ON THE INSTANTANEOUS NATURAL MORTALITY RATE OF *CHAMPSOCEPHALUS GUNNARI*, SOUTH GEORGIA (SUBAREA 48.3)

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Abstract

The instantaneous rate of natural mortality (M) of *Champsocephalus gunnari* in the South Georgia area was assessed using six different methods. Data on size composition of catches from 1964/65 to 1968/69 and the age/length key for the first half of 1972 were used in the calculations. The results provided a wide range of estimates for M. The discussion of the results suggested that M=0.56 should be used in stock assessment for *C. gunnari* in Subarea 48.3.

Résumé

Le taux instantané de mortalité naturelle (M) de *Champsocephalus gunnari* dans la zone de la Géorgie du Sud a été estimé selon six méthodes distinctes. Pour les calculs, on s'est servi des données sur la composition en tailles des captures de 1964/65 à 1968/69 et de la clé âges/longueurs pour la première moitié de 1972. Les résultats ont offert une gamme étendue d'estimations de M. L'examen des résultats semble montrer que M=0,56 devrait être utilisé lors de l'évaluation des stocks de *C. gunnari* dans la sous-zone 48.3.

Резюме

Коэффициент мгновенной естественной смертности (М) вида *Champsocephalus gunnari* в районе Южной Георгии был оценен шестью имеющимися методами. В расчетах были использованы данные по размерному составу за 1964/65 - 1968/69 гг. и размерно-возрастные ключи за первую половину 1972 г. В результате был получен широкий диапазон оценочных значений коэффициента М. Анализ результатов указывает на то, что при оценке запаса *C. gunnari* в Подрайоне 48.3 следует использовать М=0,56.

Resumen

Se evalúa el coeficiente de mortalidad natural instantánea (M) de *Champsocephalus gunnari* en la zona de Georgia del Sur, mediante seis métodos distintos. Para los cálculos se han empleado datos de composición por tallas de las capturas correspondientes a las temporadas 1964/65 a 1968/69, además de datos de la clave edad/talla del primer semestre de 1972. Se han obtenido una amplia gama de resultados de M, que una vez examinados y debatidos, demuestran que el valor adecuado de M para la evaluación de la población de *C. gunnari* en la Subárea 48.3 es de M=0.56 .

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1. INTRODUCTION

K.-H. Kock (1981) was the first to determine the instantaneous rate of natural mortality using the methods of Pauly (M=0.61) and Richter-Efanov (M=0.22). The author himself admitted that the results varied to such a degree that interpreting them was very difficult indeed. Realising that the results were contradictory and using for the most part, earlier assessments of *Notothenia rossii*, Kock made the preliminary assumption that **M** was between 0.22 and 0.38. The CCAMLR Working Group on Fish Stock Assessment later adopted 0.35 as the value of this coefficient.

Recent research, however, has determined a value of 0.45 (Sparre, 1989) and 0.55 (Frolkina and Dorovskikh, 1989) for **M**. This research was carried out using age/length composition data from catches of the "pristine" *C. gunnari* population according to the methods of Baranov, Beverton and Holt and several other methods. Therefore in 1989 the CCAMLR Working Group on Fish Stock Assessment used **M**=0.50 in its calculations as well as the previously accepted estimate of 0.35.

Since Sparre (1989) singled out the Heinke method (**M**=0.56) from all those used, the Working Group decided that this value could be used in the future on an equal footing with M=0.35 (CCAMLR-VIII, paragraph 49). The Working Group recognised the importance of accurately determining a value for **M** and decided to address the question once again in 1990 at the Ninth Meeting of CCAMLR. Taking the above factors into consideration, the authors decided to tackle once more the problem of obtaining a more precise value for **M**. In contrast to a previous study (Frolkina and Dorovskikh, 1989), the number of methods used was increased and included the Heinke, Robson-Chapman methods as well as an approach outlined in a paper by Gasiukov and Dorovskikh (1990).

2. MATERIALS AND METHODS

Data on size composition from catches taken from the seasons 1964/65 to 1968/69 were used (Table 1) as was the age/length key for the first half of 1972 (Table 2). Unlike the authors' study in 1989, growth parameter calculations and estimates of **M** were carried out using data for each individual season and for the entire period. Age composition over all seasons was determined using two procedures. The basic algorithms are described below.

(i) The Baranov Method (1914):

When fishing is either not taking place or is insignificant it is assumed that the instantaneous rate of mortality **Z=M** and

$$M = ln\left(\frac{N_{a+1}}{E_{a+1}} / \frac{N_a}{E_a}\right)$$

where N_a = catch of age group a which is fully represented in the catch; and
E_a = fishing effort.

It is assumed that fishing effort for groups a and $a+1$ is the same, i.e. $E_a = E_{a+1}$, and, consequently,

$$M = ln\,(N_{a+1}/N_a)$$

(ii) The Heinke Method (1913):

$$M = ln \frac{N_a + N_{a+1} + N_{a+2} + \ldots}{N_{a+1} + N_{a+2} + \ldots}$$

N_a is the same here as it is for the Baranov method.

(iii) The Beverton-Holt Method (1956):

$$M = \frac{1}{\bar{t} - t'}$$

where $\bar{t}$ = mean age in the catch;
t' = first age group, fully represented in the catch,

$$\bar{t} = \frac{\sum_{a=t'}^{t_k} (a+0.5) \cdot N_a}{\sum_{a=t'}^{t_k} N_a}$$

t_k = oldest age group in the catch.

(iv) The Robson-Chapman Method (1961):

$$M = ln \left(1 + \frac{1}{\bar{t} - t'}\right)$$

where $\bar{t}$ and t' are the same as for the Beverton-Holt method.

(v) The Alverson-Carney Method (1975):

$$M = \frac{3 \cdot K}{e^{T \cdot K} - 1}$$

where **K** = Bertalanffy growth equation parameter; and
T = age at which population biomass is at its maximum.

(vi) The approach suggested by Gasiukov and Dorovskikh (1990):

This approach is based on the construction of a regression curve between the rate of annual fishing mortality and fishing effort. Particular attention is paid to the value of the parameter a in this equation:

$$F_y = a + b \cdot E_y$$

where a,b = parameters of the equation;
E_y = fishing effort in year y; and
F_y = rate of fishing mortality in year y.

VPA is tuned to various values for the rate of natural mortality when calculating fishing mortality coefficients. From the suite of values **M** is taken to be the one at which the estimate of the independent parameter a is close to zero.

The following two procedures were used to calculate the age structure of the catches. The first assumes that the following data are known:

- size composition of catches; and
- age/length key.

Size composition data is used in estimating components of size classes in the catch:

$$p_a = \frac{n_l}{\sum_{l_n}^{l_k} n_l}$$

where n_l = number of fish of length l in the catch;
l_n = minimum length in the catch; and
l_k = maximum length in the catch.

The age/length key is used in determining the component of age class a which belongs to size class l:

$$p_a^l = \frac{n_a^l}{\sum_{a=a_1}^{a_2} n_a^l}$$

where n_a^l = number of fish aged a of length l in the key;
a_1 = minimum age of fish of length l;
a_2 = maximum age of fish of length l;

The component of age group a in the catch is determined by the formula:

$$p_a = \sum_{l=l}^{l_2} pl \cdot p_a^l$$

where l_1 = minimum length which may correspond to class a; and
l_2 = maximum length which may correspond to class a.

Kimura's algorithm is the basis of the second procedure for determining age composition (Kimura, 1987). This algorithm presupposes the same initial data as does the first procedure, however the age/length key may refer to a period independent of time at which data on size composition was collected.

Size composition components are estimated in the same way as in the first procedure although components of the age/length key are worked out using the following formula:

$$p_a^l = \frac{n_a^l}{\sum_{l=l_1}^{l_2} n_a^l}$$

The algorithm functions in the following iterational way:

Step 1. Starting values are determined for components of age composition in a catch:

$$p_a = \frac{1}{a_k},\ a=1,2,\ldots,a_k$$

where a_k = the number of age groups in the key.

Step 2. Estimates of these components are made for all size classes using data on the age/length key:

$$p_l' = \sum_{a=1}^{a_k} p_a \cdot p_a^l$$

Step 3. New estimates of the components of age composition are calculated according to the formula:

$$p_a' = p_a \cdot \sum_{l=l_n}^{l_k} \frac{p_l \cdot p_a^l}{\sum_{j=a_1}^{a_2} p_j \cdot p_j^l}$$

Step 4. The premise $|p_a - p_a'| < 8$ is validated. If it is accurate then:

- the new estimates of $\mathbf{p}_a'$ become current, i.e. $P_a = p_a'$, $a = 1,2,\ldots a_k$; and
- calculations given in Step 2 are continued.

3. RESULTS OF CALCULATIONS AND DISCUSSION

Age composition of catches from 1964/65 to 1968/69 and for the period as a whole is shown in Table 3. Mean length by age group for each season was calculated as the mean weighted value of length for each age group (Table 4).

The data presented served as a starting point for determination of parameters of Bertalanffy's growth curve (Table 5). Values for mean length determined using less than three elements in the sample were eliminated during calculations. Thus, the background data obtained (Tables 3 to 5) were used in calculating values of **M** for each season individually and for the entire period using all of the methods shown (Table 6). It should be noted that the small sample size in seasons 1964/65 and 1967/68 brings into question the reliability of estimates for parameters $\mathbf{L_\infty}$ and **K** since the length recorded for *C. gunnari* significantly excedes the asymptotic length and **K** is much greater than the values obtained when larger samples were taken. Therefore the Alverson-Carney method was not employed to estimate **M** for those seasons.

The results provided a wide range of estimates for **M** (from 0.16 to 1.13). It is interesting to observe that in two of the methods (Beverton-Holt and Robson-Chapman) mean age varies considerably from season to season:

Season	1964/65	1966/67	1967/68	1968/69	1964-69 Procedure 1	1964-69 Procedure 2
$\bar{t}$	5.8	4.9	4.3	4.1	4.6	4.6

Therefore, when in season 1964/65 mean age is the greatest, **M** is accordingly the lowest (Beverton-Holt, Robson Chapman methods) and in 1968/69, when mean age is the lowest then **M** (derived using the above two methods) is the greatest in comparison with the estimates of other methods.

The bottom two rows of Table 6 present the mean estimates of **M** for each season and for the whole period. The first gives values obtained using all methods while the second disregarded maximum and minimum values. In practically every case the estimate of the mean value of **M** was either equal to or greater than 0.50. Therefore any future use of **M**=0.35 will be incorrect. This view is supported by the method suggested by Gasiukov and Dorovskikh (1990).

Table 7 gives the mean weighted values of fishing mortality for the main age groups (3 to 5) calculated by VPA using the Laurec-Shepard tuning method. This was done at various levels of natural mortality which were used to construct the following regression equation:

$$F_y = a + b \cdot E_y$$

Table 8 shows **a** and **b** from the regression equation as well as the correlation coefficient which demonstrates the close link between the two. Analysis of these data indicates that the highest point of intersection (**a**=0.183) occurs at **M**=0.35. The smallest positive value (**a**=0.045) occurs at **M**=0.56. Moreover, when there is a transition of **M** from 0.56 to 0.70, the intercept sign changes from positive to negative (Table 9, Figure 1).

It may therefore be assumed that the rate of natural mortality for *C. gunnari* is not less than 0.56.

4. CONCLUSION

The authors consider that their results show the instantaneous rate of natural mortality for *C. gunnari* in Subarea 48.3 (South Georgia) to be 0.56.

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Table 1: Age composition of the "pristine" *C. gunnari* population by season.

Length (cm)	1964/65	1966/67	1967/68	1968/69	1964-69
16-17	0	3	0	0	3
18-19	0	18	0	0	18
20-21	0	9	2	14	25
22-23	0	2	8	77	87
24-25	0	23	53	138	214
26-27	4	53	111	123	291
28-29	4	91	55	41	191
30-31	4	79	19	23	125
32-33	1	50	28	39	118
34-35	4	67	38	26	135
36-37	6	72	55	17	150
38-39	14	63	46	7	130
40-41	8	78	10	0	96
42-43	13	27	0	2	42
44-45	14	13	0	0	27
46-47	2	8	0	1	11
48-49	2	6	0	3	11
50-51	0	8	0	2	10
52-53	0	6	0	3	9
54-55	0	5	0	3	8
56-57	0	0	0	0	0
58-59	0	0	0	1	1
Total	76	681	425	520	1701

Table 2: Age/length key for the first half of 1972.

Length (cm)	Age group									
	1	2	3	4	5	6	7	8	9	10
16-17	15	0	0	0	0	0	0	0	0	0
18-19	25	2	0	0	0	0	0	0	0	0
20-21	1	41	0	0	0	0	0	0	0	0
22-23	0	43	8	0	0	0	0	0	0	0
24-25	0	83	9	0	0	0	0	0	0	0
26-27	0	29	69	0	0	0	0	0	0	0
28-29	0	0	100	0	0	0	0	0	0	0
30-31	0	0	88	8	0	0	0	0	0	0
32-33	0	0	48	50	2	0	0	0	0	0
34-35	0	0	0	83	9	0	0	0	0	0
36-37	0	0	0	42	46	2	0	0	0	0
38-39	0	0	0	13	61	13	0	0	0	0
40-41	0	0	0	0	13	36	1	0	0	0
42-43	0	0	0	0	11	11	6	0	0	0
44-45	0	0	0	0	0	4	11	0	0	0
46-47	0	0	0	0	0	3	7	1	0	0
48-49	0	0	0	0	0	0	7	3	1	0
50-51	0	0	0	0	0	0	4	4	2	0
52-53	0	0	0	0	0	0	1	5	3	0
54-55	0	0	0	0	0	0	0	2	4	2

Table 3: Age composition of the "pristine" *C. gunnari* population determined using two procedures for calculations.

Age	1964/65	1966/67	1967/68	1968/69	1964-69 Procedure 1	1964-69 Procedure 2
1	0	20	0	0	20	16
2	1	129	103	355	588	384
3	11	228	169	183	591	616
4	9	132	81	53	275	246
5	20	121	68	18	227	238
6	17	83	16	3	119	131
7	16	29	0	4	49	45
8	1	10	0	4	15	12
9	0	7	0	3	10	10
10	0	1	0	2	3	2

Table 4: Mean length in the "pristine" *C. gunnari* population by age group.

Age	1964/65	1966/67	1967/68	1968/69	1964-69 Procedure 1	1964-69 Procedure 2
1	-	17.7	-	-	17.7	17.3
2	26.0	21.3	23.5	22.2	22.3	23.0
3	28.3	28.7	27.5	27.3	27.9	28.4
4	35.2	34.2	34.5	33.5	34.2	34.0
5	38.8	37.8	37.0	36.4	37.6	37.5
6	41.3	40.2	38.7	39.7	40.2	40.3
7	44.1	45.2	-	47.8	45.1	45.6
8	47.5	50.5	-	51.0	50.5	50.5
9	-	51.9	-	52.3	52.5	52.0
10	-	54.0	-	56.3	54.0	54.0

Table 5: Estimate of Bertalanffy growth curve parameters for each season and for the whole period determined by using two procedures for calculating age composition.

Parameter	Seasons					
	1964/65	1966/67	1967/68	1968/69	1964-69 Procedure 1	1964-69 Procedure 2
L_∞(cm)	47.5	86.7	45.6	77.4	80.9	82.0
t_0	0.83	-1.45	-0.34	-0.66	-1.34	-1.35
k	0.414	0.088	0.304	0.119	0.099	0.098
Sample size	5	9	5	8	10	9
Youngest group	3	1	2	2	1	1
Oldest group	7	9	6	9	10	9

Table 6: Estimates of natural mortality rate by season using various methods.

Method	Seasons					
	1964/65	1966/67	1967/68	1968/69	1964-69 Procedure 1	1964-69 Procedure 2
Baranov	0.80	0.77	0.78	0.96	0.75	0.82
Beverton-Holt	0.36	0.53	0.77	0.90	0.62	0.63
Heinke	0.16*	0.47	0.70	1.13**	0.61	0.64
Robson-Chapman	0.31	0.43	0.57	0.64	0.48	0.49
Carney	-	0.38	-	0.34	0.37	0.37
Estimate of mean **M** (Option 1)	0.475	0.516	0.705	0.794	0.566	0.590
(Option 2)	0.490	0.516	0.705	0.710	0.566	0.590

* minimum value of **M**

** maximum value of **M**

Table 7: Standardized fishing effort and mean weighted fishing mortality for the main age groups (3 to 5) at different levels of natural mortality.

Season	Effort	F (mean weighted)			
		M=0.35	M=0.50	M=0.56	M=0.70
1982/83	20 420	1.521	1.396	1.343	1.210
1983/84	15 798	2.274	2.005	1.884	1.564
1984/85	2 984	0.854	0.589	0.492	0.296
1985/86	4 483	0.259	0.186	0.159	0.104
1986/87	20 035	1.131	0.905	0.811	0.589
1987/88	15 941	0.913	0.691	0.604	0.414
1988/89	7 972	0.345	0.248	0.213	0.141
1989/90	1 497	0.113	0.089	0.079	0.057

Table 8: Parameters of a regression correlation between the rate of fishing mortality and fishing effort at different levels of natural mortality.

Natural Mortality Rate	Parameters		Correlation Coefficient **R**
	a	**b**	
0.35	0.183	0.0000667	0.718
0.50	0.081	0.0000613	0.722
0.56	0.045	0.0000586	0.721
0.70	0.022	0.0000510	0.715

Table 9: Preliminary estimates of fishing mortality obtained from the regression equation in Table 8.

	F (Preliminary)			
	M=0.35	**M=0.50**	**M=0.56**	**M=0.70**
20 420	1.545	1.333	1.242	1.019
15 798	1.237	1.049	0.971	0.784
2 984	0.382	0.264	0.220	0.130
4 483	0.482	0.356	0.308	0.207
20 035	1.519	1.309	1.219	1.000
15 941	1.246	1.058	0.979	0.791
7 972	0.715	0.570	0.512	0.384
1 497	0.283	0.173	0.133	0.054
0	0.183	0.081	0.045	-0.022

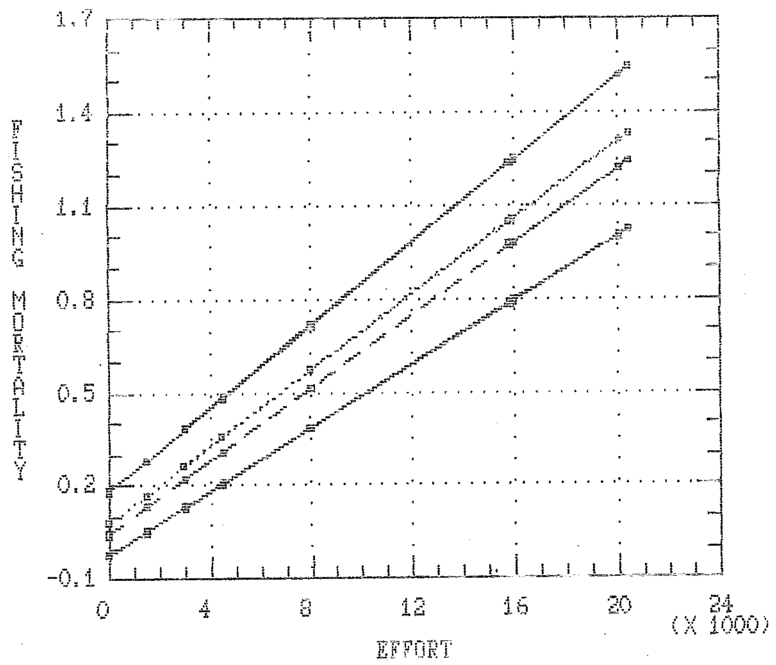

Figure 1: Functions of fishing mortality coefficients and fishing effort for different values of natural mortality.
1 - **M**=0.35   3 - **M**=0.56
2 - **M**=0.50   4 - **M**=0.70

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