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. \(F_{\text{qm}}\) and \(F_{\text{max}}\) 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 icefish (*Champsocephalus gunnari* Lonnberg, 1905).
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1981, 1985a, 1985b, 1990, Ślósarczyk et al. 1984, Mucha and Ślósarczyk 1988, Sosiński and Szlakowski 1992) and unpublished (Cielniaszek, Szlakowski and Traczyk, unpubl.; Cielniaszek and Szlakowski, unpubl.)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:
Mackerel icefish from South Georgia area

— R/V "Hill Cove" in 1989/90;

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


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 $F_{\text{max}}$ 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 plotting 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.

<table>
<thead>
<tr>
<th>Fishing season</th>
<th>International catches (tonnes)</th>
<th>Polish catches (tonnes)</th>
<th>Share of Polish catches (%)</th>
<th>Polish commercial CPUE (t/d)</th>
<th>Survey CPUE (t/h)</th>
<th>CPUE estimates used for tuning (t/d)</th>
<th>Swept area biomass estimates (tonnes)</th>
<th>Biomass estimates used for tuning (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975/76</td>
<td>12290</td>
<td>5</td>
<td>0.04</td>
<td>—</td>
<td>0.167</td>
<td>1.9</td>
<td>—</td>
<td>49.8</td>
</tr>
<tr>
<td>1976/77</td>
<td>93400</td>
<td>3185</td>
<td>3.41</td>
<td>10.8</td>
<td>10.8</td>
<td>226.6</td>
<td>226.6</td>
<td></td>
</tr>
<tr>
<td>1977/78</td>
<td>7557</td>
<td>2069</td>
<td>27.38</td>
<td>1.2</td>
<td>—</td>
<td>1.2</td>
<td>2.4</td>
<td>25.2</td>
</tr>
<tr>
<td>1978/79</td>
<td>641</td>
<td>110</td>
<td>17.16</td>
<td>0.3</td>
<td>—</td>
<td>0.3</td>
<td>1.2</td>
<td>12.2</td>
</tr>
<tr>
<td>1979/80</td>
<td>7592</td>
<td>753</td>
<td>9.92</td>
<td>1.1</td>
<td>—</td>
<td>1.1</td>
<td>—</td>
<td>25.3</td>
</tr>
<tr>
<td>1980/81</td>
<td>29384</td>
<td>9166</td>
<td>31.19</td>
<td>8.9</td>
<td>—</td>
<td>8.9</td>
<td>88.4</td>
<td>88.4</td>
</tr>
<tr>
<td>1981/82</td>
<td>46311</td>
<td>4446</td>
<td>9.60</td>
<td>11.6</td>
<td>—</td>
<td>11.6</td>
<td>46.2</td>
<td>46.2</td>
</tr>
<tr>
<td>1982/83</td>
<td>128194</td>
<td>13</td>
<td>0.01</td>
<td>—</td>
<td>24.1</td>
<td>—</td>
<td>127.9</td>
<td></td>
</tr>
<tr>
<td>1983/84</td>
<td>79997</td>
<td>8098</td>
<td>10.12</td>
<td>15.2</td>
<td>15.2</td>
<td>41.3</td>
<td>41.3</td>
<td></td>
</tr>
<tr>
<td>1984/85</td>
<td>14148</td>
<td>389</td>
<td>2.75</td>
<td>0.6</td>
<td>—</td>
<td>3.6</td>
<td>9.8</td>
<td></td>
</tr>
<tr>
<td>1985/86</td>
<td>11107</td>
<td>2506</td>
<td>22.76</td>
<td>12.8</td>
<td>12.8</td>
<td>27.5</td>
<td>27.5</td>
<td></td>
</tr>
<tr>
<td>1986/87</td>
<td>71151</td>
<td>2236</td>
<td>3.14</td>
<td>23.2</td>
<td>0.313</td>
<td>23.2</td>
<td>47.3</td>
<td>47.3</td>
</tr>
<tr>
<td>1987/88</td>
<td>34619</td>
<td>787</td>
<td>2.27</td>
<td>8.1</td>
<td>0.044</td>
<td>8.1</td>
<td>17.9</td>
<td>17.9</td>
</tr>
<tr>
<td>1988/89</td>
<td>21359</td>
<td>2.6</td>
<td>0.01</td>
<td>—</td>
<td>0.094</td>
<td>13</td>
<td>20.8</td>
<td>20.8</td>
</tr>
<tr>
<td>1989/90</td>
<td>8087</td>
<td>523</td>
<td>6.47</td>
<td>37.1</td>
<td>0.437</td>
<td>37.1</td>
<td>40.3</td>
<td>40.3</td>
</tr>
<tr>
<td>1990/91</td>
<td>40</td>
<td>40</td>
<td>—</td>
<td>—</td>
<td>0.079</td>
<td>4.6</td>
<td>15.2</td>
<td>15.2</td>
</tr>
<tr>
<td>1991/92</td>
<td>5.3</td>
<td>5.3</td>
<td>—</td>
<td>—</td>
<td>0.144</td>
<td>6.3</td>
<td>28.1</td>
<td>28.1</td>
</tr>
</tbody>
</table>

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
Mackerel icefish from South Georgia area

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
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.
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 catches 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.

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.

<table>
<thead>
<tr>
<th>Authors</th>
<th>K</th>
<th>$t_o$</th>
<th>L$_{inf}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olsen, 1955*</td>
<td>0.3878</td>
<td>1.3557</td>
<td>42.10 cm</td>
</tr>
<tr>
<td>Kock, 1981*</td>
<td>0.1570</td>
<td>0.3849</td>
<td>65.10 cm</td>
</tr>
<tr>
<td>Sosiński, 1981</td>
<td>0.3542</td>
<td>0.4040</td>
<td>45.55 cm</td>
</tr>
<tr>
<td>Kochkin, 1985*</td>
<td>0.1296</td>
<td>-0.6722</td>
<td>71.94 cm</td>
</tr>
<tr>
<td>Frolkina and Dorovskikh, 1989*</td>
<td>0.1340</td>
<td>-0.2798</td>
<td>68.90 cm</td>
</tr>
<tr>
<td>This estimation</td>
<td>0.1995</td>
<td>-0.4573</td>
<td>61.75 cm</td>
</tr>
</tbody>
</table>

* from Frolkina and Dorovskikh, 1989

Using the asymptotic length ($L_{inf} = 61.75$ cm) data as well as length-weight relationship ($W = 0.00021 \cdot L^{3.3315}$) 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.

<table>
<thead>
<tr>
<th>Name of author or method</th>
<th>Estimate of M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rikhter—Efano, 1976**</td>
<td>0.54</td>
</tr>
<tr>
<td>Kock, Duhamel &amp; Hureau*</td>
<td>0.48</td>
</tr>
<tr>
<td>Baranov**</td>
<td>0.58</td>
</tr>
<tr>
<td>Beverton and Hold, by age**</td>
<td>0.60</td>
</tr>
<tr>
<td>Beverton and Holt, by length**</td>
<td>0.51</td>
</tr>
<tr>
<td>Alverson—Carney**</td>
<td>0.32</td>
</tr>
</tbody>
</table>

* 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 (\(F_{\text{max}}\)) 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>
<thead>
<tr>
<th>(t_c)</th>
<th>(F_{\text{max}})</th>
<th>(F_{0.1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.503</td>
<td>0.288</td>
</tr>
<tr>
<td>2</td>
<td>1.039</td>
<td>0.401</td>
</tr>
<tr>
<td>3</td>
<td>—</td>
<td>0.519</td>
</tr>
<tr>
<td>4</td>
<td>—</td>
<td>0.628</td>
</tr>
</tbody>
</table>

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 \(F_{\text{max}}\) (=0.888), is presented in Fig. 4.
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 age.
Fig. 6. Log catchability estimates for age groups 2 and 3.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age 1</td>
<td>100</td>
<td>3290</td>
<td>2866</td>
<td>26</td>
<td>207</td>
<td>176</td>
<td>23746</td>
<td>3941</td>
</tr>
<tr>
<td>Age 2</td>
<td>4790</td>
<td>3084</td>
<td>26135</td>
<td>2905</td>
<td>5369</td>
<td>148650</td>
<td>158309</td>
<td>175115</td>
</tr>
<tr>
<td>Age 3</td>
<td>8803</td>
<td>35158</td>
<td>6745</td>
<td>1151</td>
<td>15558</td>
<td>8961</td>
<td>26385</td>
<td>14264</td>
</tr>
<tr>
<td>Age 4</td>
<td>5729</td>
<td>34747</td>
<td>3119</td>
<td>193</td>
<td>7692</td>
<td>6150</td>
<td>21588</td>
<td>114048</td>
</tr>
<tr>
<td>Age 5</td>
<td>3690</td>
<td>36392</td>
<td>1349</td>
<td>39</td>
<td>1089</td>
<td>6677</td>
<td>5277</td>
<td>14264</td>
</tr>
<tr>
<td>Age 6</td>
<td>3075</td>
<td>36392</td>
<td>885</td>
<td>9</td>
<td>227</td>
<td>2987</td>
<td>2639</td>
<td>4129</td>
</tr>
<tr>
<td>Age 7</td>
<td>1715</td>
<td>24056</td>
<td>422</td>
<td>9</td>
<td>148</td>
<td>1230</td>
<td>959</td>
<td>1689</td>
</tr>
<tr>
<td>Age 8</td>
<td>1230</td>
<td>13775</td>
<td>379</td>
<td>22</td>
<td>148</td>
<td>527</td>
<td>480</td>
<td>1030</td>
</tr>
<tr>
<td>+gp</td>
<td>3334</td>
<td>18710</td>
<td>253</td>
<td>22</td>
<td>59</td>
<td>351</td>
<td>480</td>
<td>563</td>
</tr>
</tbody>
</table>

Mackerel icefish

| 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

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Table VIII

Summary statistics from the VPA tuning.

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

Mackerel icefish fishing mortality (F) at age

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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. During 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.

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T a b l e IX

(traditional VPA terminal F’s estimated using Hybrid method).
Mackerel icefish stock numbers at age (start)

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Totalbio 289449 176537 78622 84105 101076 170215 255525 225779 136397
Totsbio 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 (at 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.
of year) and overall stock weight (TSB and SSB).

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|        | 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>
<thead>
<tr>
<th>Recruitment option</th>
<th>TSB (tonnes)</th>
<th>SSB (tonnes)</th>
<th>Basis</th>
<th>FBAR 2—4</th>
<th>Catch</th>
<th>TSB (tonnes)</th>
<th>SSB (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34818</td>
<td>29673</td>
<td>FBAR 89/90</td>
<td>0.545</td>
<td>10524</td>
<td>25126</td>
<td>22421</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$F$ (0.1)*</td>
<td>0.486</td>
<td>9615</td>
<td>26270</td>
<td>23553</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$F$ (0.1)**</td>
<td>0.400</td>
<td>8205</td>
<td>28055</td>
<td>25320</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$F$ (const.SSB)</td>
<td>0.215</td>
<td>4782</td>
<td>32445</td>
<td>29673</td>
</tr>
<tr>
<td>2</td>
<td>45304</td>
<td>33319</td>
<td>FBAR 89/90</td>
<td>0.545</td>
<td>12638</td>
<td>38644</td>
<td>32500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$F$ (0.1)*</td>
<td>0.486</td>
<td>11536</td>
<td>40118</td>
<td>33946</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$F$ (0.1)**</td>
<td>0.400</td>
<td>9828</td>
<td>42414</td>
<td>36202</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$F$ (const.SSB)</td>
<td>0.499</td>
<td>11783</td>
<td>39787</td>
<td>33619</td>
</tr>
</tbody>
</table>

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 slightly 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.

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 interpretation 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 $L_{\text{inf}}$ 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.
Acknowledgments. The authors wish to extend their thanks to Dr J. Horbowy for his critical review of the manuscript and useful suggestions, and to Dr R. Grzebielec for his assistance in making use of MAFFVPA and CCAMLR YR programs.

References

Streszczenie


Oszacowane na podstawie dostępnych materiałów biologicznych i wykorzystane do dalszych obliczeń parametry wzrostu z równania von Bertalanffy’ego \( k = 0.1995, t_0 = -0.4573, L_{\text{illf}} = 61.75 \) cm porównano z ocenami innymi autorów (Tab. III). Wykres oszacowanej zależności masa — długość \( W = 0.00021 \cdot L^{3.3315} \) użytej do obliczenia \( W_{\text{inf}} \) (2042,0 g) przedstawiono na rys. 3. W case of equal weights and different methods 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 \( F_{\text{max}} \) przy założeniu 4 poziomów jednolitego wieku pierwszego odlowu \( (t_c = 1...4) \) (Tab. V) posłużyło 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 — Shepheada 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 współczynnika 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 wynosił 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.

Józef Sosiński and Andrzej Paciorkowski

A review of Polish fishery and assessment of fish stock biomass off South Georgia.

Revised and accepted December 15, 1993
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 pomińciem pokoleń o liczebności przekraczającej 600 milionów osobników (Tab. XI, opcja 2).

Dla każdej opcji uzupełnienia przyjęto 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 \( F_{a1} \) (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.