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CHARACTERISTICS OF AGE AND GROWTH OF MACKEREL (*SCOMBER SCOMBRUS* L.) FROM NORTHWEST ATLANTIC

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Age of mackerel caught in Northwest Atlantic in 1983-1984 was determined from otoliths. Growth rate was obtained from direct measurements and back calculations. Growth rate differed noticeably between particular year classes as well as sexes.

INTRODUCTION

Atlantic mackerel is, along with herring, the most important pelagic fish in Northwest Atlantic. It was of special importance in 1970-1976, when catches exceeded 200 thousand tons annually, mostly due to heavy fishing by European distant water fleets. Scientific studies on an international scale developed in this period as well. Their range increased in the last years of this period, notwithstanding a decrease of total catches and of the catch per unit effort. Introduction in 1977 of the exclusive fishery zone limited mackerel catches to about 30.000 tons annually. At the same time, Northeast Fisheries Center in Woods Hole, USA (a research center of the National Marine Fisheries Service), has overtaken the problem of mackerel stock assessment from the International Commission for the Northwest Atlantic Fisheries (ICNAF). As a result of these changes, scientists from a number of countries became less interested in this species, this being a typical situation in cases when exploitation of a species is limited. However, in order to understand the mechanisms affecting the fish biomass, it is necessary to study the stock also in case of less intensive fishing. In view of this, studies were undertaken in order to determine age composition of mackerel stock in Northwest Atlantic and to characterize growth rate of this fish.

MATERIALS AND METHODS

Materials were collected during two research-commercial cruises of Polish trawlers m/t „Kunatka" (type B-29) in 1983 and m/t „Admirał Arciszewski" (type B-89) in 1984 to Northwest Atlantic. Both ships used similar midwater trawls. Totally, 41 fish samples were collected in Subareas 5-6 of the Northwest Atlantic Fisheries Organization (NAFO), 17 in 1983 and 24 in 1984 (Fig. 1, Table 1).

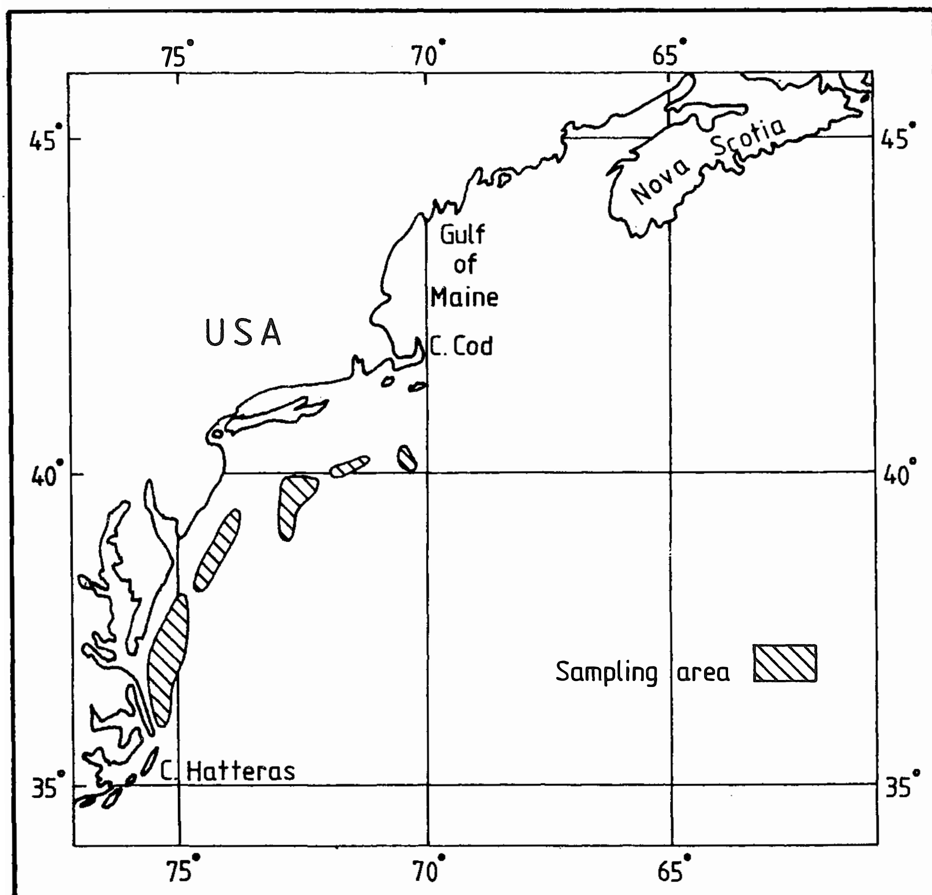

Fig. 1. Distribution of sampling stations of mackerel in Northwest Atlantic in 1983-1984

Table 1

A review of the studies performed

Period		Number of samples	Number of fish			
			length measurement	age determination	otolith measurement	back-calculation
1983	March	2	1561	30	29	29
	April	11	1851	425	422	419
	May	4	453	225	223	220
	March – May	17	3865	680	674	668
1984	January	8	10 947	233	233	223
	February	3	6 054	120	120	120
	March	7	12 553	485	483	468
	April	6	10 367	192	190	184
	January – April	24	39 921	1 030	1 026	995
Total	1983 – 1984	41	43 786	1 710	1 700	1 663

Length of all fish was measured *(longitudo caudalis)*. All other measurements given in this paper relate to this length. Length was measured up to 0.1 cm, but the fish were divided into length classes at 1 cm intervals, rounding up the results to the nearest cm. In cases when total length (l.t.) was recalculated into longitudo caudalis or vice versa (this being done in order to compare the results), the following equations were used (Hunt and Stobo, 1976):

$$\text{l.caud.} = -0.0382 + 0.927\,\text{l.t.} \tag{1}$$

$$\text{l.t.} = 0.0412 + 1.0787\,\text{l.caud.} \tag{2}$$

Mackerel age was determined from otoliths, under a binocular. Before reading, the otoliths were immersed in water. Opinions on the readibility of particular otolith parts in mackerel are controversial (Fig. 2). Steven (1952) and Morawski (1976) suggested that the most reliable results were obtained using postrostrum, while Bolster (1963) and Nesterowicz (1971) stated that rostrum was more readible. I have noted that in most cases the posterior otolith part (*postrostrum*) was more readible, although sometimes only the anterior part (*rostrum*) could have been used, and in exceptional cases only antirostrum. 1 st of January was taken as an assumed date of fish birth.

Rate of growth was estimated by direct measurements as well as back calculations. The first method consisted of calculating mean length of the fish belonging to particular age groups. This method is less labour demanding than the method of back calculations, but the results are less reliable. This is due to a few facts: 1) fish samples may be collected in different periods of the growing season so the

Table 2

Mean length of mackerel age groups in Northwest Atlantic in 1983–1984. L. caud. (cm). o – immature fish

Age	1983						1984						Total 1983 – 1984					
	♂		♀		o + ♂ + ♀		♂		♀		o + ♂ + ♀		♂		♀		o + ♂ + ♀	
	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n
1	21.00	3	21.50	2	17.83	30	–	–	–	–	21.00	1	21.00	3	21.50	2	17.94	31
2	28.57	44	28.31	42	28.40	88	28.19	21	26.82	45	26.84	100	28.45	65	27.54	87	27.57	188
3	34.85	26	34.96	27	34.91	53	32.65	141	32.69	155	32.62	300	32.99	167	33.03	182	32.97	353
4	37.73	22	38.32	22	38.02	44	36.92	26	36.85	27	36.89	53	37.29	48	37.51	49	37.40	97
5	38.53	59	39.17	52	38.83	111	38.87	23	39.83	24	39.36	47	38.62	82	39.38	76	38.99	158
6	38.90	10	39.69	13	39.35	23	39.44	43	39.67	54	39.57	97	39.34	53	39.67	67	39.53	120
7	40.00	2	40.13	8	40.10	10	40.00	8	40.40	10	40.22	18	40.00	10	40.28	18	40.18	28
8	39.82	17	40.52	27	40.25	44	40.33	12	40.73	15	40.56	27	40.03	29	40.60	42	40.37	71
9	40.09	64	40.30	60	40.19	124	40.50	38	40.79	39	40.65	77	40.25	102	40.49	99	40.37	201
10	39.91	23	40.47	43	40.27	66	40.69	61	40.95	88	40.85	149	40.48	84	40.79	131	40.67	215
11	40.42	12	40.80	15	40.63	27	40.67	39	41.23	39	40.95	78	40.61	51	41.11	54	40.87	105
12	40.67	6	41.29	7	41.00	13	42.13	8	41.67	12	41.85	20	41.50	14	41.53	19	41.52	33
13	41.00	2	42.25	4	41.83	6	41.50	4	42.00	11	41.87	15	41.33	6	42.07	15	41.86	21
14	42.00	1	42.00	5	42.00	6	41.83	6	42.67	6	42.25	12	41.86	7	42.36	11	42.17	18
15	41.00	2	41.60	5	41.43	7	41.86	7	42.33	6	42.08	13	41.67	9	42.00	11	41.85	20
16+	41.25	4	–	–	41.25	4	41.00	6	42.29	7	41.69	13	41.10	10	42.29	7	41.59	17

resulting mean fish lengths may differ even for the same year class in the same calendar year, 2) gear selectivity may result in an overestimation of the mean length of fish belonging to younger age groups.

As regards the method of back calculations, caudal radius of the otoliths was first measured (R) (Fig. 2) and then correlation was calculated between this radius and caudal fish length (Fig. 3). This correlation appeared to be almost linear for fish 16-48 cm in length, being expressed by the equation:

$$R = 0.051\ \text{l.caud.} + 0.2946 \qquad (3)$$

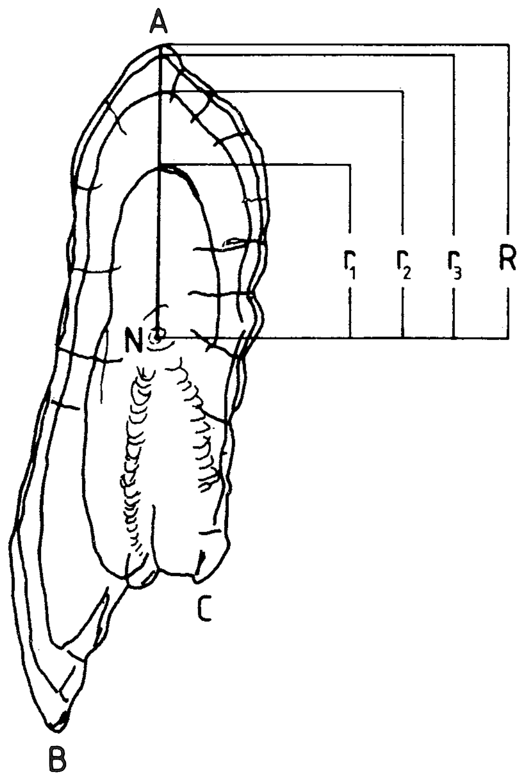

Fig. 2. Scheme of mackerel otolith structure with measured radii (r_1, r_2, r_3, R). A-postrostrum, B-rostrum, C-antirostrum, N-nucleus, R-caudal otolith radius

In view of the fact that the point at which the regression line crossed the abscissa was shifted, back calculations were made with Rosa Lee method, using the equation:

$$L_t = \frac{(L - c)\, r_t}{R} + c \qquad (4)$$

where:

L_t – fish length at age t,

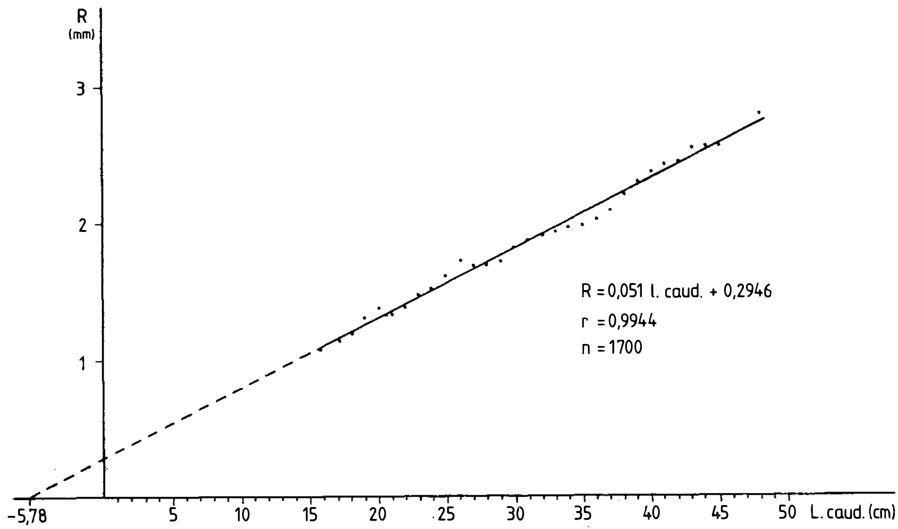

Fig. 3. Dependence between caudal length (l.caud.) and length of caudal otolith radius (R) in mackerel

L – fish length at the moment of catch,

R – total otolith radius,

r_t – otolith radius at age t,

c – correction resulting from the shift of the regression line in relation to the coordinates.

Value of c was calculated from equation (3); it amounted to −5.78 cm.

Otoliths of some older fish were partly unreadible, i.e. only a few first growth zones were clearly visible, while the edge of otolith was quite unreadible. In these cases, measurements embraced only the radii in the readible part and total otolith radius. Kompowski (1981) found that in horse mackerel, otoliths of rapidly growing fish were more readible. They were characterized by broader distances between hyaline zones. In of this, unreadible otoliths were not totally discared as this would result in an overestimation of the growth rate.

Von Bertalanffy's equation was fitted to the empirical data obtained from back calculations:

$$L_t = L_\infty [1 - e^{-k(t - t_0)}] \qquad (5)$$

where:

t – fish age,

L_t – fish length at age t,

L_∞ – asymptotic length,

k – catabolism coefficient,

t_0 – theoretical age at which the fish begin to grow.

Parameters of von Bertalanffy's equation (L_∞, k and t_0) were determined using the method by Allen (1966). Moreover, in order to determine the suitability of various growth models for characterizing mackerel growth, theoretical growth of this species was estimated according to the models of Gompertz (after Beverton and Holt, 1957) and Ford-Walford (after Gulland, 1969) as well as using a polynomial of the 2nd order (Szypuła, 1977).

RESULTS

Length distribution

Fig. 4 presents length distribution of mackerel caught in NAFO Subareas 5-6 by Polish trawlers in 1983-1984. Length of the fish under study ranged from 14 to 49 cm, the length distribution being different in particular years. In 1983 (Fig. 4a) this distri-

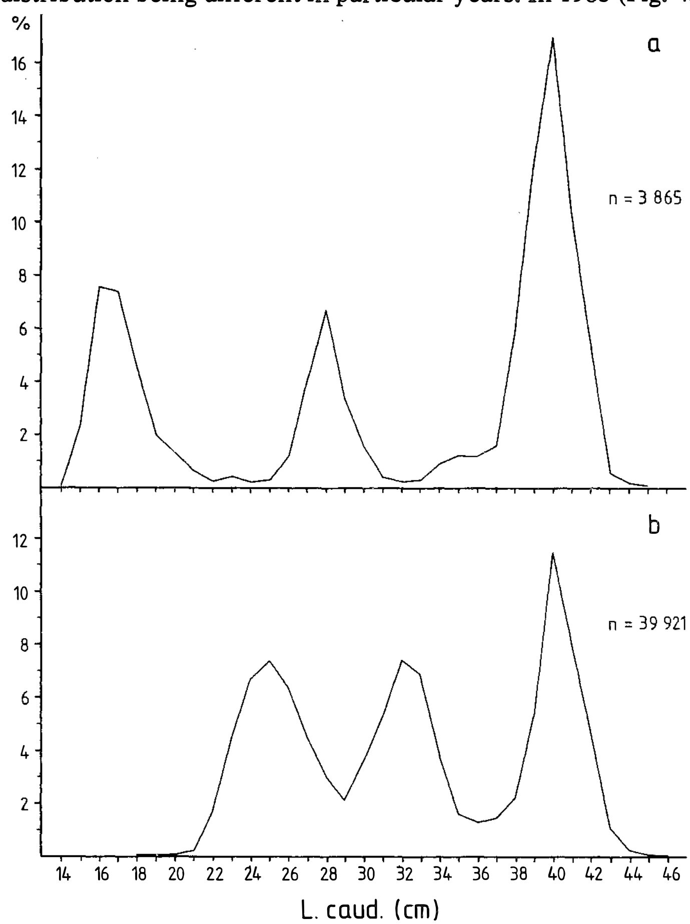

Fig. 4. Length distribution of mackerel caught in Northwest Atlantic (Subareas 5-6 NAFO); a) March-May 1983, b) January-April 1984

bution showed three peaks, the modal values of these being 16-17 cm, 28 cm and 40 cm, while the mean fish length amounted to 31.57 cm. In 1984 (Fig. 4b) there were also three length peaks, but their modal values were 25 cm, 32-33 cm and 40 cm, the mean fish length being 32.49 cm. In 1984 there were practically no small fish (14-19 cm) in the catch although the same fishing gear was used and the fishing took place beyond the coastal area in both years. This suggests that in 1984 smaller fish were less abundant. On the other hand, appearance of one modal value at 25 cm instead 28 cm and another at 32-33 cm, while such fish were scarce in 1983, suggests that particular year classes of mackerel differed as to the growth rate in the first years of life.

Age composition

Mackerel, similarly as a number of pelagic fishes forming schools, is characterized by considerable fluctuations of the recruitment, so that its catches are usually predominated by a few year classes, and it is possible to observe these year classes in consecutive years. This phenomenon was clearly noticeable in mackerel caught in 1983-1984 (Fig. 5). In 1983 younger fish (age group 1 and 2) were most numerous,

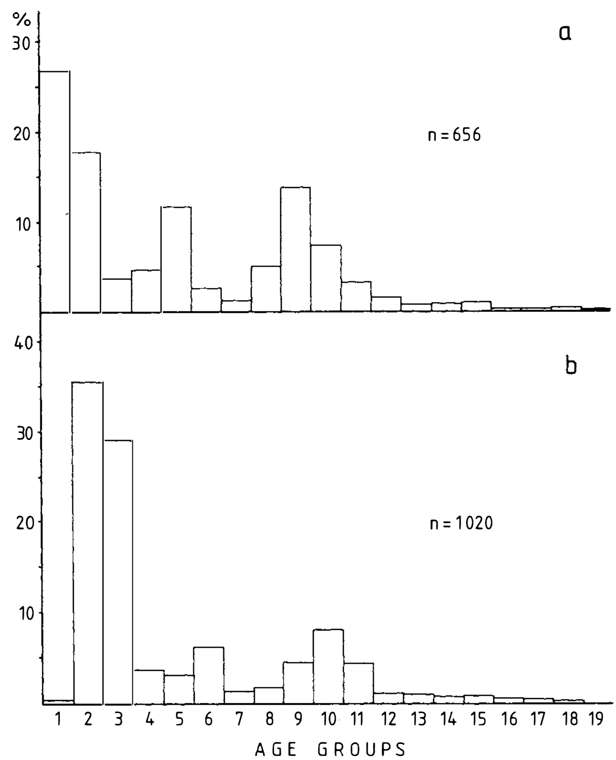

Fig. 5. Age composition (%) of mackerel catches in Northwest Atlantic (Subareas 5-6 NAFO); a) March-May 1983, b) January-April 1984

constituting 45% of the total mackerel catch. As regards older fish, age group 5 (11.5%) i.e. the fish born in 1978, and age groups 9(13.6%) and 10 (7.9%) i.e. born in 1974 and 1973 were most numerous (Fig. 5a). In 1984 the following age groups were dominating: 2(33.4%), 3(28.3%), 6(6.6%), 10(8.7%) and 11 (4.7%) i.e. the fish born in 1982, 1981, 1978, 1974 and 1973 (Fig. 5b) and most numerous also in 1983. It is interesting to note that in 1984 there were almost no fish in the age group 1, pointing to strong year class of 1982 (age group 1 in 1983) and weak of 1983.

The oldest fish found were 19 (1983 catch) and 18 years old (1984 catch) but totally the fish older than 12 years were scarce, not exceeding 1%. Mean age of mackerel in the catch decreased from 4.89 in 1983 to 4.58 in 1984.

Growth rate

Growth in length was estimated at first by calculating mean fish length in particular age groups (Table 2). Rate of growth in length was very rapid during the first two years of fish life, becoming much slower in the third year. Significant inhibition of the growth rate was observed since the fourth year. Attention should be given to noticeable differences in the growth rate between particular year classes, especially in the first 3-4 years of life. For instance, mackerel belonging to age group 3 in 1983 were almost 2.3 cm longer than the fish at the same age caught in 1984. Similar differences were noted for age groups 2 and 4. Length differences noted in 1983 and 1984 for age groups 2-4 were statistically significant (Student's t test).

Comparing growth rate of males and females caught in 1983 and 1984 (Table 2) it can be noted that males aged 2 years were longer than females. On the other hand, no differences between the sexes were found in fish aged 3 years. As regards older fish, females tended to be longer than males, but the differences usually did not exceed 1 cm.

Back calculations (Table 3) made it possible to use not only the data on mean lengths of particular year classes in 1983-1984, as in direct measurements method, but also the data on earlier growth of a number of mackerel year classes occuring in the catch. Older fish appeared to be characterized by much slower growth rate in the first years of life compared to younger fish, this bias being typical of the back calculations method. Average lengths in consecutive years of mackerel life obtained from back calculations were lower than those estimated from direct measurements, the only exceptions being l_1 and l_2. Most pronounced differences were observed within age range 4-9 years, suggesting more rapid mackerel growth in the last years.

Data on mackerel growth given in Table 3 were used to calculate the parameters of von Bertalanffy's equation:

$$L_{\infty} = 40.81 \text{ cm}, k = 0.3804, t_0 = -0.6749$$

Table 3

Growth rate of mackerel in Northwest Atlantic. Back calculations from the otoliths. L. caud. (cm)

Age	n	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}	L_{13}	L_{14}	L_{15}	L_{16}
1	31	17.94	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2	188	18.02	27.57	–	–	–	–	–	–	–	–	–	–	–	–	–	–
3	350	18.38	28.83	32.97	–	–	–	–	–	–	–	–	–	–	–	–	–
4	97	19.91	31.59	35.32	37.40	–	–	–	–	–	–	–	–	–	–	–	–
5	158	19.97	30.75	35.23	37.34	38.99	–	–	–	–	–	–	–	–	–	–	–
6	119	19.56	30.05	34.33	36.58	38.28	39.53	–	–	–	–	–	–	–	–	–	–
7	27	19.50	28.74	33.28	35.87	37.56	39.02	40.17	–	–	–	–	–	–	–	–	–
8	71	17.66	26.50	31.78	34.50	36.27	37.81	39.15	40.37	–	–	–	–	–	–	–	–
9	198	17.18	26.21	31.39	33.68	35.42	36.86	38.14	39.29	40.37	–	–	–	–	–	–	–
10	213	17.12	25.98	30.91	33.27	34.87	36.28	37.55	38.70	39.75	40.68	–	–	–	–	–	–
11	104	16.70	25.32	29.98	32.63	34.19	35.63	36.95	38.09	39.12	40.05	40.86	–	–	–	–	–
12	33	17.90	25.71	30.04	32.61	34.09	35.44	36.52	37.68	38.70	39.72	40.57	41.32	–	–	–	–
13	21	17.59	25.56	29.68	31.93	33.67	35.13	36.22	37.30	38.25	39.33	40.22	41.04	41.78	–	–	–
14	17	17.94	24.64	28.62	31.16	33.14	34.87	36.15	37.18	38.13	39.09	39.95	40.75	41.51	42.25	–	–
15	19	17.06	23.78	27.62	30.70	32.38	33.67	34.94	36.09	37.06	38.03	38.92	39.71	40.49	41.20	41.94	–
16+	17	15.64	21.93	26.21	28.82	30.18	31.77	33.13	34.31	35.40	36.40	37.30	38.17	38.88	39.66	40.31	40.97
n	1663	1662	1631	1434	1071	967	807	685	658	590	397	194	93	65	46	30	13
$\bar{x}$	–	18.16	27.83	32.40	34.58	35.98	36.81	37.62	38.67	39.52	40.05	40.26	40.40	40.75	41.13	41.24	40.97
Range	–	10.58–26.52	17.78–35.94	22.39–38.83	24.48–40.02	27.26–42.00	28.38–42.00	30.52–42.84	31.95–44.00	33.14–43.00	33.83–44.00	34.87–43.97	36.07–44.93	36.76–45.50	37.45–46.27	37.79–47.23	38.38–48.00
s	–	2.33	2.79	2.53	2.49	2.34	1.96	1.64	1.56	1.41	1.47	1.54	1.74	1.80	1.82	1.93	2.35

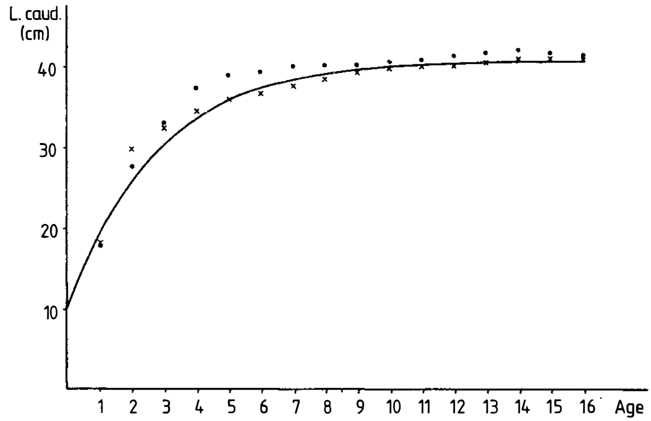

Fig. 6. Growth rate of mackerel in Northwest Atlantic according to von Bertalanffy's equation; points – direct measurements , crosses – back calculations

Table 4

Theoretical growth rate of mackerel calculated from various models: von Bertalanffy [1], Ford-Walford [2], Gompertz [3], polynomial of the 2nd order [4]. Empirical data [5], l. caud. (cm)

Age	1	2	3	4	5
1	19.23	17.50	18.16	23.42	18.16
2	26.06	27.33	23.21	26.58	27.83
3	30.73	32.85	27.57	29.44	32.40
4	33.92	35.95	31.13	32.00	34.58
5	36.10	37.69	33.90	34.27	35.98
6	37.59	38.67	35.99	36.23	36.81
7	38.61	39.22	37.54	37.89	37.62
8	39.30	39.53	38.67	39.26	38.67
9	39.78	39.71	39.49	40.32	39.52
10	40.11	39.81	40.07	41.09	40.05
11	40.33	39.86	40.49	41.56	40.26
12	40.48	39.89	40.78	41.72	40.40
13	40.59	39.91	40.99	41.59	40.75
14	40.66	39.92	41.14	41.16	41.13
15	40.70	39.92	41.24	40.43	41.24
16	40.74	39.92	41.32	39.40	40.97
Average difference between empirical (column 5) and theoretical data	0.60	0.92	1.07	1.43	–

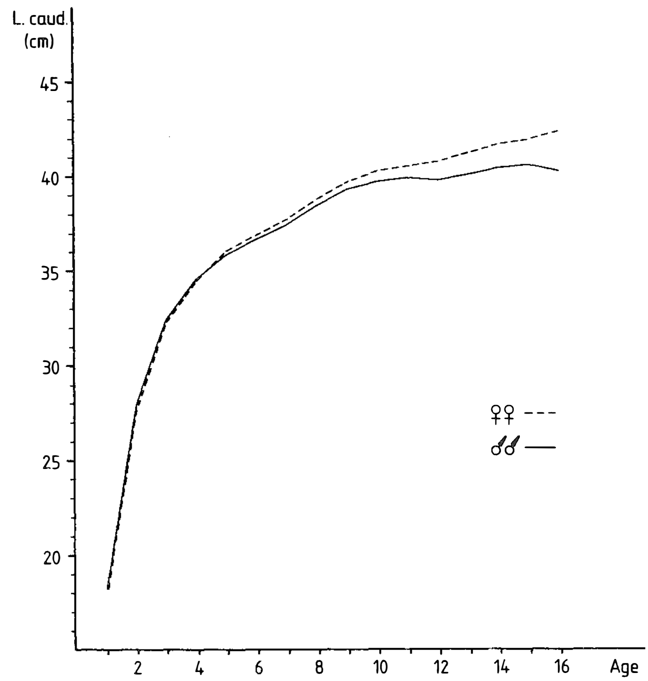

Fig. 7. Growth rate of mackerel males and females in Northwest Atlantic according to back calculations from the otoliths, l.caud. (cm)

Theoretical curve of mackerel growth, drawn using these parameters, is presented in Fig. 6. Theoretical values usually fit well those obtained from back calculations. Notwithstanding this, mackerel growth in length, with very large increments in the first two years of life, and very small ones for fish older than 4 years, is not very typical for fish. As a result, it is difficult to fit the theoretical model to the empirical data. In case of von Bertalanff'y equation, these difficulties are reflected in L_{∞} which appeared to be lower than mean lengths of the oldest fish (age groups 14-16). Irrespective of these discrepancies, von Bertalanffy's model reflects better real mackerel growth than other more frequently used models (Table 4).

Back calculations made separately for males and females confirmed the differences noted in the growth rate between two sexes (Fig. 7). In the first 6 years of life no sex prevailed as to the growth rate, and the differences between mean lengths were not significant statistically[x)]. Only in case of fish older than 7 years, females became significantly longer than males and the differences increased with the fish age.

[x)] Statistical significance was verified using Student's t test for the differences between two means.

DISCUSSION

Reliability of mackerel age determinations was studied mostly by the authors dealing with this fish in Northeast Atlantic. Their opinions are controversial. Steven (1952) examined 8422 pairs of mackerel otoliths and stated that 25.% were unreadible, this being true mostly of fish older than 6 years. Postuma (1972) also advocated that age determinations were reliable for young mackerel (up to 5 years), while the otoliths of older fish were hardly readible. In addition to this, experiments on simultaneous reading of the same otoliths by a number of researchers showed that in case of older fish the results were less consistent than for younger fish. Hamre (1978) analysed the effect of fishing on mackerel stock in the North Sea and he grouped together all fish older than 8 years, explaining that their otoliths were unreadible. On the other hand, Bolster (1963) advocated that if proper light was used, age of older mackerel (10 years and more) could have been determined precisely. Scientists studying mackerel in Northwest Atlantic limited themselves (in the papers known to the author) only to stating that the fish age was determined from otoliths, without mentioning any difficulties. Moores et al. (1975) mentioned that discrepancies in the results were delt with by a third researcher (age was determined by two scientists), but nothing was said about the substance of these discrepancies. In view of the fact that age was determined for a number of age groups, and no difficulties were mentioned even in case of older fish, it might be assumed that otoliths of mackerel from Northwest Atlantic were readible and interpretable. However, the literature (Isakov, 1977; Anderson, 1982) gave some examples of considerable discrepancies in determining mackerel age. Moreover, these discrepancies were related to younger fish, the age of which should be doubtless and possible to verify with Petersen's curve. Since the discrepancies did occur, it is obvious that determination of age in case of older fish (which is always more difficult) must be connected with a risk of error, the more so that for fish aged 4 years and more it is not possible to use Peterson's method. These fish form right--hand side peak at the graph of length distribution (Fig. 4).

Domination of particular age groups in mackerel catches changes from year to year, reflecting passage of most abundant year classes into consecutive age groups. The strongest year class in the past, which dominated in the catches for a number of years (until 1969) was born in 1959. The next exceptionally strong year class was the one born in 1967. It was intensively exploited in 1967-1977 and constituted 25% of the total mackerel catch (Anderson and Paciorkowski, 1980). Since 1976 the year class born in 1974 dominated in the catch for as many as 6 years. This year class appeared to be the second most numerous since 1967 year class. As late as 1981 almost 21% of the catch were represented by 1974 year class (Anderson, 1982), and studies by Paciorkowski and Mucha (1982) showed that also in 1982 this year class was most numerous. In the eighties, apart from the 1974 year class, the catch contained also fish of 1978 year class, representing 22% in the catch of 1980 (Anderson, 1982), 21.8% in 1982 (Paciorkowski and Mucha, 1982) and 9.9% in 1983 (Paciorkowski et al., 1983), as well as 1975 and 1973 year classes, the latter representing about 10% each in 1982 (Paciorkowski and Mucha, 1982), and 8.3 and 6.6% respectively in 1983 (Paciorkowski et al., 1983). Attention is also drawn to numerous share of age groups 1 and 2 in Polish catches in 1983, and age groups 2 and 3 in the catches in 1984, at almost complete lack in the latter catch of fish from age group 1 (Fig. 5). This suggests strong year class of 1981 and especially of 1982, the same being observed also by other authors (Anderson, 1982; Paciorkowski and Mucha, 1982; Paciorkowski et al., 1983; Giedz and Paciorkowski, 1984).

Comparing the data given by different authors with those presented in this paper, it is readily seen that the estimates of age composition of the exploited mackerel stock in the eighties are quite consistent. It should be underlined that age determinations made by different authors gave similar results also for older mackerel, this being very important (1974 year class belonged in 1983-1984 to 9-10 age groups). Hence, it may be concluded that determination of mackerel age in Northwest Atlantic can be reliable also for older than 6-8 years fish.

Authors of the papers published in the seventies and dealing with mackerel growth obtained similar results irrespective of the method used (Table 5). Studies carried out in the first years of the next decade revealed that mackerel growth accelerated. In 1981-1982 fish belonging to age groups 2-6 were characterized by much higher mean lengths than those observed in the previous decade (Paciorkowski, 1985). In 1983-1984, fish 4-7 years old were noticeably longer (Table 5). Closer analysis of the data by Paciorkowski (1985) and of my own data (Table 2 and 5) revealed that rapid growth was related most of all to the year classes born in 1976-1980. For example, year class of 1979, characterized by the most rapid growth, was 4.99 cm longer in 1981 that the mean length of the respective age group in the seventies (age group 2), by 5.2 cm in 1982, by 5.39 cm in 1983, and by 4.98 cm in 1984 (calculated on the basis of Table 5). For the 1978 year class these differences were from 4.90 cm in 1981 (age group 3), through 4.87 in 1982, 4.45 cm in 1983, to 3.69 cm in 1984 (age group 6). For the year classes born in 1976, 1977 and 1980 these differences were only slightly lower. As mentioned before, acceleration of mackerel growth in the eighties did not embrace the whole stock; year classes born in 1981 and 1982 were characterized by slower growth than those born in 1976-1980 (Table 2 and 5) while 1982 year class attained mean length of only 26.84 cm at 2 years of age (1984) i.e. 0.87 cm less than the mean length of fish for this age group in the seventies, and as many as 5.86 cm less than the fish in age group 2 belonging to 1979 year class.

Theoretical curves of mackerel growth according to von Bertalanffy's equation and parameters of this equation obtained by different authors are presented in

Table 5

Mean length of particular age groups of mackerel caught in different periods in Northwest Atlantic. L. caud. (cm)

Region	Period of studies	Age groups																Method	Source
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
New England	1968–1975 (I–XII)	23.5	27.2	29.8	32.2	34.1	35.7	37.3	38.2	38.9	39.1	–	–	–	–	–	–	direct measurements	Isakov, 1976
New Scotia	1970–1973 (IV–XII)	24.1	27.5	30.6	32.9	34.2	–	–	–	–	–	–	–	–	–	–	–	direct measurements	Isakov, 1976
New Foundland	1970–1973 (VI–VIII)	–	29.5	32.1	33.9	35.6	37.1	38.0	39.1	40.7	40.2	40.9	–	–	–	–	–	direct measurements*	Moores et al., 1975
Subarea 5 ICNAF	1970 (XI)	22.6	28.9	32.6	–	–	–	–	–	–	–	–	–	–	–	–	–	back-calculation*	Nesterowicz, 1971
Subarea 5 ICNAF	1970–1972	21.6	27.3	29.7	31.7	33.9	36.2	37.9	39.1	39.9	40.5	–	–	–	–	–	–	direct measurements*	Uciński, 1973
Subarea 6 ICNAF	1972 (III–IV)	21.6	27.3	29.6	32.0	33.5	34.6	36.4	–	–	–	–	–	–	–	–	–	back-calculation*	Morawski, 1976
New Scotia	1974 (V–X)	23.9	26.3	31.9	33.1	35.0	35.8	36.1	36.9	38.4	39.0	–	–	–	–	–	–	direct measurements	Hunt (in Anderson and Paciorkowski, 1980)
	–	22.9	27.7	30.9	32.6	34.4	35.9	37.1	38.3	39.5	39.7	40.9	–	–	–	–	–	arithmetical mean from measurements	–
Subareas 5 and 6 NAFO	1981 (I–IV)	18.6	32.7	35.8	35.6	38.0	38.8	38.9	39.1	39.3	39.8	40.1	40.7	–	–	–	–	direct measurements	Paciorkowski, 1985
Subareas 5 and 6 NAFO	1982 (I–IV)	18.4	31.1	36.1	37.5	38.2	39.0	38.6	39.3	40.0	39.9	40.3	40.9	42.4	41.8	42.2	42.7	direct measurements	Paciorkowski, 1985
Subareas 5 and 6 NAFO	1983–1984 (I–V)	17.9	27.6	33.0	37.4	39.0	39.5	40.2	40.4	40.4	40.7	40.9	41.5	41.9	42.2	41.9	41.6	direct measurements	Own studies
Subareas 5 and 6 NAFO	1983–1984 (I–V)	18.6	27.8	32.4	34.6	36.0	36.8	37.6	38.7	39.5	40.1	40.3	40.4	40.8	41.1	41.2	41.0	back-calculation	Own studies

* l.t. originally, recalculated to l. caud.

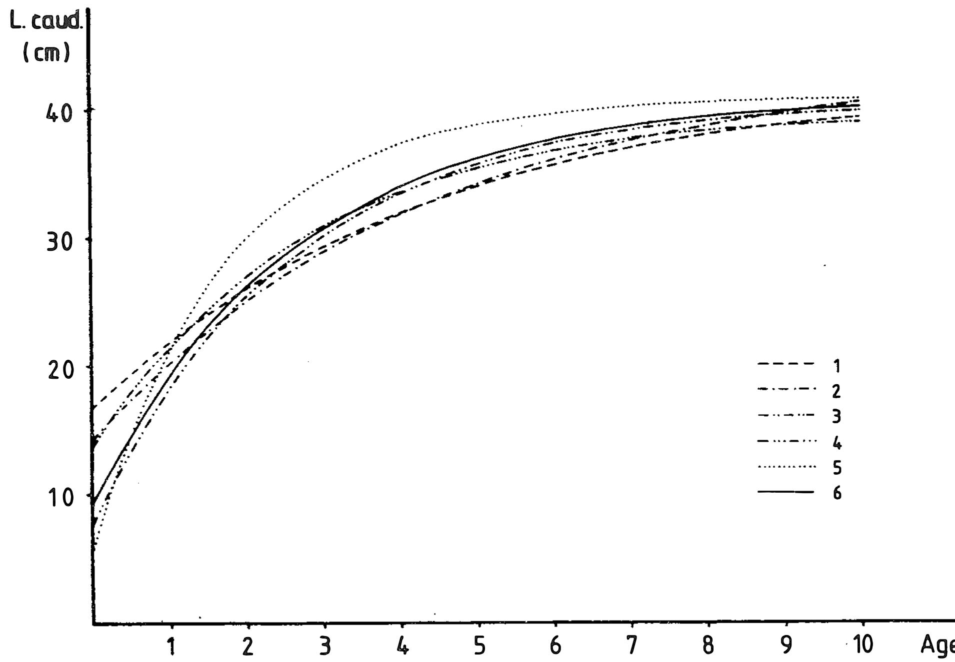

Fig. 8. Theoretical growth rate of mackerel in Northwest Atlantic according to von Bertalanffy's equation as calculated by different authors: 1 Paciorkowski et al., 1973; 2. Draganik and Uciński, 1972; 3. Morawski, 1976; 4. Moores et al., 1975; 5. Paciorkowski, 1985; 6. own studies

Table 6 and Fig. 8. Theoretical length of mackerel in consecutive years of life, calculated from different basic data, are very similar (with the exception of l_1 for which the differences are more pronounced), differing in one case only. Parameters for this untypical curve of growth were obtained on the basis of mean lengths in age groups of mackerel caught in 1981-1983 (Paciorkowski, 1985). These catches contained a few mackerel year classes characterized by an exceptionally rapid growth, affecting parameters k and t_0 of the equation. These parameters differed considerably from those usually obtained for mackerel in Northwest Atlantic. It seems that the use of direct length measurements in calculating theoretical growth curves should be limited only to the cases when particular year classes do not differ much as to the growth rate, or when studies are carried out for a longer period. This is the reason why Paciorkowski (1985) omitted high catabolism coefficient (k) in calculating the parameters of Beverton and Holt catch equation for mackerel caught in 1981-1983 (Table 6). It was stated that the coefficient was related to a very brief period and was not confirmed by the results of other studies.

Studies described in this paper were carried out in 1983-1984 when the percentage of rapidly growing year classes in the catch was still high. Thus, the method of back

Table 6

Parameters of von Bertalanffy's equation, and calculated theoretical lengths of màckerel in particular years of life as estimated by different authors. L. caud. (cm)

Region	Period of studies	Age (years)										Equation parameters			Source
		1	2	3	4	5	6	7	8	9	10	L_∞	K	t_o	
Subarea 5 ICNAF	1970-1972 (I–V)	21.9	26.0	29.3	31.9	33.9	35.6	36.9	37.9	38.7	39.4	42.00*	0.228	−2.2476	Paciorkowski et al., 1973
Subareas 5 and 6 ICNAF	1970-1971 (I–XII)	20.1	24.9	28.9	31.8	34.2	36.0	37.5	38.7	39.7	40.4	43.20*	0.234	−1.68	Draganik i Uciń-ski, 1972
New Foundland	1970-1973 (VI–VIII)	21.3	26.9	30.8	33.5	35.4	36.7	37.6	38.3	38.7	39.0	39.73*	0.36	−1.14	Moores et al., 1975
Subareas 5 5 and 6 ICNAF	–	21.5	26.0	29.5	32.2	34.3	35.9	37.2	38.2	39.0	39.6	41.70*	0.25	−1.9	ICNAF, 1973
Subareas 5 and 6 NAFO	1981-1983 (I–IV)	21.1	29.7	34.6	37.3	38.8	39.6	40.1	40.4	40.5	40.6	40.70	0.584	−0.248	Paciorkowski, 1985
Subarea 6 ICNAF	1972 (III–IV)	18.1	25.3	30.2	33.5	35.7	37.3	38.3	39.0	39.5	39.8	40.50	0.387	−0.53	Morawski, 1976
Subareas 5 and 6 NAFO	1983-1984 (I–V)	19.2	26.1	30.7	33.9	36.1	37.6	38.6	39.3	39.8	40.1	40.81	0.3804	−0.675	Own studies
North Sea	1959-1969 (IV–V)	16.9	25.8	30.9	33.8	35.4	36.3	36.8	37.1	37.3	37.4	37.50	0.57	−0.05	Postuma, 1972

* l.t. originally, recalculated to l. caud.

calculations was used. This method eliminates the differences of growth rate between fish year classes. As a result, theoretical growth of mackerel did not differ much from the results obtained earlier for mackerel in Northwest Atlantic (Fig. 8). It is worth noting that parameters of von Bertalanffy's equation are almost the same (and thus so are the growth curves) as those obtained by Morawski (1976) (Table 6, Fig. 8). In both cases the growth rate was estimated by back calculations. Taking into account 10-year difference, i. e. totally different composition of the exploited mackerel stock, it may be concluded that the method is a reliable one and can be used to characterize mackerel growth. At the same time, the highest differences of the mean length are noted for fish aged t=1 year although the curves of theoretical growth are similar. Most probably this results from an overestimation of the mean length attained by mackerel after the first year of life (l_1) as the authors used the method of direct growth measurements. In practice, fish lengths are measured in different periods of the growing season. In case of age group 1, the fish increase their average length from spring till autumn much more than the older age groups (Biegelow and Schroeder, 1953). Consequently, mean calculated from such measurements would exceed the real l_1 value much more than for other age groups. This mean was then used as an empirical value to calculate the parameters of von Bertalanffy's equation. As a results, theoretical l_1 value is overestimated, while t_0 and k parameters of the equation become underestimated[x)]. This is confirmed by the results of Moores et al. (1975) related to estimation of the parameters of von Bertalanffy's equation. These authors used data from direct measurements made from June till August, but also paid attention to the effect of time since the assumed fish birth (1 January). They took into account additional growth during this time, so that age t was established as being 2.6, 3.6 etc. Data presented in Table 6 reveal that this method of calculating coefficient k gave almost identical results to those obtained by Morawski (1976) as well as by myself in course of this work.

Biegelow and Schroeder (1953) reviewed the results of Nilsson from 1914. This author stated that growth rate of North European mackerel was slower than of American mackerel. Biegelow and Schroeder commented that growth rate of American mackerel varied so much the differences presented by Nilsson might have been accidental. However, subsequent studies confirmed Nilsson's suggestion. Theoretical length of mackerel in consecutive years of life, calculated on the basis of 11-year studies of the North Sea stock (Postuma, 1972) revealed that rate of growth was similar to that found for east USA shelves until 6-7 year of the fish life, whereas later on the North Sea mackerel grew slower (Table 6). The oldest specimen from the west of Ireland and south part of the Bay of Biscay did not exceed 39 cm, notwithstanding

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x) This does not refer to L_∞ which is relatively stable and usually reliable, as the length of the oldest fish is similar irrespective of the method used to estimate growth rate.

the fact that at age of 3-5 years they were as big as in Northwest Atlantic, reaching maximally 32-35 cm (Dawson, 1986). In the Celtic Sea mackerel growth is very slow, so that the fish never exceed 37 cm (op.cit.), the average length at the age of 10 years being 35-36 cm (Lockwood and Shepherd, 1984).

CONCLUSIONS

1. Fishes belonging to the same year class dominated the catch in both years of studies. These were year classes of 1982, 1981, 1974, 1978 and 1973. The oldest fish were 18-19 years old, but older age groups (over 12) did not exceed 1%.

2. A review of the results of a number of studies on mackerel age revealed that age determinations from fish otoliths may be reliable even for the oldest fish.

3. Mackerel growth rate is most rapid in the first two years of life. It slows down in the third year, and becomes inhibited since the fourth.

4. There are no length differences between the sexes untill 6th year of the fish life. In case of older fish, females become longer than males, the difference being statistically significant and increasing with fish age.

5. Von Bertalanffy's equation is more suitable in characterizing real mackerel growth than the models by Gompertz, Ford-Walford or a polynomial of the 2nd order, although theoretical asymptotic length (L_{∞}) tends to be lower than average length of the fish in the oldest age groups.

6. Growth rate of mackerel year classes born in 1976-1980 was much more rapid than of those born by the end of the sixties and the begining of the seventies, as well as of those born in 1981-1982.

REFERENCES

Allen K. R., 1966: A method of fitting growth curves of the von Bertalanffy type to observed data. – J. Fish. Board Can., 23,2: 163-179.

Anderson E. D., 1982: Status of the Northwest Atlantic mackerel stock – 1982. – NMFS, NEFC, Woods Hole Lab. Ref. Doc. No. 82-44.

Anderson E. D., A. J. Paciorkowski, 1980: A review of the Northwest Atlantic mackerel fishery. – Rapp. P.–v. Reun. Cons. int. Explor. Mer, 177: 175-211.

Beverton R. J. H., S. J. Holt, 1957: On the dynamics of exploited fish populations. – U.K. Min. Agric. Fish., Fish Invest., Lond., Ser. 2, **19**: 533 pp.

Biegelow H. B., W. C. Schroeder, 1953: Fishes of the Gulf of Maine. – U.S. Fish Wildl. Serv., Fish. Bull., 53: 577 pp.

Bolster G. C., 1963: The age Determination of the mackerel (*Scomber scomber* L.) from the otoliths by means of top and sub stage illumination. – ICES, C. M. 1963/130.

Dawson W. A., 1986: Changes in Western mackerel (*Scomber scombrus*) spawning stock composition during the spawning season. – J. mar. biol. Ass. U. K., **66**, 2: 367-383.

Draganik B., S. Uciński 1972: Charakterystyka głównych cech biologicznych makreli poławianej przez polskie trawlery na łowiskach Nowej Anglii. (w:) Kompleksowe opracowanie wyników badań w 1971 r. określające warunki środowiska morskiego oraz ocena stanu zasobów ryb Atlantyku półn.-zach. [Characteristics of basic biological parameters of mackerel caught by Polish trawlers on the fishing grounds off New England. In: Complex presentation of the results of studies in 1971 related to marine environmental conditions and fish resources in Northwest Atlantic. Manuscript]. – MIR, Gdynia - maszynopis.

Giedz M., A. Paciorkowski, 1984: Preliminary report on the results of the Joint Polish – US Atlantic Mackerel Research Fishery in 1984. – Sea Fisheries Institute, Gdynia.

Gulland J.A., 1969: Manual of methods for fish stock assessment. Part I. Fish population analysis. FAO Man. Fish. Sci., 154 pp.

Hamre J., 1978: The effect of recent changes in the North Sea mackerel fishery on stock and yield. – Rapp. P.–v. Reun. Cons. int. Explor. Mer, **172**: 197-210.

Hunt J.J., W.T. Stobo, 1976: Conversion factors for length measurments of Atlantic mackerel. – ICNAF Res. Doc. 76/XII/136.

ICNAF, 1973: Report of Standing Committee on Research and Statistics – June 1973. App. I. Report of Assessment Subcommittee. Annex I. Report of ad hoc Mackerel Working Group. – INCAF, Redbook, 1973 (Part I): 87-94.

Isakov V. I., 1976: On some results of biological studies on mackerel from the Northwest Atlantic. – ICNAF Res. Doc. 76/VI/52.

Isakov V. I., 1977: Estimation of stock and total allowable catch of mackerel in the Northwest Atlantic for 1977-1978. – ICNAF Res. Doc. 77/VI/41.

Kompowski A., 1981: Ostroboki – *Trachurus trachurus* (L., 1758) *Trachurus trecae* Cadenat, 1949 i*Trachurus picturatus* (Bowdich, 1825) wschodniego Atlantyku. Systematyka i biologia. [The East Atlantic horse mackerel species: *Trachurus trachurus* (L., 1758), *Trachurus trecae* Cadenat, 1949, and *Trachurus picturatus* (Bowdich, 1825). Systematics and biology.] – AR Szczecin, Rozprawy, **79**: 321 pp. (in Polish)

Lockwood S. J., J. G. Shepherd, 1984: An assessment of Western mackerel stock. – J. Cons. int. Explor. Mer, 41, 2: 167-180.

Moores J.A., G.H. Winters, L.S. Parsons, 1975: Migrations and biological characteristics of Atlantic mackerel (*Scomber scombrus*) occuring in Newfoundland waters. – J. Fish. Res. Board Can., **32**, 8: 1347-1357.

Morawski M. S., 1976: Charakterystyka wzrostu otolitu oraz tempo wzrostu długości ciała makreli (*Scomber scombrus* L.) z północno-zachodniego Atlantyku. [A characteristic of otolith growth and the rate of growth of body length in the Northwest Atlantic mackerel (*Scomber scombrus* L)]. – Zeszyty Naukowe Wydziału Biologii i Nauk o Ziemi Uniwersytetu Gdańskiego, Oceanografia, 3: 81-91. (in Polish)

Nesterowicz O., 1971: Wiek i tempo wzrostu makreli (*Scomber scombrus* L.) z północno-zachodniego Atlantyku. [Age and growth rate of mackerel (*Scomber scombrus* L.) from the Northwest Atlantic. M. Sc. Thesis manuscript]. – Praca magisterska, maszynopis. Zakład Ichtiologii AR w Szczecinie. (in Polish)

Paciorkowski A., 1985: Wpływ rybołówstwa i czynników naturalnych na zmiany wielkości zasobów makreli na szelfie północno-zachodniego Atlantyku w latach 1962-1982. [The effect of fishery and of natural factors on changes in mackerel resources over the shelf of the Northwest Atlantic in 1962-1982. Doctors manuscript]. – Praca doktorska, maszynopis. Zakład Ichtiologii MIR, Gdynia. (in Polish)

Paciorkowski A., M. Liwoch, R. Grzebielec, W. Borowski, S. Uciński, 1973: A preliminary assessment of the state of mackerel stock of ICNAF Subarea 5 and Statistical Area 6, 1968 – 1972. – ICNAF Res. Doc. 73/98.

Paciorkowski A., M. Mucha, 1982: Report on biological observations and exploratory fishing data collected during the Joint Polish – US Atlantic Mackerel Survey on m/t Kanaryjka in 1982. – Sea Fisheries Institute, Gdynia.

Paciorkowski A., M. Mucha, J. Warzocha 1983: Report on the preliminary results of the Joint Polish – US Atlantic Mackerel Survey in 1983. – Sea Fisheries Institute, Gdynia.

Postuma K. H., 1972: On the abundance of mackerel *Scomber scombrus* in the northern and northeastern North Sea in the period 1959-69. – J. Cons. int. Explor. Mer, **34**, 3: 445-465.

Steven G. A., 1952: Contributions to the biology of the mackerel, *Scomber scombrus* L. III. Age and growth – J. mar. biol. Ass. U.K., **30**, 3: 549-568.

Szypuła J., 1977: Zastosowanie wielomianów 2-go i 3-go stopnia do characterystyki wzrostu ryb. [Application of second and third order polynomials to fish growth description]. – AR Szczecin, Rozprawy, **52**: 74 pp. (in Polish)

Uciński S., 1973: Charakterystyka biologiczno-eksploatacyjna makreli *Scomber scombrus* Linnaeus 1758 z północno-zachodniego Atlantyku. [Biological and fishery characteristics of mackerel, *Scomber scombrus* Linnaeus 1758, in the Northwest Atlantic. M. Sc. Thesis manuscript]. – Praca magisterska, maszynopis. Zakład Ichtiologii AR w Szczecinie. (in Polish)

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CHARAKTERYSTYKA WIEKU I WZROSTU MAKRELI (*SCOMBER SCOMBRUS* L.) POŁAWIANEJ W PÓŁNOCNO-ZACHODNIM ATLANTYKU

STRESZCZENIE

W latach 1983 i 1984 zebrano w północno-zachodnim Atlantyku materiały w celu określenia wieku i szybkości wzrostu długości makreli atlantyckiej (rys. 1, tab. 1). Wiek ryb oznaczono na podstawie otolitów (rys. 2). Szybkość wzrostu określono metodą pomiarów bezpośrednich oraz metodą odczytów wstecznych. Długość badanych makreli zawierała się w granicach 14-49 cm, a rozkład długości miał charakter trójwierzchołkowy, choć był różny w poszczególnych latach (rys. 4). W obydwu latach dominowały liczebnie ryby należące do pięciu pokoleń: 1982, 1981, 1978, 1974 i 1973, natomiast najstarsze osobniki, których wiek oznaczono, miały 18-19 lat (rys. 5).

Wzrost makreli jest nierównomierny – bardzo szybki w pierwszych dwóch latach życia, wyraźnie zwolniony w trzecim roku i bardzo wolny począwszy od czwartego roku życia (tab. 2 i 3). Stwierdzono ponadto wyraźne różnice w szybkości wzrostu poszczególnych pokoleń – szczególnie szybki wzrost cechował pokolenia urodzone w latach 1976-1980. Samce i samice charakteryzowały się podobną szybkością wzrostu w pierwszych 6 latach życia, natomiast wśród starszych osobników zaznacza się przewaga długości samic, która rośnie z wiekiem (rys. 7). Na podstawie danych z tabeli 3 obliczono parametry równania von Bertalanffy'ego, które wynoszą: $L_\infty = 40{,}81$ cm; $K = 0{,}3804$; $t_0 = -0{,}6749$. Pomimo pewnych trudności z dopasowaniem teoretycznego modelu von Bertalanffy'ego do danych empirycznych, wyrazem których było ustalenie L_∞ na poziomie niższym od średniej długości najstarszych grup wieku, właśnie ten model najlepiej oddaje rzeczywisty przebieg wzrostu długości makreli w porównaniu do innych częściej stosowanych modeli wzrostu (tab. 4).

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