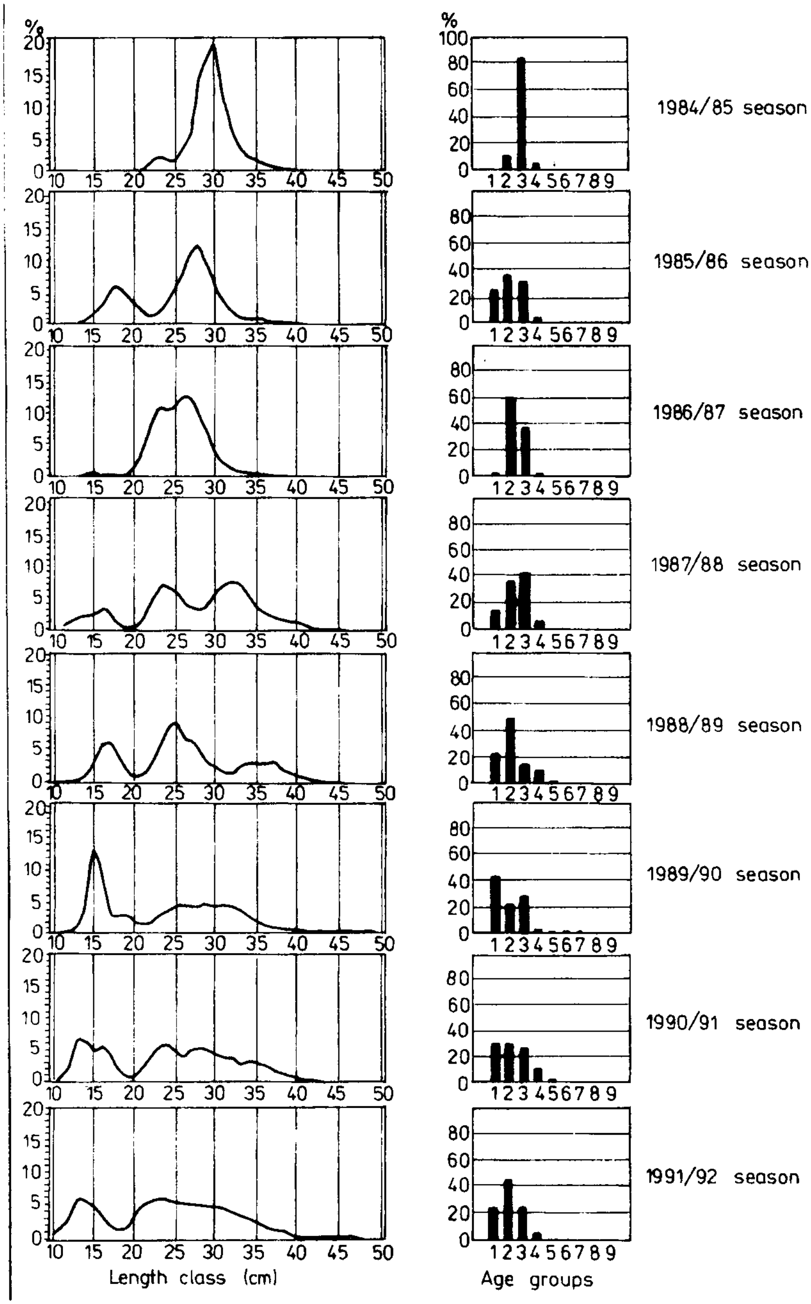


Fig. 2. Length and age distribution of mackerel icefish catchs from South Georgia area in 1975/76–1991/92 fishing seasons.

group 2 in fishing seasons 1980/81–1983/84 were abundant, which is reflected by the achieved fishing results (Tab. I).

In the next fishing season the exploited stock was also characterized by relatively abundant 3 years old fish, as well as juvenile fish 12–18 cm in length belonging to age group 1.

Basic biological parameters of the stock

— Growth rate

A considerable increase of the biological data base collected during Polish investigations in the South Georgia shelf, compared to materials analysed in 1981 (Sosiński 1981), induced an attempt to reevaluate the Von Bertalanffy growth equation parameters. The results obtained may be, however, of limited value, taking into account the relatively small number of age groups included to achieve a fully reliable estimate.

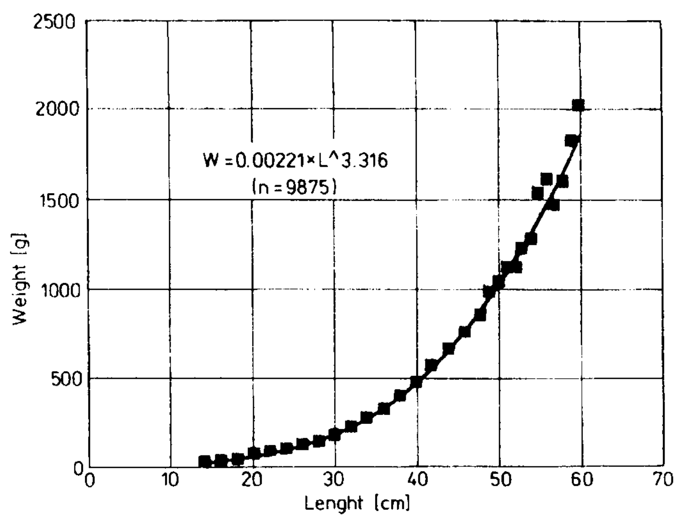


Fig. 3. Length–weight relationship.

Kock, Duhamel and Hureau's (1985) as well as Frolkina and Dorovskikh (1989) reviews of mackerel icefish age determinations made by many authors, reveal considerable discrepancies of the estimates. The resulting differences between mean length at age, especially distinct in case of fish older than 5–6 years, contribute to large differentiations of the von Bertalanffy equation parameters calculated on that basis. In Tab. III some of those estimates are compared with parameters calculated using mean length at age derived from Polish investigations conducted in 1983/84–1988/89. The Polish data from 1989/90–1991/92 seasons could not be included into the length at age calculations due to the insufficient number of specimens older than age 6 to obtain reliable length at age estimates.

Table III

Parameters of linear growth for mackerel icefish calculated by different authors.

Authors	K	Parameters t_0	$L_{inf.}$
Olsen, 1955*	0.3878	1.3557	42.10 cm
Kock, 1981*	0.1570	0.3849	65.10 cm
Sosiński, 1981	0.3542	0.4040	45.55 cm
Kochkin, 1985*	0.1296	−0.6722	71.94 cm
Frolkina and Dorovskikh, 1989*	0.1340	−0.2798	68.90 cm
This estimation	0.1995	−0.4573	61.75 cm

* from Frolkina and Dorovskikh, 1989

Using the asymptotic length ($L_{inf.} = 61.75$ cm) data as well as length-weight relationship ($W = 0.00021 \cdot L3.3315$) calculated on the basis of Polish data — the value of asymptotic weight ($W_{inf.} = 2042.0$ g) was determined. The weight-length relationship (Fig. 3) was based on length and weight measurements of 9875 specimens ranging from 17 to 60 cm in length.

— Natural mortality

Polish data have not comprised age distributions from the inceptive period of the fishery. On the basis of the available data a more precise estimation of natural mortality than that carried out by Frolkina & Dorovskikh (1989) was not possible. A range of natural mortality estimates of mackerel icefish obtained by several authors with different methods is presented in Tab. IV.

Table IV

Mackerel icefish natural mortality (M) estimates.

Name of author or method	Estimate of M
Rikhter – Efanov, 1976**	0.54
Kock, Duhamel & Hureau*	0.48
Baranov**	0.58
Beverton and Hold, by age**	0.60
Beverton and Holt, by length**	0.51
Alverson – Carney**	0.32

* data from Sosiński, 1981
**calculated by Frolkina and Dorovskikh, 1989

Taking into account the considerable range (0.32 – 0.60) of the resulting estimates of the natural mortality coefficient (M), for purpose of this assessment it was decided to accept a single value of $M = 0.5$, which is approximately equal to an arithmetic mean of the values included in Tab. IV.

— Yield per recruit

Yield changes of the South Georgia mackerel icefish stock as a function of fishing mortality (F) and the age of first capture (t_c) were calculated with Beverton and Holt yield per recruit model assuming "knife edge" recruitment. Maximum fishing mortality (F_{max}) and optimum fishing mortality ($F_{0.1}$) values calculated on that basis for t_c ranging from 1 to 4 years at $M = 0.5$ are shown in Tab. V.

Table V

Maximum (F_{max}) and optimum of fishing mortality ($F_{0.1}$) at different levels of age of first capture (t_c) calculated with Beverton and Holt model.

t_c	F_{max}	$F_{0.1}$
1	0.503	0.288
2	1.039	0.401
3	–	0.519
4	–	0.628

To allow for a more realistic (than the "knife edge") exploitation pattern of the year-classes recruiting to the stock, which resulted from selection factors (S) obtained from VPA, the Thompson and Bell method (Ricker 1985) was used. The plot of Y/R curve, calculated on basis of mean S's from 1975/76–1988/89 seasons using CCAMLR computer programme showing the position of respective values of $F_{0.1}$ (=0.486) and F_{max} (=0.888), is presented in Fig. 4.

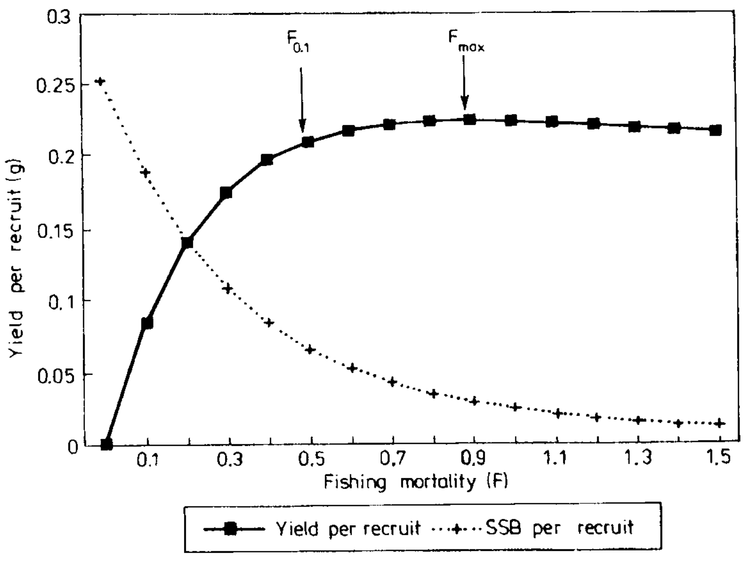


Fig. 4. Long – term yield and spawning stock biomass calculated with Thompson and Bell method.

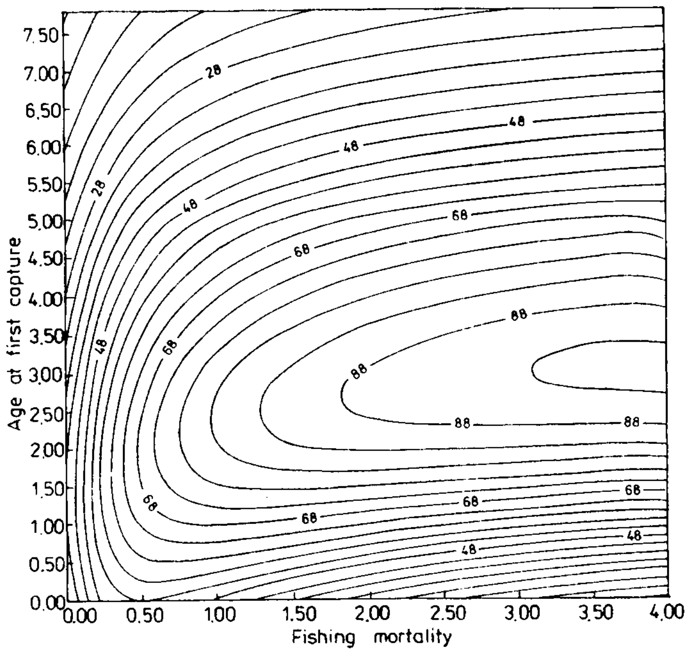


Fig. 5. Isopleths of yield per recruit.

Beverton and Holt model was applied also to calculate yield as a function of both F and t_c, and thus to plot isoplethes (Fig. 5). The plot shows clearly that the largest yield can be reached when t_c is at the level of 2 – 3 years. Any further increase of t_c would not be profitable since it could lead to a decline in yield.

Table VI

Data inputs used for VPA runs.

Data	Age								
	1	2	3	4	5	6	7	8	+gp
Mean weight at age (kg)*	0.02	0.08	0.18	0.31	0.50	0.66	0.81	0.89	0.96
Natural mortality (M)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Proportion mature at age	0.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Prop. of M before spawn.	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Prop. of F before spawn.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

* refers to both catch and stock

Fishing mortality and stock biomass estimates

The historical changes of fishing mortality (F) and the stock biomass have been estimated with traditional VPA developed by Gulland (1965). The analysis covered 17 years from 1991/92 back to 1975/76. The data on mean weight at

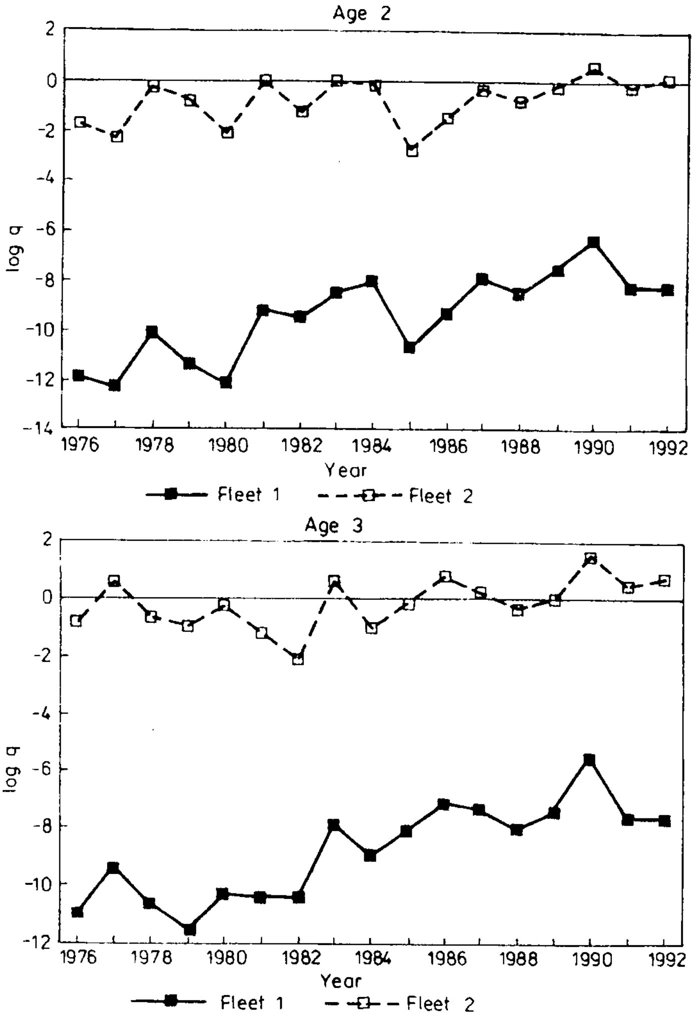


Fig. 6. Log catchability estimates for age groups 2 and 3.

Mackerel icefish

Year	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83
Age								
1	100	3290	2866	26	207	176	23746	3941
2	4790	3084	26135	2905	5369	148650	158309	175115
3	8803	35158	6745	1151	15558	8961	26385	257150
4	5729	34747	3119	193	7692	6150	21588	114048
5	3690	36392	1349	39	1089	6677	5277	14264
6	3075	36392	885	9	227	2987	2639	4129
7	1715	24056	422	9	148	1230	959	1689
8	1230	13775	379	22	148	527	480	1030
+gp	3334	18710	253	22	59	351	480	563
Totalnum	32464	205602	42153	4376	30498	175709	239861	571929
Tonsland	12290	93400	7557	641	7592	29384	46311	128194

Note: TONSLAND = total catch in tonnes

age, natural mortality (M), proportion mature of age, proportion of M before spawning and proportion of F before spawning used in VPA runs are shown in Tab. VI. Total catch at age in number matrix (Tab. VII) was calculated by applying Polish catches age distribution (Fig. 2) to the total international catches. It was decided to include into the analysis very low survey catches of 1990/91 and 1991/92 so as to arrive to as realistic stock size at the beginning of 1992/93 as possible.

VPA was tuned with Laurec—Shepherd and hybrid method using tuning module of the MAFFVPA programme. Fishing mortality in the oldest age group was taken to be the arithmetic mean of the F's of the 3 younger age groups in each year. Two fleets assumed to reflect the stock abundance indices were included in the tuning: Polish commercial fleet mean CPUE and the trawl survey biomass estimates (Tabs. I and II). Calculation option providing for log catchability was chosen. The overall mean F was calculated as the weighted mean of the F corresponding to particular fleets; weighting factor being the reciprocal of individual F's variance. Due to the trend observed in the log catchability (q) estimates for Fleet 1 (Polish commercial fleet catch and effort) as shown in Fig. 6 — the terminal q was estimated from the trend using time as explanatory variate. In Fig. 6 only ages 2 and 3 log catchability estimates are being included as example of very similar trends present in other ages as well.

Sigma (int.) coefficients resulting from tuning were in general at acceptable level below or slightly above 1 (Tab. VIII) with exception of age 1. The Sigma (int.) is a measure of a standard error of the F estimate. The Sigma (ext.) is a measure of the scatter of individual F_i estimates (corresponding to different fleets) about the weighted mean F_i. The Sigma (overall) is one of the two measures above whichever is larger (Anon. 1989).

Trial runs of separable VPA has not been successful since no acceptable exploitation pattern could be reached. A single run resulting in a dome shape

Table VII

catch numbers at age (Numbers · 10—3).

1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92
4525	156	23897	11333	29034	28258	25535	89	10
694646	8278	32165	368305	70597	62371	13690	89	19
32432	65367	29076	236093	83722	19602	17024	81	10
17347	3671	3453	11333	11932	12856	1845	27	3
4525	156	727	1889	1193	2928	714	3	1
754	312	818	630	398	509	417	1	0
500	156	363	400	1600	764	298	0	0
100	100	91	200	300	300	200	0	0
50	30	50	40	50	100	50	0	0
754880	78227	90639	630221	198826	127688	59773	290	43
79997	14148	11107	71151	34619	21359	8087	40	5

Table VIII

Summary statistics from the VPA tuning.

Age group	Sigma (int.)	Sigma (ext.)	Sigma (overall)	Variance ratio
1	1.820	1.720	1.820	0.89
2	0.765	0.997	0.997	1.699
3	0.699	1.000	1.000	2.053
4	0.699	0.810	0.810	1.342
5	1.020	0.621	1.020	0.371
6	0.959	0.591	0.959	0.380
7	1.140	0.172	1.140	0.023

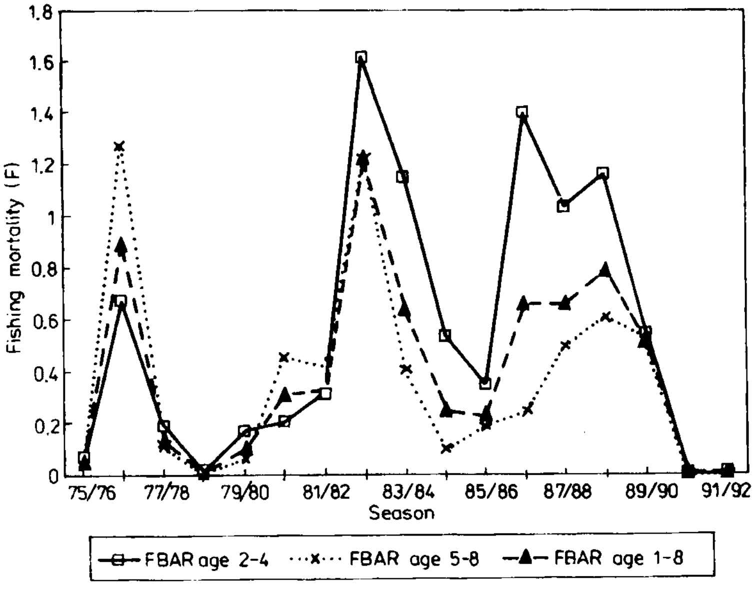


Fig. 7. Fishing mortality (F) changes from 1975/76 to 1991/92.

Mackerel icefish fishing mortality (F) at age

Year	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83
Age								
1	0.0008	0.0162	0.0137	0.0001	0.0002	0.0002	0.0519	0.0030
2	0.0429	0.0389	0.2378	0.0234	0.0350	0.3299	0.2891	0.9788
3	0.1084	0.7245	0.1534	0.0199	0.2317	0.1030	0.1226	1.8690
4	0.0702	1.2465	0.1733	0.0079	0.2471	0.1867	0.5498	2.0056
5	0.0381	1.2938	0.1809	0.0040	0.0765	0.5059	0.3404	1.4722
6	0.0630	0.9380	0.1179	0.0022	0.0385	0.4369	0.5588	0.7237
7	0.0553	1.56551	0.0313	0.0021	0.0614	0.4236	0.3442	1.4424
8	0.0521	1.2658	0.1100	0.0027	0.0588	0.4555	0.4145	1.2128
+gp	0.0521	1.2658	0.1100	0.0027	0.0588	0.4555	0.4145	1.2128
FBAR 1–8	0.0539	0.8861	0.1273	0.0078	0.0937	0.3052	0.3339	1.2134
FBAR 2–4	0.0738	0.6700	0.1882	0.0170	0.1713	0.2065	0.3205	1.6178

S curve within age groups 1–5 ended up, however, with rather not realistic biomass estimate (of about 500,000 tonnes) in 1975/76 and quite high estimates (200,000–300,000 tonnes) in the intermediate years.

Mean fishing mortalities of age groups 1–8 resulting from VPA ranged from 0.0002 in 1991/92 to 1.2 in 1982/83 (Tab. IX, Fig. 7). The very small values observed in 1978/79 and the two last years were due to low level or absence of any commercial fishing. Durig 1975/76–1981/82 period the mean F's of older age groups 5–8 were greater or at the same level as F's of younger ages. From 1982/83 until 1989/90 F's of younger age groups considerably exceeded F's of older ages. Fluctuations of F coincided very closely with changes in magnitude of the total catch of mackerel icefish. During 7 out of 15 years of the mackerel icefish stock exploitation the mean F's of ages 1–8 exceeded $F_{0.1}$ (0.486) estimated with Thompson and Bell method (Fig. 4); in one case (1976/77) it was at the F_{max} level (0.888) and in another case (1982/83) it was by 35% above $F_{0.1}$.

Total stock biomass estimates resulting from the VPA (Tab. X, Fig. 8) reveal three periods of the biomass increase. The first in 1975/76 when the biomass was at its highest level of 289,449 tonnes, the second in 1981/82 and 1982/83 when two relatively abundant year-classes 1979/80 and 1980/81 accumulated to increase the stock biomass to 255,525 and 225,779 tonnes, respectively, and the last period during which the biomass peaked at 124,007 tonnes in 1986/87. The spawning biomass was at its highest level of 182,088 tonnes in 1975/76. It was reduced by fishing to about 1/4 of that level over the next 5 years and increased again to 99,169 tonnes in 1981/82.

There was a constant decrease of the spawning stock biomass (SSB) between 1985/86 and 1989/90 from 30,736 to only 7,396 tonnes. After two years duration of the fishery moratorium in 1990/91 and 1991/92 the biomass rised to around the level of 1985/86 which was still 6 fold lower than the biomass at the beginning of the whole period included in calculations.

Table IX

(traditional VPA terminal F's estimated using Hybrid method).

1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92
0.0272	0.0002	0.0273	0.0570	0.1548	0.3246	0.3222	0.0006	0.0000
1.7214	0.0867	0.0740	1.1161	0.8743	0.8591	0.3650	0.0022	0.0002
0.7184	1.2863	0.7158	1.9919	1.4290	1.0111	0.9428	0.0044	0.0004
0.9926	0.2233	0.2710	1.0859	0.8003	1.6028	0.3270	0.0043	0.0003
0.5858	0.0266	0.0857	0.3287	0.4301	0.6895	0.4770	0.0009	0.0003
0.3648	0.0970	0.2615	0.1364	0.1463	0.4739	0.2704	0.0013	0.0001
0.2436	0.1644	0.2163	0.2756	0.9011	0.6699	0.8565	0.0001	0.0002
0.3981	0.0960	0.1878	0.2469	0.4925	0.6112	0.5348	0.0008	0.0002
0.3981	0.0960	0.1878	0.2469	0.4925	0.6112	0.5348	0.0008	0.0002
0.6315	0.2476	0.2299	0.6548	0.6535	0.7803	0.5120	0.0018	0.0002
1.1441	0.5321	0.3536	1.3979	1.0345	1.1577	0.5449	0.0036	0.0003

Mackerel icefish stock numbers at age (start

Year / Age	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83	1983/84
1	169335	260391	267055	326300	1093479	1305443	595077	1662742	21843
2	144826	102630	155401	159769	197891	663069	791656	342669	1005467
3	108355	84156	59875	74309	94668	115895	289149	359596	78100
4	107044	58966	24734	31151	44184	45542	63416	155144	33650
5	125298	60523	10282	12615	18746	20931	22919	22196	12664
6	63820	73158	10067	5205	7621	10533	7655	9890	3089
7	40396	36345	17368	5427	3150	4448	4127	2655	2909
8	30694	23182	4607	10210	3285	1797	1766	1774	381
+gp	83200	31486	3071	10211	1315	1198	1766	970	190
Totalnum	872969	730839	552461	635196	1464338	2168855	1777531	2557638	1350293
Totalbio	289449	176537	78622	84105	101076	170215	255525	225779	136397
Totspbio	182088	37732	39739	47755	41244	56352	99169	23319	19328

Note: TOTALBIO = total stock biomass (TSB) in tonnes
TOTSPBIO = spawning stock biomass (SSB) in tonnes
TOTALNUM = total stock in numbers (TSN)

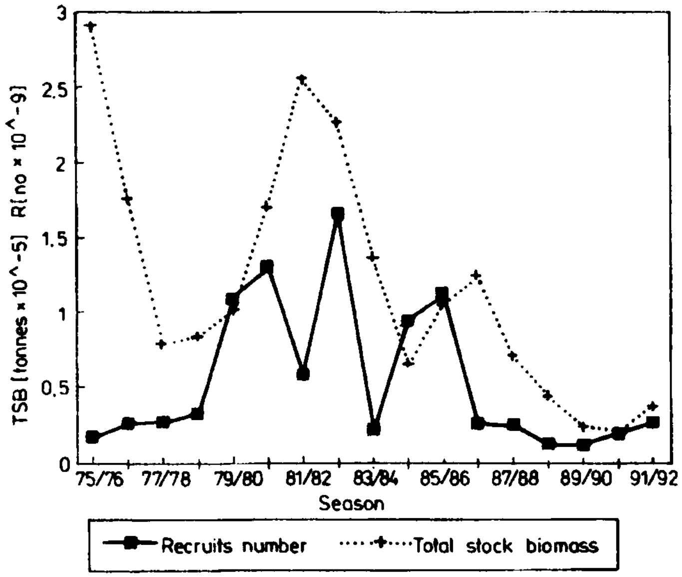


Fig. 8. Total stock biomass (TSB) and recruitment (et age 1) changes in 1975/76–1991/92 fishing seasons.

The plot of relationship between spawning stock biomass and recruitment in numbers (Fig. 9) indicates a greater probability of appearance of less abundant year-classes when SBB falls below 20,000 tonnes. However, with the stock fluctuating between 20,000 and 60,000 tonnes both poor and rich year-classes may be produced.

Table X

of year) and overall stock weight (TSB and SSB).

1984/85	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93
942680	1127613	259303	255581	127823	116235	197172	116235	116235
126218	571644	665535	148561	132783	56039	51079	119523	70500
109051	70198	322004	132230	37590	34111	23595	30912	72480
23095	18275	20812	26647	19213	8294	8059	14249	18742
7564	11205	8453	4262	7260	2346	3628	4867	8640
4276	4468	6238	3691	1681	2210	883	2198	2951
1301	2354	2086	3301	1934	635	1023	535	1333
1383	669	1150	961	813	600	164	620	324
415	368	230	160	271	150	164	620	376
1215983	1806794	1285811	575393	329368	220621	285766	289759	291581
65480	104336	124007	71556	44268	24587	20959	27332	34818
17036	30736	17513	14925	9078	7396	9951	20227	29673

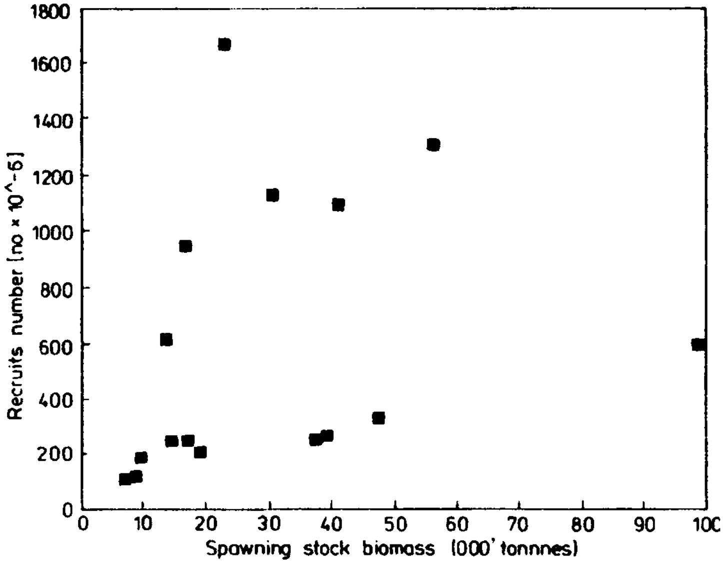


Fig. 9. Stock-recruitment relationship.

Catch projections

The estimated stock size in terms of number in 1990/91 and 1991/92 depends to a large extent on selection factors for age groups 1 and 2 in the terminal year resulting from the tuning procedure. Since the actual recruitment numbers of age group 1 in 1991/92 (610,911 millions) obtained from VPA were considerably higher than those estimated for a few preceding years it was decided, for the

purpose of catch prediction, to replace it with the least abundant year-class 1989/90 of 116,235 millions of specimens. The reason for adopting such conservative recruitment numbers was to avoid too optimistic stock estimates not being sufficiently supported by survey results and particularly to eliminate the effect of over-optimistic assumptions on the recommended catch levels and the stock biomass in the next year. To prepare catch projections for 1992/93 and to calculate their consequences for the stock biomass at the beginning of the split year 1993/94 two recruitment options of age group 1 were assumed:
— a pessimistic one accepting recruitment of 116,235 millions of specimens as already explained (Tab. XI, recruitment option 1),
— a more optimistic one based on a long-term average recruitment of 264,000 millions from 1975/76 – 1990/91 period, excluding abundant year-classes exceeding 800,000 millions of specimens (Tab. XI, recruitment option 2).

To calculate predicted catches 4 levels of F (referred to the most heavily exploited in the recent years age groups 2 – 4) were assumed:
— the same as in the last year before moratorium (1989/90),
— at the level of $F_{0.1}$ as estimated with Thompson and Bell method,
— at the level of $F_{0.1}$ as calculated with Beverton and Holt model,
— F resulting in no change of SSB between July 1992 and July 1993 (Tab. XI).
The predicted catches for recruitment option 1 range from 4,782 tonnes to 10,524 tonnes. For recruitment option 2 the predicted catches are at somewhat higher level between 9,828 and 12,638 tonnes (Tab. XI). The differences between both adopted $F_{0.1}$ reference levels in terms of catch in either recruitment option do not exceed 2,000 tonnes. Perhaps the most important conclusion to be drawn from these calculations is that should the recruitment to the stock be as poor as assumed in the option 1 then both TSB and SSB would

Table XI

Projected catches of mackerel icefish in 1992/93 season.

	July 1992		1992/93			July 1993	
Recruitment option	TSB (tonnes)	SSB (tonnes)	Basis	FBAR 2–4	Catch	TSB (tonnes)	SSB (tonnes)
1	34818	29673	FBAR 89/90	0.545	10524	25126	22421
			F (0.1)*	0.486	9615	26270	23553
			F (0.1)**	0.400	8205	28055	25320
			F (const.SSB)	0.215	4782	32445	29673
2	45304	33319	FBAR 89/90	0.545	12638	38644	32500
			F (0.1)*	0.486	11536	40118	33946
			F (0.1)**	0.400	9828	42414	36202
			F (const.SSB)	0.499	11783	39787	33619

Note: Recruitment option 1 = recr. no. at age 1 = 116,235,000;
Recruitment option 2 = recr. no. at age 1 = 264,000,000;
* F (0.1) calculated with Thompson and Bell method (=0.486);
** F (0.1) calculated with Beverton and Holt Y/R model (=0.400) assuming age at first capture = 2;

decrease in July 1993 unless the mean F is diminished to below 50% of $F_{0.1}$. If the second recruitment option is adopted then practically in all cases SSB in July 1993 remains at the same level as July 1992 or shightly increases. However even in that recruitment option the total stock biomass would decline. Overall consequences of adoption of different F levels for TSB and catch changes are easily visible from the plot in Fig. 10.

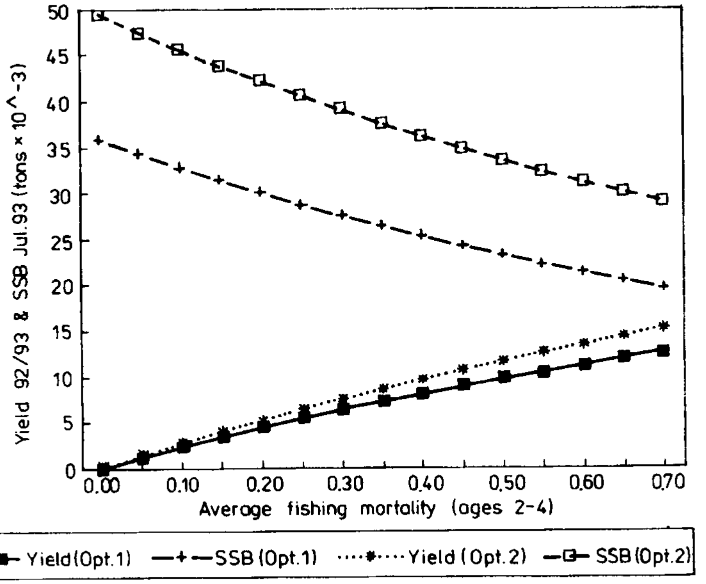


Fig. 10. Short term yield and spawning biomass.

Discussion

This work was aimed at achieving two goals; firstly to present results of 15 years of Polish investigations on the biology of mackerel icefish of the South Georgia stock with particular emphasis on length and age structure changes and secondly using the collected data with support of some vital biological information from literature to attempt to relate these findings with the fishery intensity and the stock biomass and recruitment trends. The last but not the least objective was to determine the extent to which a single country biological and fisheries data may be used to reflect the current stock state and serve as a secondary guidance for its short term predictions.

Limited value of a single country data compared to pooled information furnished to CCAMLR Fish Stock Assessment Working Group (WG-FSA) especially refers to length and age composition. The former being effected by differences in fishing gears used as well as in fishing power of various vessel types involved, fishing ground chosen, depth of fishing and its timing within the season. Deficiency of the latter stems too from differences in intepretation of otoliths growth zones habitually followed by age readers of each country (Frolkina and Dorovskikh 1990). In case of mackerel icefish it is coupled with additional interpretation difficulties posed by less pronounced seasonality of the Southern Ocean. Differences in ageing by various authors and their influence on $L_{inf.}$ were discussed by Kock, Duhamel and Hureau (1985). Discrepancies between Polish and Soviet icefish catch age compositions were noted by Kock (1991). Their influence on other important biological parameters of the stock, e.g. coefficients K and t_0 of von Bertalanffy growth equation obtained by various authors may be seen in Tab. III.

In spite of many above mentioned reservations as well as application of the unstandarized Polish CPUE data in the VPA tuning procedure — the resulting estimates of the fishing mortality, the optimum fishing mortality, the stock biomass and the projected catch level do not depart much from the WG-FSA estimates (Anon. 1991). Years when the total stock biomass reached its maximum and minimum match exactly. Some differences concern, however, the absolute value of the biomass estimates. According to the present estimate the maximum stock biomass in 1976/77 – 1990/91 (the period considered by the Working Group) amounted to 225,779 tonnes (age group 1 and older) while according to the WG-FSA estimate the stock biomass peaked at 180,000 tonnes. The successive biomass peak in 1986/87 resulting from the present estimate reached only 124,007 tonnes while the WG-FSA biomass estimate was higher and reached 140,000 – 160,000 tonnes depending on abundance indices used for tuning. Also the declining trend of the stock biomass in 1986/87 – 1990/91 period in both cases is similar, however, according to the WG-FSA VPA option tuned with commercial CPUE data the biomass decreased in the terminal year to only 15,000 tonnes while according to the present estimate it declined to 20,959 tonnes.

A similar convergence refers to estimate of $F_{0.1}$ and the projected catches in the year following the terminal year. The WG-FSA F estimates which assumed knife edge selection at $t_c = 2$ range from 0.39, for the adopted M level of 0.48, to 0.44 for M assumption of 0.56 (Anon. 1991). According to the present estimate adopting the same value of $t_c = 2$ and assuming $M = 0.50$, the value of $F_{0.1}$ equals 0.40. The resulting projected catch at similar age 1 recruitment levels (289,863 millions in the WG-FSA option and 264,000 millions adopted in the present option) totals 9,672 tonnes according to the WG-FSA calculations and 9,828 tonnes according to the present estimate.

Comparison of the present assessment with that carried out by the WG-FSA allows to conclude that in some cases data originated from a single country participating in a fishery can become a reliable basis of a stock assessment and result in a similar management advice.

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Streszczenie

Jednym z najważniejszych gatunków wykorzystywanych przez rybołówstwo w rejonie szelfu Georgii Południowej (Rys. 1) jest kergulena (*Champsocephalus gunnari* Lonnberg, 1905). Polska uczestniczy w badaniach kerguleny w omawianym rejonie od 1976 r., a polskie rybołówstwo podjęło tutaj połowy w styczniu 1977 r. Wysokość polskich połowów kerguleny na szelfie Georgii Południowej w sezonach połowowych 1976/77 do 1991/92 przedstawia tabela I. Polskie badania biologiczne i połowowe (Tab. II) nad stanem zasobów omawianego stada posłużyły do podjęcia próby niezależnego oszacowania niektórych jego parametrów biologicznych oraz zmian wielkości jego biomasy i śmiertelności w sezonach 1976/77 – 1991/92, a następnie do porównania uzyskanych wyników z rezultatami pracy Grupy Roboczej CCAMLR d/s szacowania zasobów (WG-FSA).

Śmiertelność połowową, zmiany biomasy całkowitej stada i biomasy stada tarłowgo w sezonach 1975/76 – 1991/92 oszacowano metodą analizy populacji wirtualnej (VPA). Użyty do obliczeń rozkład polskich połowów kerguleny pod względem długości i wieku przedstawia rys. 2.

Oszacowane na podstawie dostępnych materiałów biologicznych i wykorzystane do dalszych obliczeń parametry wzrostu z równania von Bertalanffy'ego ($k=0.1995$, $t_0=-0.4573$, $L_{inf.}=61.75$ cm) porównano z ocenami innych autorów (Tab. III). Wykres oszacowanej zależności masa – długość ($W=0.00021 \cdot L3.3315$) użytej do obliczenia $W_{inf.}$ (2042,0 g) przedstawiono na rys. 3. Na podstawie wybranych z literatury, wykonanych różnymi metodami ocen wielkości współczynnika śmiertelności naturalnej (M) przyjęto do dalszych obliczeń wartość zbliżoną do średniej ($M=0,5$) (Tab. IV).

Do wyznaczenia wartości $F_{0.1}$ i F_{max} przy założeniu 4 poziomów jednolitego wieku pierwszego odłowu ($t_c=1...4$) (Tab. V) posłużono się modelem produkcji Bevertona i Holta. Te same parametry — uwzględniając wynikający z VPA rozkład współczynników selekcji (S) — oszacowano metodą Thompsona i Bella (Rys. 4). Model Bevertona i Holta posłużył również do wykreślenia izoplet (Rys. 5).

Dane wejściowe do VPA przedstawiono w tabeli VIII. Macierz całkowitych połowów kerguleny w grupach wieku — obliczoną na podstawie rozkładów wiekowych polskich połowów — zamieszczono w tab. VII. Zestrajanie VPA przeprowadzono metodą Laureca – Shepherda oraz metodą hybrydową przyjmując jako wskaźniki liczebności polskie połowy i polski nakład połowowy (flota 1) oraz szacunki biomasy (flota 2), uzyskane metodą przetrałowanej powierzchni (Tab. II). Wybrano opcję programu opierającą się na zlogarytmowanych współczynnikach łowności (q). Startową wartość q oszacowano z uwzględnieniem trendu występującego w oszacowanych wartościach q „floty 1", co przedstawiono na rys. 6. Uzyskane z procedury zestrajania współczynniki Sigma (int.) były na ogół na dopuszczalnym poziomie lub tylko nieco go przewyższały (Tab. VIII).

Oszacowane metodą VPA zmiany śmiertelności połowowych w grupach wieku przedstawiono w tab. IX i na rys. 7. Wyniki VPA wskazują, że całkowita biomasa stada (TSB) w ostatnim rozpatrywanym sezonie 1991/92 wynosiła 34,818 ton i była w przybliżeniu 10-krotnie niższa niż w sezonie 1975/76 (Tab. X, Rys. 5). Biomasa stada tarłowego (SSB) spadła do minimalnego poziomu 7,396 ton w sezonie 1989/90. Po 2-letnim okresie przerwy w połowach w ostatnich 2 sezonach obie biomasy wzrosły do poziomu około 30,000 ton. Wykres zależności pomiędzy wielkością stada tarłowego a liczebnością rekrutacji (Rys. 9) wskazuje, że przy aktualnym poziomie biomasy stada istnieje prawdopodobieństwo pojawiania się roczników zarówno o małej, jak i wysokiej liczebności.

Wysokość przewidywanych połowów w sezonie 1992/93 oraz wynikających stąd poziomów biomasy na początku sezonu 1993/94 (lipiec 1993 r.) obliczono przyjmując dwa założenia co do wysokości uzupełnienia stada przez ryby z 1 grupy wieku w sezonach 1991/92 i 1992/93:

1) na niższym poziomie — po 116,235 milionów ryb (Tab. XI, opcja 1),

2) na poziomie średniej rekrutacji w sezonach 1975/76—1990/91, wynoszącej 264 miliony ryb, z pominięciem pokoleń o liczebności przekraczającej 600 milionów osobników (Tab. XI, opcja 2).

Dla każdej opcji uzupełnienia przyjęło 4 arbitralnie dobrane poziomy intensywności połowów w sezonie 1992/93 (Tab. XI).

Uzyskane wyniki wskazują na decydujący wpływ wielkości uzupełnienia na dalsze kształtowanie się zmian biomasy stada. Jeśli pierwsza opcja rekrutacji jest prawdziwa, to w celu utrzymania takiej samej biomasy stada tarłowego (TSB) w lipcu 1993, jaka istniała w lipcu 1992 wysokość F w sezonie 1992/93 należałoby zmniejszyć w przybliżeniu o 50% w stosunku do któregokolwiek z dwóch poziomów $F_{0.1}$ (Tab. XI). Połów wyniósłby wówczas tylko 4,872 tony. Jeśli prawdziwa jest druga opcja uzupełnienia, to dla utrzymania TSB na nie zmienionym poziomie F nie powinna przekraczać poziomu F oszacowanego metodą Thompsona i Bella (Tab. XI). Połów wyniósłby wówczas 11,783 tony. Całość oszacowanych zmian TSB i wielkości połowów w funkcji śmiertelności połowowej przedstawiono na rys. 10.

Z porównania przeprowadzonej oceny z szacunkiem dokonanym przez WG-FSA wynika, że pomimo zastosowania w niniejszej pracy danych biologicznych i połowowych pochodzących z jednego tylko państwa uczestniczącego w połowach uzyskane rezultaty dotyczące stanu stada są zbieżne i prowadzą do podobnych wniosków w zakresie regulacji połowów.