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SELECTED BIOLOGICAL PARAMETERS AND THE ABUNDANCE OF THE SPAWNING POPULATION OF ROACH R*UTILUS RUTILUS* (L.) FROM LAKES GARDNO AND ŁEBSKO

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ABSTRACT

The abundance of the spawning population of roach females from the coastal lakes Gardno (2 468 ha) and Łebsko (7 140 ha) located in the Słowiński National Park was estimated for the 1987-1992 period. Following bream, roach is the second most common cyprinid species in regulated fisheries catches. The size of the spawning population was estimated using Virtual Population Analysis and long-term fisheries statistics. Female roach dominated the exploited population at 62.4% in Lake Gardno and 64.3% in Lake Łebsko. During the analyzed period, more roach females were caught in Lake Gardno, which is more than twice as small as Lake Łebsko. Of the generations analyzed (1985, 1986, 1987, 1988, 1989 and 1990), more abundant years occurred in Lake Gardno. The most abundant generation in the two lakes was that of 1985, and following it, each subsequent generation was “weaker” than the preceding had been. The size of the spawning stock was shaped the youngest age groups (2+, 3+, 4+), with the 4+ and 3+ groups dominating in lakes Gardno and Łebsko, respectively. The decline in the spawning stock during the analyzed period was more pronounced in Lake Gardno. It is most likely that progressing eutrophication and increased average air temperatures in the last two decades caused the abundance of the roach spawning population in Lake Gardno to decline in the late 1980s. A consequence of this was a three-fold drop in the number of eggs released at spawning grounds. Meanwhile, the roach population at Lake Łebsko, which has deteriorated to a lesser degree, did not exhibit such strong fluctuations in abundance.

Key words: roach *Rutilus rutilus* (L.), age composition, generations, exploited population, spawning population.

INTRODUCTION

The progressive eutrophication of water causes changes in the biomass and species composition of fish. The effect of this phenomenon in the waters of northern Europe is seen in the increased abundance of cyprinid fishes, especially bream and roach. Roach dominates in more trophic waters because its food spectrum is wide and it replaces species which prefer clearer waters [10]. This species is able to feed on zooplankton and benthos and, in hypereutrophic water, even on macrophytes and detritus [12, 18, 20, 23, 24, 26, 30, 33].

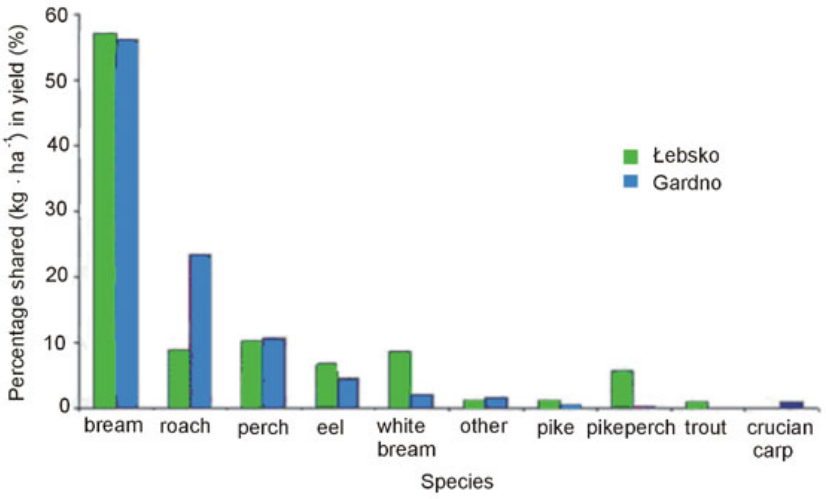
Other factors which stimulate the dynamic development of roach populations is that it is a highly fecund species and its main predators, pikeperch and pike, are overfished.

As it feeds on zooplankton, roach removes the organisms which filter phytoplankton and through its excreted feces it quickly reintroduces mineral substances into circulation; this induces worsening water clarity and can prompt algal blooms [1, 32]. Attempts at biomanipu-lation are thus being made to prevent the further degradation of waters by removing species, including roach, which are the most impervious to the effects of progressing eutrophication [11, 22]. Species such as these which dominate the environment pose a threat to the balance of faunal biodiversity [13, 25].

The aim of the observations presented in this paper was to analyze the dynamics of changes in the abundance of virtual and spawning populations of roach in the largest lakes in the Słowiński National Park (SNP) - Gardno (2 468 ha) and Łebsko (7 140 ha) (Fig.1).

Fig 1. Area and maksymal depth of the Gardno and Łebsko Lakes

Fig 2. Percentage of different fish species in catches made in lakes Gardno and Łebsko from 1991 to 2001



Of the many lakes in the SNP, fishing is conducted only in these two. The fisheries statistics in the logs of the two studied lakes indicate that bream and roach dominate the catches. Since the 1970s, catches of predatory pikeperch and pike have remained on a low level with the former constituting only several percent and the latter not exceeding 1% of total catches. In the last decade, roach was second only to bream *Abramis brama* (L.) in Gardno and third following bream and perch *Perca fluviatilis* (L.) in Łebsko in terms of the biomass of fish caught (Fig.2). Pike and pikeperch catches remained on a low level from 1991 to 2001 at an average of 0.4 % in Gardno and approximately 7% in Łebsko. These species could not have had a significant impact on the size of the stock of planktivorous roach in these lakes.

MATERIALS AND METHODS

The structures of the exploited roach populations in lakes Gardno and Łebsko was analyzed based on material caught by fishermen from 1983 to 2001. These samples provided information regarding the sex, body length (Lc), total weight and age of the roach caught by fishermen. Data concerning the magnitude of fisheries catches in the 1987-2001 period was drawn from the management logs of the individual lakes.

The period from June 1 of a given year (T) to May 31 of a given year (T+1) was used to determine number of females caught by fishermen. This meant that the beginning of the year was during the period when new generations are born and the first annual ring is laid down.

Samples for analyses were chosen randomly from catches which had been made with seines (22 mm mesh size in the bag) and fyke-nets (20 mm mesh size) [4, 5]. The fish were measured to the nearest mm and weighed to the nearest g. Age was determined from scales taken from the first row above the lateral line under the dorsal fin.

The method used in this paper to estimate the abundance of the virtual population allows calculating the number of fish from various years which are alive in a given year. Fisheries statistics can be used for this providing that the exploitation intensity of the studied population is similar [21]. The virtual population describes the minimum abundance of the exploited population, since the calculations do not take into consideration those fish which died of natural causes.

Weight data was recorded for 1 801 grade M and 243 grade S specimens from Lake Gardno and 835 grade M and 561 grade S specimens from Lake Łebsko. This data was used to determine the average weight of roach from these grades in both lakes (Tables 1, 2), which was 76.3 g and 236.8 g in Gardno and 88.5 g and 265.3 g w Łebsko for grades M and S, respectively. According to Polish inland fisheries standards, grade M refers to roach up to 150 g while grade S refers to those above 150 g.

Table 1. Mean weight of roach from Gardno Lake samples

Sampling date	Sortyment (Individual)			
	M, g	n	S, g	n
13.04.1983	65.365	159	210.100	10
2.10.1984	69.467	75	185.000	2
25.09.1985	76.442	95	222.963	27
26.08.1986	94.158	101	200.000	2
7.10.1987	75.080	250	187.647	17
21.09.1988	90.875	80	196.667	27
7.11.1989	66.129	62	196.250	4
18.11.1992	45.377	106	190.000	1
26.07.1995	49.500	55	174.500	2
14.11.1996	85.856	59	209.800	8
30.09.1997	62.293	41	-	0
22.04.1998	106.056	36	489.857	7
12.05.1998	69.705	15	-	0
9.09.1998	127.056	18	182.273	22

Table 1 cont.

7.10.1998	60.265	49	-	0
21.04.1999	71.382	54	277.369	11
12.05.1999	75.663	12	-	0
12.10.1999	67.560	52	-	0
13.10.1999	73.833	12	280.000	2
9.11.1999	86.961	82	250.333	9
4.04.2000	51.822	20	303.862	38
12.10.2000	91.341	126	199.389	18
15.11.2000	120.375	24	176.500	8
19.04.2001	80.604	87	286.749	10
15.05.2001	72.533	45	272.833	6
7.08.2001	91.500	42	184.143	7
18.09.2001	88.273	44	301.200	5
$\overline{X}$	**76.34**	1 801	**236.80**	243

Table 2. Mean weight of roach from Łebsko Lake samples

Sampling date	Sortyment (Individual)			
	M, g	n	S, g	n
24.09.1985	116.667	3	270.213	47
8.10.1987	83.077	13	325.000	14
20.11.1987	133.333	12	310.331	121
27.03.1995	125.000	2	247.478	23
29.03.1995	71.766	30	154.000	1
26.07.1995	135.929	14	204.414	29
21.05.1996	75.256	39	219.833	6
1.10.1997	89.375	16	198.750	4
28.10.1997	119.895	19	221.200	10
17.03.1998	99.083	12	168.333	6
21-22.04.1998	78.800	60	380.552	29
13.05.1998	76.200	31	-	0
8.10.1998	99.371	35	285.604	48
22-25.03.1999	93.096	88	223.919	32
20-22.04.1999	64.305	93	292.375	14
9.11.1999	79.333	18	279.000	4
7.12.1999	133.000	5	212.880	25
4.04.2000	39.419	10	335.408	14
27.04.2000	84.723	101	158.750	4
19.05.2000	109.083	24	185.000	4
7.06.2000	93.780	50	179.417	12
16.11.2000	107.068	59	205.125	16
13.12.2000	98.792	24	238.656	32
19.04.2001	104.726	10	437.281	7
16.05.2001	87.797	36	211.500	46
8.08.2001	87.613	31	195.000	13
$\overline{X}$	**88.7**	835	**265.27**	561

The number of specimens of a given grade caught in a given year was determined by dividing the weight of the fish of the grade by the average specimen weight. The statisitcs regarding catches in Lake Gardno in 1999 and 2000 indicate that from this period the roach were no longer sorted. This is why calculations of the number of specimens caught were based on the average figures of both grades combined.

The sex of 1 252 Gardno and 920 Łebsko specimens from various periods was determined and provided a basis for establishing the male to female ratio and the percentage of sexually immature specimens from the exploited population. Evaluating the percentage of the sexes allowed the number of females caught by fishermen from 1987-1988 to 2000-2001 to be determined.

The female age distribution which was determined from the samples allowed for the abundance of particular age groups in both exploited populations to be estimated for the years analyzed.

In order to simplify calculations, it was assumed that the percentage of females in the fished population remained constant and that the mortality of roach females in particular age groups did not vary significantly during the analyzed period.

The material collected in the fall-winter period over a dozen years was used to determine the body length growth rate of roach. The values used were obtained from direct measurements of 2 002 Gardno and 1 318 Łebsko specimens, and the average length for each age group of fish was calculated. The dependence was expressed as a second degree polynomial.

The virtual abundance of subsequent female generations $\mathbf{V_{(x,T)}}$ in the catches was determined by summing the number of fish of a given year which were caught in subsequent years of the analyzed period beginning with age group x (age at recruitment) in year T and ending with the oldest female of that age group noted in the catches. The formula by Ricker [21] was used in the calculations:

$$\mathbf{V_{(x,T)} = N_{(x,T)} + N_{(x+1,\,T+1)} + N_{(x+2,\,T+2)} + \ldots\ldots\ ,}$$

where:

$N_{(x,T)}$ is the number of females caught from age group x in year T.

The life span of the female generation from recruitment (age group 2+) to the upper age limit of 13 (no older specimens were noted in the material collected) was taken into consideration in the calculations, and this is how the virtual abundance of generations of females which spawned in the 1987-2000 period was determined.

The sum of the virtual abundance of all the generations of females in a given year is the estimated virtual population of female roach in the analyzed year $\mathbf{V_T}$:

$$\mathbf{V_T = V_{(x,T)} + V_{(x+1,T)} + V_{(x+2,\,T)} + \ldots\ldots}$$

This is considered by many researchers to be the most accurate method for estimating the abundance of fish generations in a natural basin in which the fish are caught with the same gear and at a constant intensity throughout the years [2, 3, 16, 17, 21].

RESULTS

The body length of the roach caught in the two lakes ranged from 7.1 to 33.0 cm (Figs 3, 4). A greater quantity of larger specimens was caught in Lake Łebsko. The plots illustrating the body length distribution of the fish are positively skewed with the modal value shifted to the left. The most numerous group in Lake Łebsko, at approximately 23% of the caught fish, were specimens from the 16.1-18.0 cm length class, while in Lake Gardno the share of roach in the most numerous length class (14.1-16 cm) was 35%. Fish from this class constituted 20% of the material collected from Lake Łebsko.

Fig 3. Percentage of roach specimens in body length classes in the samples from Lake Gardno according to sex

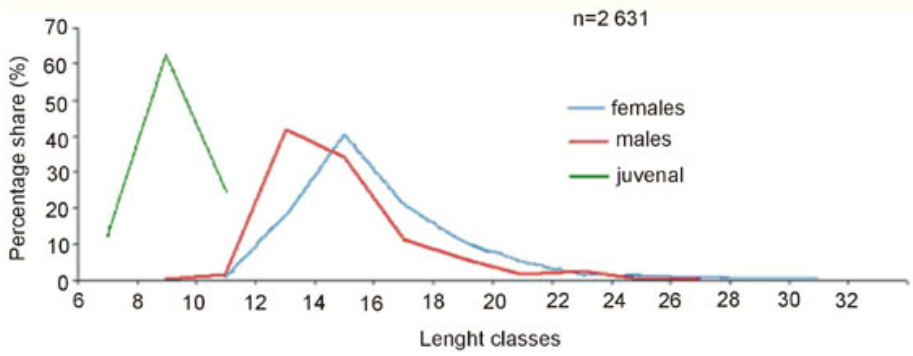
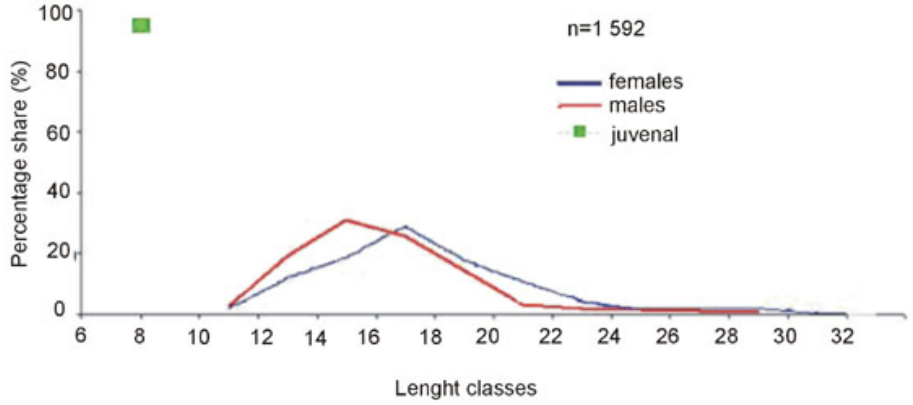


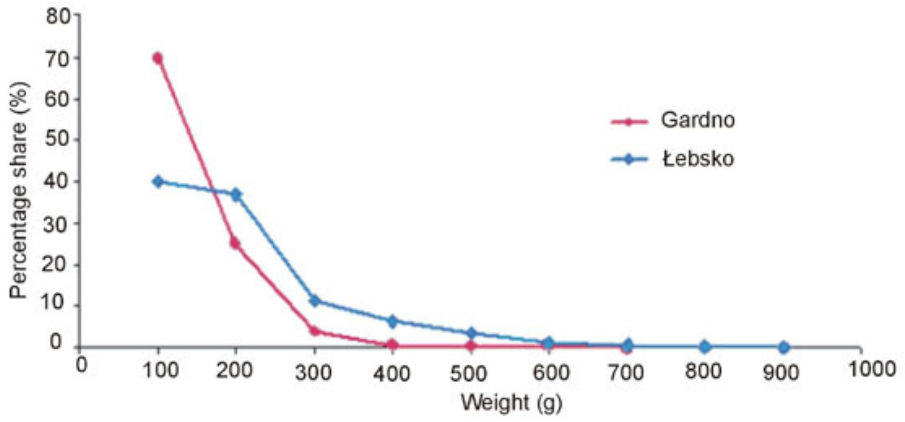
Fig 4. Percentage of roach specimens in body length classes in the samples from Lake Łebsko according to sex



Juvenile specimens occurred in the catches at a body length (**Lc**) above 6 cm. In the 10.1-12.0 cm length class they comprised 25% of the fish caught in Lake Gardno and 100% in Lake Łebsko. Males occurred at a body length of 9.1 cm in Gardno and 11.1 cm in Łebsko, and dominated the population at body lengths of approximately 13 and 15 cm, respectively. Mature females were noted in the two lakes in classes above 10 cm and were most numerous in the 14.1-16.0 cm length class in Gardno, comprising 40% of the specimens caught. Larger females dominated in Lake Łebsko with 30% of the specimens in the 16.1-18.0 cm length class.

Specimens which weighed less dominated in the catches from Lake Gardno, and roach from the 100 g weight class constituted 70% of the fish caught, while specimens in the next weight class (to 200 g) constituted 25%. Fish in the remaining weight classes totaled 5% of the specimens caught (Fig. 5). Most of the roach from Lake Łebsko also fell into the first two weight classes with 40% in the first (to 100 g) and 37% in the second (to 200 g). Larger roach in this lake constituted 23%, which is 18% more than in Lake Gardno.

Fig 5. Percentage of different weight classes in catches



Roach from age groups 3+ (37%) and 4+ (34%) dominated the catches from Lake Gardno (Fig. 6). Specimens from the 2+ and 3+ groups comprised about 10% of the fish caught, while specimens from the remaining age groups of 1+, 6+ to 10+ and 12+ occurred rarely and comprised less than 2% of the catches. Specimens from the 4+ and 5+ age groups dominated in the catches from Lake Łebsko at 26% and 24%, respectively (Fig. 7). There were fewer fish caught in the 2+ (about 2.5%), 3+ and 6+ (15%) and 7+(above 5%) age groups. Roach from the youngest (1+) and oldest (8+ - 12+) age groups were noted rarely, and the share of none of the groups exceeded 3%.

Fig 6. Sex ratio of roach in Lake Gardno by age groups

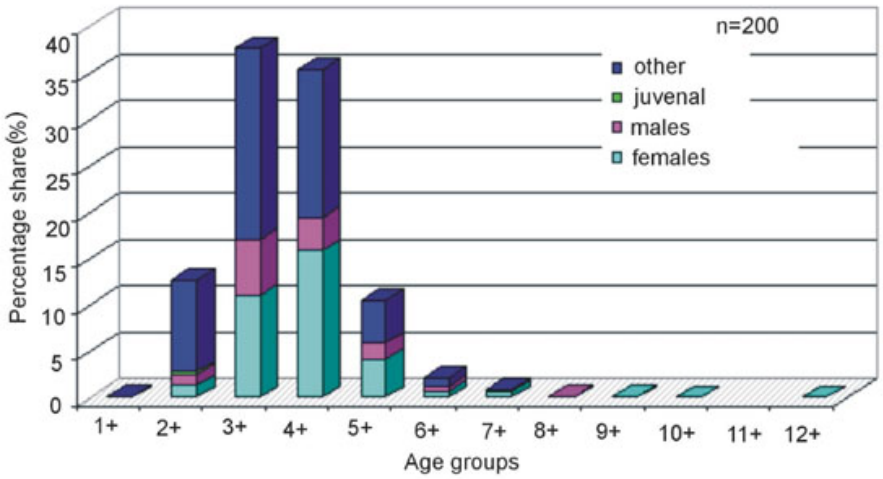
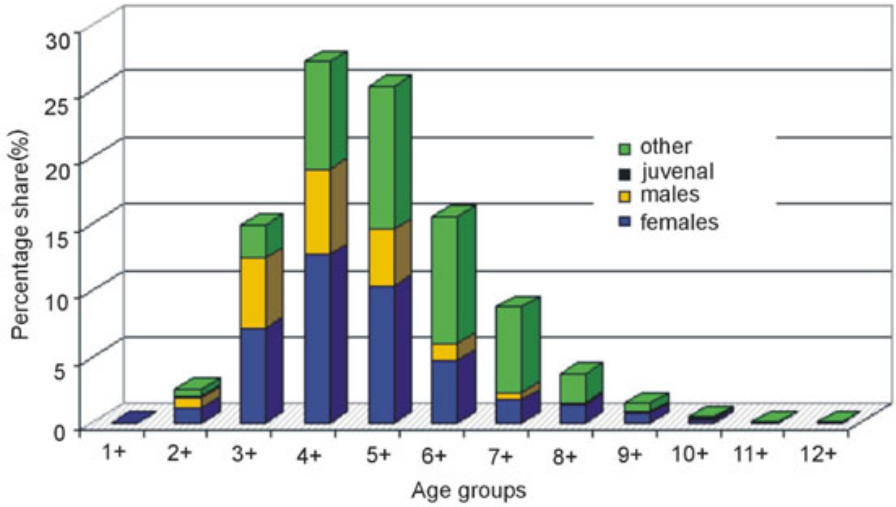


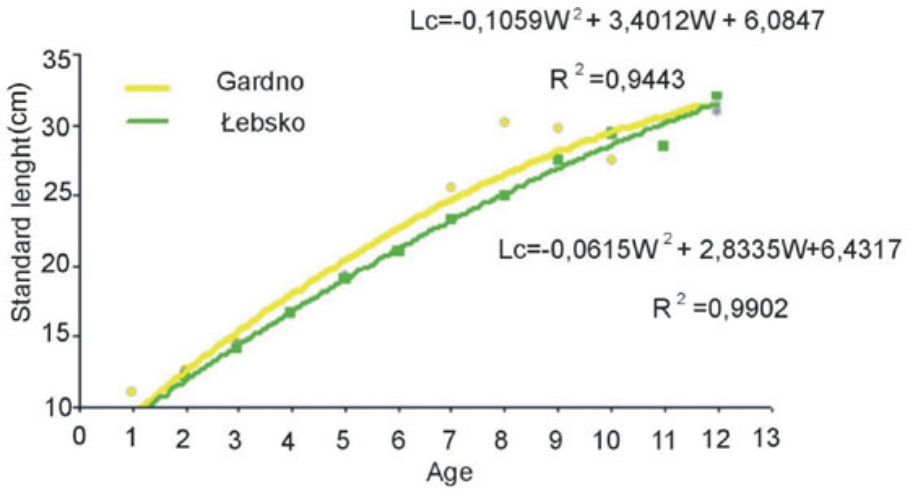
Fig 7. Sex ratio of roach in Lake Łebsko by age groups



Roach females appeared in the catches generally in the third year of life (2+ age group), and fish from this age group and older dominated the catches of this species. No male specimens older than nine or eleven years old were noted in lakes Gardno or Łebsko, respectively.

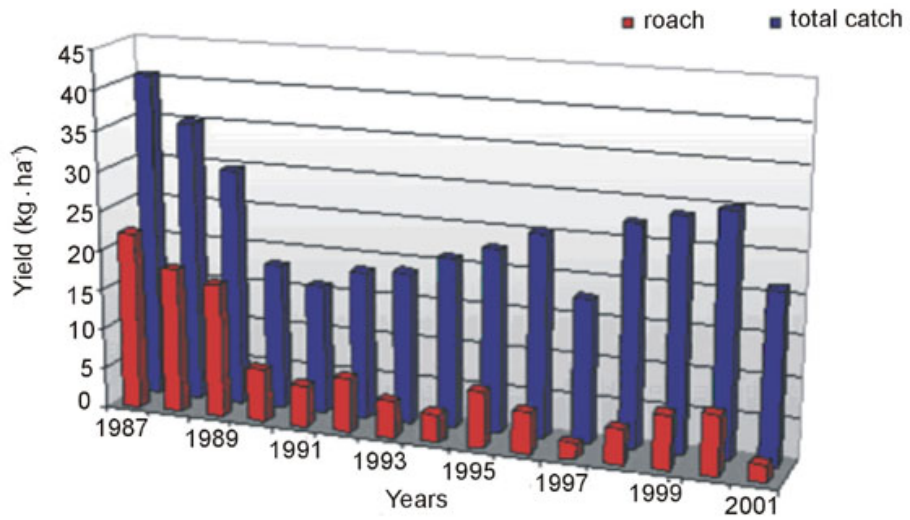
The growth rate of the roach from the analyzed Słowiński National Park lakes was rapid, and the fish attained 19 cm in body length by the sixth year of life (Fig. 8). According to Wilkońska [29], this is very rapid. Younger specimens (three and four year olds) as well as eight, nine and ten year olds in Lake Gardno grew faster than their counterparts did in Lake Łebsko. Similar growth rates were confirmed for specimens from the population aged five, six and seven. The oldest fish, past the tenth year of life, grew faster in Lake Łebsko. Thirteen-year-old females in both lakes attained body lengths exceeding 30 cm.

Fig 8. Growth rate of roach body length



The total catch magnitude of the fish in Lake Gardno during the 1987-2001 period was an average of 24.79 kg $ha^{-1}year^{-1}$, including 7.84 kg $ha^{-1}year^{-1}$ of roach (which constituted 31.7% of the catch). Roach catches during this same period in Lake Łebsko comprised only 8.61% of the total catch of 23.45 kg $ha^{-1}year^{-1}$. At the beginning of the 1990s, catches in Lake Gardno fell from the level of more than 14 kg ha^{-1} in the 1980s to less than 5 kg ha^{-1} in the 1990s. During this period there was a decrease noted in the catches of all fish species. By the end of the 1990s, there was an increase in total catches, with the exception of those of roach which remained below the levels of the 1980s (Fig. 9).

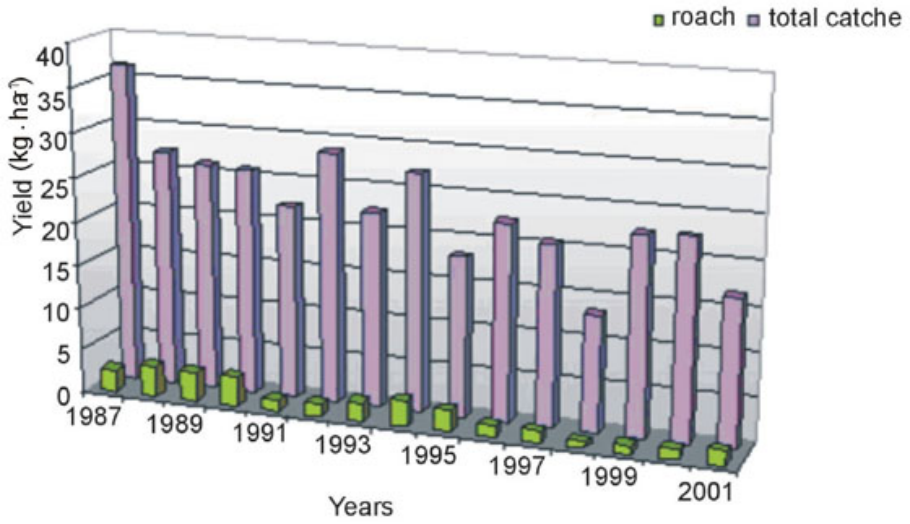
Fig 9. Catches in Lake Gardno



Catches in Lake Łebsko did not fluctuate as much as those in Lake Gardno during the analyzed period, with catches of both roach and other species remaining on a similar level. The largest catch was in 1987 (more than 35 kg ha^{-1} of mainly bream) and the smallest in 1998 (12 kg fish ha^{-1} – Fig. 10).

The roach from Lake Łebsko had a higher average specimen weight at 88.5 g for grade M and 265.3 g for grade S than that of the roach caught in Lake Gardno which weighed approximately 12 g and 28 g less, respectively.

Fig 10. Catches in Lake Łebsko



Grade M roach dominated in Lake Gardno comprising from 98-100% of the weight of the catch of this species. The share of these smaller specimens in Lake Łebsko was lower and ranged from approximately 73 to 8% of the catch weight of this species; only in 1994 was the catch of this specimen size exceptionally large at 91%. Grade S roach were caught by fishermen in Lake Łebsko in quantities not exceeding 27% of the total weight of the annual catch of this species. An even smaller quantity of this grade was caught in Lake Gardno (2%), and the management logs indicate that from 1999 this grade was not caught. This was because fishermen stopped segregating the catch in 1999 and entered the total catch figure under the grade M heading. From 1987/88 to 1989/90 roach catches exceeding 300 000 specimens were made in Lake Gardno. Catches exceeding 100 000 fish were noted in Lake Gardno in 1990/91, 1994/95 and 1996/97 and in Lake Łebsko in 1991/92, 1992/93 and from 1996/97 to 2000/2001. There was a significant fall in the abundance of roach catches in Lake Łebsko in 1998/99 when only 41 500 specimens were caught (Table 3).

Table 3. Number of roach caught by fishermen between 1987 and 2000

Year	Gardno			Łebsko		
	Sortyment (Individual)					
	S	M	S+M	S	M	S+M
1987/88	2 830	509 899	512 729	23 412	77 985	101 397
1988/89	6 918	607180	614 097	44 650	164 711	209 361
1989/90	7 751	436 932	444 683	36 616	126 974	163 590
1990/91	1 534	80 733	82 267	35 590	139 385	174 976
1991/92	1 517	188 243	189 760	19 365	54 897	74 261
1992/93	1 755	217 318	219 072	20 712	77 180	97 892
1993/94	1 984	103 675	105 659	19 467	124 464	143 931
1994/95	646	78 046	78 692	22 488	134 094	156 582
1995/96	1 011	271 676	272 687	13 192	139 009	152 201
1996/97	13	87 057	87 070	12 007	63 565	75 572
1997/98	8	114 868	114 877	18 388	61 077	79 464
1998/99	161	116 629	116 791	7 471	33 996	41 468
1999/00	122 249		122 249	10 118	72 453	82 571
2000/01	148 313		148 313	9 947	54 395	64 342

S – specimens of more than 150 g.
M – specimens of less than 150 g.

Table 4. Percentage of females, males and juveniles in the samples

Lake	Sex			
	n	♀	♂	juv
Gardno	1 252	63.10	36.34	0.56
Łebsko	920	64.35	35.54	0.11

Females were the dominant sex in the catches both in terms of abundance and biomass, and they comprised 62.4% of all the specimens from Lake Gardno and 64.35% of those from Lake Łebsko (Table 4).

The fewest females (under 50 000 specimens) were caught in Gardno in 1994/95 and in Łebsko in 1991/92, 1996/97, 1998/98 and 2000/01. Exceptionally high numbers of female roach (exceeding 100 000 specimens) were caught in 1987/88-1989/90, 1991/92, 1992/93, 1995/96 in Lake Gardno and in 1988/89-1990/91 and 1994/95 in Lake Łebsko. Over the course of the 14 years of the analyzed period, more females were caught in Lake Gardno; this was the result mainly of abundant roach catches (exceeding 250 000 females annually) in the first three years of the analyzed period. During the periods mentioned above, among the highest catches of roach females in Lake Gardno were made in 1987/88, 1988/89 and 1989/90 and the maximum was in the 1988/90 season when 387 495 female specimens were caught. More than six-fold fewer specimens (49.6-54.9 thousand) were caught in Lake Gardno in 1990/91, 1994/95 and 1996/97. In Lake Łebsko the highest roach catches were noted in 1988/89 at 134 724 females, and in the 1989/90 and 1990/91 seasons when 105 271 and 112 597 specimens were caught, respectively. The smallest catch was recorded for the 1998/99 season when only 26 685 specimens were caught. In the remaining periods, the fluctuation of this figure was higher and fell within the range of 47 800 to 100 800 roach females caught annually. The average catch of females in Lake Gardno in 1987-2001 was 140 125 specimens per computational year; this figure for Lake Łebsko was almost two-fold lower at 74 352 specimens. In Lake Gardno, in 1987/88 and 1996/97 higher catch figures were recorded and both of these seasons were preceded by years with lower catches. From the 1997/98 season, catches in this lake have remained stable at a level of 70 000 specimens. Meanwhile, fluctuations in the abundance of catches of female roach in Lake Łebsko follows an annual cycle (Table 5).

Table 5. Number of females caught in different period

Year	Lake	
	Gardno	Łebsko
1987/88	323 534	65 248
1988/89	387 495	134 724
1989/90	280 595	105 271
1990/91	51 911	112 597
1991/92	119 739	47 788
1992/93	138 236	62 992
1993/94	66 671	92 620
1994/95	49 653	100 760
1995/96	172 066	97 942
1996/97	54 939	48 630
1997/98	72 487	51 135
1998/99	73 694	26 685
1999/00	77 139	53 136
2000/01	93 585	41 406

Table 6. Age structure of females in the samples

Age groups	Lake			
	Gardno		Łebsko	
	n	%	n	%
2+	30	5.78	17	3.19
3+	175	33.72	94	17.64
4+	210	40.46	166	31.14
5+	72	13.87	135	25.33
6+	12	2.31	62	11.63
7+	12	2.31	23	4.31
8+	3	0.585	20	3.75
9+	3	0.585	10	1.88
10+	1	0.19	4	0.75
11+	0	0	1	0.19
12+	1	0.19	1	0.19
∑	519	100	533	100

Females from the 4+ age group dominated in both lakes (Gardno – 40.46% and Łebsko – 31.14%), while those from the 3+ (33.72%) and 5+ (13.87%) age groups in Gardno and the 3+ (17.4%) and 5+ (25.33%) age groups in Łebsko were less abundant. Older females from the 6+ to the 9+ age groups were noted rarely in Lake Gardno (less than 3%). Females which were even older were observed sporadically and some age groups, i.e. 11+, were not noted at all in the catches (Table 6).

The material collected permitted estimating the number of females caught from six generations confirmed in the two lakes from recruitment to the upper age limit in the analyzed period. It should be added that there is a lack of data regarding the abundance of females from the 11+ and 12+ age groups in the last two generations (1989 and 1990); however, in light of the probable low numbers of specimens this age, something which can be inferred from the data presented, the years 1989 and 1990 were also used in comparisons.

Of the analyzed roach generations in 1985, 1986, 1987, 1988, 1989, the most abundant were in Lake Gardno (Tables 7, 8). Only the 1990 generation was more abundant in Lake Łebsko. The most abundant generation of female roach was in 1985 with 277 000 specimens in Gardno and 102 000 in Łebsko (Table 9). After this year, each subsequent generation, with the exception of that of 1990 in Łebsko, was “weaker” than the previous one had been. The least abundant virtual female generation in Lake Gardno was that of 1990 (78 000 specimens) and in Lake Łebsko that of 1989 (74 000 females). More females spawned at the age of recruitment (2+ age group) in Lake Gardno (78 000-277 000) than in Lake Łebsko (73 000-101 000) in the years analyzed. The ten-year-old generation in Lake Gardno and the eleven-year-old generation in Lake Łebsko probably did not number more than a thousand females, and there were about 100 of the oldest specimens (13+) noted in the years analyzed.

Table 7. Virtual abundance of roach females V(x,T) in different generations in Gardno Lake

Generations	Years of catches														
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	V (x,T)
1975	615														615
1976	0	736													736
1977	615	0	533												1 148
1978	1 893	736	0	99											2 728
1979	1 893	2 267	533	0	228										4 921
1980	7 474	2 267	1 641	99	0	263									11 744
1981	7 474	8 951	1 641	304	228	0	127								18 725
1982	44 874	8 951	6 482	304	700	263	0	94							61 668
1983	1E+05	53 746	6 482	1 199	700	809	127	0	327						194 291
1984	1E+05	2E+05	38 919	1 199	2 766	809	390	94	0	104					310 157
1985	**18 700**	**1E+05**	**1E+05**	**7 200**	**2 766**	**3 193**	**390**	**290**	**327**	**0**	**138**				277 196
1986		**22 397**	**94 617**	**21 003**	**16 608**	**3 193**	**1 540**	**290**	**1 007**	**104**	**0**	**140**			160 899
1987			**16 218**	**17 504**	**48 446**	**19 173**	**1 540**	**1 147**	**1 007**	**321**	**138**	**0**	**147**		105 641
1988				**3 000**	**40 376**	**55 930**	**9 247**	**1 147**	**3 975**	**321**	**424**	**140**	**0**	**178**	114 738
1989					6 921	46 613	26 975	6 887	3 975	1 269	424	431	147	0	93 642
1990						7 990	22 481	20 090	23 865	1 269	1 674	431	451	178	78 429
1991							3 854	16 744	69 618	7 620	1 674	1 702	451	547	102 210
1992								2 870	58 020	22 229	10 054	1 702	1 782	547	97 204
1993									9 945	18 526	29 328	10 221	1 782	2 162	71 964
1994										3 176	24 443	29 817	10 699	2 162	70 297
1995											4 190	24 850	31 210	12 980	73 230
1996												4 260	26 011	37 865	68 136
1997													4 459	31 557	36 016
1998														5 409	5 409

Table 8. Virtual abundance of roach females V(x,T) in different generations in Łebsko Lake

Generations	Years of catches														
	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	V (x,T)
1975															124
1976	124	256													380
1977	489	256	200												945
1978	1 227	1 010	200	214											2 651
1979	2 447	2 533	790	214	91										6 075
1980	2 812	5 052	1 979	844	91	120									10 898
1981	7 588	5 807	3 948	2 117	358	120	176								20 114
1982	16 528	15 668	4 537	4 222	898	472	176	191							42 692
1983	20 318	34 126	12 243	4 853	1 792	1 184	695	191	186						75 588
1984	11 510	41 953	26 665	13 095	2 060	2 362	1 741	756	186	92					100 420
1985	**2 081**	**23 765**	**32 781**	**28 521**	**5 558**	**2 715**	**3 473**	**1 894**	**735**	**92**	**97**				101 712
1986		**4 298**	**18 570**	**35 063**	**12 105**	**7 326**	**3 992**	**3 779**	**1 841**	**365**	**97**	**51**			87 487
1987			**3 358**	**19 862**	**14 881**	**15 956**	**10 772**	**4 343**	**3 673**	**914**	**384**	**51**	**101**		74 295
1988				**3 592**	**8 430**	**19 616**	**23 460**	**11 718**	**4 221**	**1 824**	**961**	**200**	**101**	**79**	74 202
1989					1 524	11 112	18 842	25 523	11 391	2 096	1 918	502	399	79	73 386
1990						2 009	16 338	31 377	24 809	5 656	2 204	1 001	999	311	84 704
1991							2 955	17 774	30 499	12 318	5 947	1 150	1 993	778	73 414
1992								3 214	17 277	15 144	12 953	3 103	2 290	1 553	55 534
1993									3 124	8 578	15 923	6 759	6 180	1 785	42 349
1994										1 551	9 020	8 310	13 459	4 815	37 155
1995											1 631	4 707	16 546	10 488	33 372
1996												851	9 373	12 893	23 117
1997													1 695	7 304	8 999
1998														1 321	1 321

Table 9. Females spawning populations from 1987 to 1992

Lake	Age groups	Spawning year					
		1987	1988	1989	1990	1991	1992
Gardno	2+	277 196	160 899	105 641	114 738	93 642	78 429
	3+	310 157	258 496	138 502	89 423	111 738	86 721
	4+	194 291	201 062	127 833	43 885	71 919	71 362
	5+	61 668	63 390	44 281	14 304	22 882	23 473
	6+	18 725	16 794	9 644	5 362	7 104	6 274
	7+	11 744	11 251	7 843	3 162	4 163	4 338
	8+	4 921	4 270	2 300	1 361	1 963	1 397
	9+	2 728	3 028	2 003	659	1 057	1 263
	10+	1 148	835	761	362	355	357
	11+	736	533	99	228	263	127
	12+	615	736	533	99	228	263
V_T		883 929	721 294	439 440	273 583	315 314	274 004
Łebsko	2+	101 712	87 487	74 295	74 202	73 386	84 704
	3+	100 420	99 631	83 189	70 937	70 610	71 862
	4+	75 588	88 910	75 866	64 619	51 075	62 180
	5+	42 692	55 270	46 957	43 085	29 556	36 194
	6+	20 114	26 164	21 144	20 292	24 564	17 451
	7+	10 898	12 526	10 496	8 901	7 197	9 006
	8+	6 075	8 086	6 719	5 959	4 048	5 137
	9+	2 651	3 628	3 034	2 771	1 737	2 256
	10+	945	1 424	1 095	1 055	654	839
	11+	380	456	414	305	211	296
	12+	124	256	200	214	91	120
V_T		361 599	383 838	323 409	292 340	263 129	290 045

The abundance of the spawning population in Lake Gardno decreased in the 1987-1992 period. In both 1990 and 1992 as much as 69% fewer females spawned in comparison with 1987, the year in which the highest female abundance of 884 000 specimens was recorded. Meanwhile, the abundance of the spawning stock in Lake Łebsko did not fluctuate to the same degree; the difference between the most and least abundant years was 32% with values ranging from 263 000 females in 1991 to 384 000 females in 1988 (Table 9).

The size of the spawning stock was shaped principally by the three youngest age groups of 2+, 3+ and 4+, with the 4+ and 3+ groups dominating in lakes Gardno and Łebsko, respectively. Beginning in 1988, the abundance of the 2+ and 3+ age groups fell, and in 1992 the most significant fall in the abundance of females (72%) in these age groups in comparison to 1987 was recorded. This was responsible for the limited abundance of the spawning stock. In Lake Łebsko the abundance of the roach spawning stock in these two age groups did not exhibit such a pronounced decline. In 1991 when the abundance of the spawning stock was at its lowest, females from the 3+ and 4+ age groups comprised 71% of the number of specimens from 1987.

DISCUSSION AND CONCLUSIONS

The age composition of fish from different basins varies depending on factors such as the intensity of fishing and predation. When exploitation is heavy, the stock is composed of younger and smaller specimens, and predation by cormorants and predatory fish is limited, above all else, to young fish. The effects of these factors can lead to a rapid decline in population size in a short period. The intensity of fishing in the studied lakes has not varied much over the last two decades, and seine catches and the setting of fyke-nets was similar in both lakes at the beginning of the 1990s [4]. The abundance of the cormorant population feeding in these lakes in the 1980s and

early 1990s was large (approximately 5 000 specimens – information from park officials). A decline in the numbers of these birds has been noted since the late 1990s, and currently the size of the cormorant population feeding in the SNP does not exceed 1 500, according to park officials. Populations of predatory pike and perch were not numerous as is indicated by low catches of these species. It is plausible that predation by the cormorants had an impact on the abundance of roach in these lakes. Nor can it be ruled out that the significant fall in the numbers of roach caught in the early 1990s in Lake Gardno was caused by climate change. Analyses of the average monthly and annual temperature in this region indicates that there was a long-term increase from 7.2°C in the 1881-1930 period to 8.4°C in 1991-2000. Air temperature impacts the temperature of aquatic basins, especially in the case of the studied lakes which are shallow, devoid of thermal stratification and well-mixed to the bottom. This means that the water temperature in these lakes adapts more rapidly to the air temperature. Thus, air temperature can be useful in describing changes in the thermal state of lakes Gardno and Łebsko in the analyzed period.

The annual temperature variations in 1984-2000 ranged between 6.4-9.7°C, with the average at 8.2°C. The coldest periods, which could have decelerated roach gonad development, were noted in 1987 (6.4°C), 1996 (6.6°C) and 1985 (6.8°C). During the pre-spawning months (January to May) in these years the average temperature fell below 0°C.

Statistical analyses of the correlation of the annual air temperature averages (**TY**) and the average from five months (**TS** – from January to May) in the analyzed years (for example in 1985) with the abundance of females caught two years later (in 1987/88) indicated that there was a negative correlation for the population from Lake Gardno ($r = - 0.573$) at a level of $\alpha = 0.05$, as is illustrated by the following:

	TY-$N_{(2+,T)}$	**TS-$N_{(2+,T)}$**	**r (α=0.05)**
Lake Gardno	-0.573	-0.573	0.532
Lake Łebsko	-0.153	-0.169	0.532

This means that a rise in temperature in the lake during the year as well as in the period preceding the spawning season causes higher mortality rates in the new generation. Such a correlation was not confirmed for the roach from Lake Łebsko ($r = - 0.153$, $r = - 0.169$).

There is a negative correlation between air temperature in the year in which spawning occurred and catches of females in Lake Gardno two years later when the new generation was at recruitment age. This is evidence of the negative impact higher temperatures have on the mortality rates of young roach stages in Lake Gardno.

This process can be explained as follows: the smaller surface area and volume of Lake Gardno in comparison with Lake Łebsko and its less intense water exchange render it more susceptible to eutrophication and degradation. It follows that in warm years the air-water heat exchange is more intense and the water in Lake Gardno heats faster. This lake is heavily loaded with nitrogen and phosphorous in its waters, organisms and bottom sediments. The most threatening source of nutrients for roach are decomposing sediments (especially when the ratio of active bottom area to lake volume is high – according to Cydzik et al. [8]). As the water in the shallow littoral becomes warmer during warm springs and summers, hydrogen sulfide displaces oxygen. Oxygen deficiencies and toxic hydrogen sulfide probably caused high mortality among the larvae and fry inhabiting this environment. The warmest years, during which this process would have been most intense, were 2000 (9.7°C), 1990 (9.5°C), 1999 (9.3°C), 1989 (9.3°C), 1992 (8.9°C), 1994 (8.8°C). It should also be added that the average temperature in the five months preceding spawning in 1989, 1990, 1998 and 2000 was exceptionally high at more than 6°C, with an average for the entire period of 4.52°C. Thus, environmental conditions during these years were not conducive to the development of larvae which is evident in the weak recruitment of the roach population in Lake Gardno.

No such dependence was observed in Lake Łebsko. This is most certainly due to this lake's lower susceptibility to degradation thanks to its more advantageous morphometry, larger volume and stronger inflows of marine waters [28].

The recruitment of fish to the exploited population is shaped by the fish's behavior and habitat and its sensitivity to hydrological and climatic factors, such as temperature of water level variations which can occur in warm years [15]. Mingelbier et al. [15] studied two smelt populations in the St. Lawrence estuary and confirmed that there is a positive correlation between the aforementioned factors and the recruitment of smelt which inhabited the deep canals in the north of the basin. The second population, which inhabited the shallow, southern coastal area of the estuary, reacted differently; there was a fall in the number of recruits when temperatures or water levels rose.

Many authors have reported that climatic factors have an impact on the recruitment and growth of various fish species. Mann and Mills [14] and Cowx [6, 7] link an exceptionally hot summer in the year preceding dace and roach spawning with accelerated somatic growth in that year, which, as a consequence, reduced fecundity in the following spawning season. Ponton and Gardeaux [19] maintained, that in Lake Geneva, climatic factors, such as strong wind, increase the mortality of roach larvae and limit the abundance of some generations.

Dippner [9] reported a negative correlation between the influence of global warming (temperature anomalies in surface waters) on the recruitment of marine species such as mackerel, cod, saithe and whiting.

The cyclic occurrence of strong and weak generations in roach populations inhabiting eutrophic lakes in England is explained by Townsend and Perrow [27] as the result of the absence of any specimens older than 4+ and the related feeding competition for zooplankton. When a strong generation occurs and food availability is low, the older specimens grow more slowly and fecundity is limited. This results in the next generation being weaker. Townsend and Perrow maintained that cyclicality does not occur when the roach population is composed of many older age groups because competition for food does not occur. They also suggested that the occurrence of abundant and less abundant generations might be related to climatic factors which initiate this cyclicality.

Wysokiński et al. [31] linked the abundance of pikeperch generations with years when water temperatures during the spawning period were lower in comparison with periods when weaker years were born.

Similar conclusions were drawn from the analyses of changes in the abundance of the roach population in Lake Gardno. Cyclicality in recruitment was not confirmed. Advanced eutrophication and a rise in the average air temperature probably contributed to worsened spawning conditions, which led to a decrease in the abundance of the roach population in Lake Gardno at the end of the 1980s. The direct consequence of this was that fewer eggs were released by the population, which meant that the generations were less and less abundant.

The population composed of larger roach specimens in Lake Łebsko, in which degradation was less pronounced, remained balanced, and during the six-year study period the abundance of the spawning stock did not vary significantly.

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