Ann. Zool. Fennici 33: 397–401 ISSN 0003-455X
Helsinki 28 November 1996

Size-selective mortality in an exploited perch population and the reconstruction of potential growth

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Received 17 October 1995, accepted 5 May 1996

This study assesses the extent of size-selective mortality exerted on perch cohorts recruited to the commercial gillnet fishery in Lake IJssel. The size distribution of the 1985 cohort was surveyed with bottom trawling before and after the winter commercial gillnet fishery, from 1985 till 1990. Ageing and reconstruction of individual growth was done, using opercular bones from fish collected during the surveys and scales sampled from the commercial gillnet catch. The reconstructed potential average size of the 1985 cohort showed that the size reached after five summers could have been 26.9 cm, whereas average length observed in the population was 25.3 cm. Correlations between population size and back-calculated size were highest for back-calculations for the previous year. When earlier back calculations were considered, the correlations became poor or even insignificant. These findings stress the large individual differences in growth history within a cohort and show that the size selective mortality of perch can only be proven over relatively short growth trajectories of less than one year.

1. Introduction

Size-selective mortality of a fish population is often related to size-selective predation (Reimchen 1990). The size distributions of particular cohorts of the fish populations determine the predator-prey interaction within the fish community and can result in a higher risk of mortality for small individuals of a cohort than for larger fish (Parma & Deriso 1990). Because of this selective disappearance of the smaller individuals from a cohort due to predation, the average size at age will increase. Fishing gears may also cause size-selective mortality of the fish population under exploitation (Mulligan & Leaman 1993). Differences in catchability cause the average size of fish caught by the fishery to be larger then average size of the population and therefore the mean size of a cohort vulnerable to the fishing gear will reduce (Smith *et al.* 1990). Using the average size of such a cohort for growth parameter estimates will introduce bias known as "Lee's phenomenon" (Ricker 1969, Duncan 1980). The reduction of the average size of a cohort due to fishery will result in an underestimation of the actual growth of the population.

This study estimates the extent of size-selective mortality of a specific cohort of perch *Perca fluviatilis* from Lake IJssel, the Netherlands, recruited to the commercial gillnet fishery. Willemsen (1977) described the growth of perch in Lake IJssel. Age groups 3, 4 and 5 are exploited by the gillnet fishery (Buijse *et al.* 1992a). In our study, the size of the perch that survived a growing season was back calculated and compared with the actual length distribution, that was observed at that time. The analysis was conducted for the cohort 1985 because of its high abundance, which was 5 times the 1980–1990 average. The cohort was followed for 5 years.

2. Material and methods

2.1. Background and study area

Lake IJssel is a shallow eutrophic freshwater lake with a surface area of 187 000 ha. Its chemical and physical characteristics are described by Willemsen (1977). The fish community consists of eel (*Anguilla anguilla*), smelt (*Osmerus eperlanus*), bream (*Abramis brama*), perch (*Perca fluviatilis*), pikeperch (*Stizostedion lucioperca*), roach (*Rutilis rutilis*) and ruff (*Gymnocephalus cernua*) (Buijse & van Densen 1992).

Commercially important fish species in Lake IJssel are eel, pikeperch and perch (Van Densen *et al.* 1990). The yield for perch varied between 2 and 4 kg/ha over the last 20 years. The fish are mainly caught in gillnets (minimum mesh 101 mm, stretched) during the winter season. The regulated minimum length amounts 22 cm (total length) and a closed season has been installed during the spawning season (15 March–1 July). The instantaneous fishery mortality F for perch was estimated approximately 1 yr^{-1}. Age group 5 with an average length of approximately 31 cm is not fully exploited by the fishery because for perch the L_{opt} (length, which shows maximum selectivity) in the selectivity curve for 101 mm gillnets equals 32.7 cm (s = 2.1 cm) (Buijse *et al.* 1992b). As for younger year-classes this means that the catchability of the larger fish in the cohort is higher in comparison with smaller fish. This implies that the average size of a year-class will decline due to selective removal of the larger individuals.

2.2. Sampling and aging

The 1985 perch cohort was analyzed because the group 0 abundance of this cohort was highest for the period 1966–1989: 775 individual 0+ perch/10 min trawling (Buijse *et al.* 1992a).

Perch were sampled by trawling. The sampling area and program is described in detail by Buijse *et al.* (1992a). A benthic trawl with 20 mm stretched mesh was used for sampling. The 1985 cohort was followed through 1990. A lakewide trawl survey was made in November of each year. Additional sampling was done in June, August and September of 1987, August and September 1988 and March, June and August 1989. Fish from different size classes were selected for ageing on 10 sampling dates. The selected fish were measured to the nearest mm, sexed and the left operculum was dissected, rinsed and stored in paper envelopes. The opercula zonation was enumerated and the radius measured (Le Cren 1947) using a binocular with a periscope. The operculum image was projected on a digitizing tablet interfaced with a personal computer to measure. Successive growth marks (annuli) were registered. Total length was related to operculum length via a power function. Intermediate radii measurements were used to back-calculate the mean length of Perch in the previous year and compared with the actual mean length using a student *t*-test.

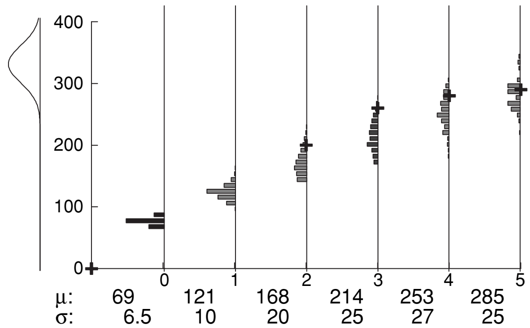

Fig. 1. Length frequency distribution of the 1985 cohort at different ages. The selectivity of the commercial gillnets (101 mm stretched) is depicted to the left of the Y-axis, which represents size of the fish.

For back-calculation, a body proportional relation (Francis 1990) was used:

$$TL_i = (OL_i/OL_c)^{\alpha} \times TL_c \qquad (1),$$

where: TL_c = Total length of perch at capture (mm), TL_i = Total length of perch at age i (mm), OL_c = Length of perch operculum at capture (mm), OL_i = Length of perch operculum at age i (mm), α = Exponent in the power relation of total length and operculum size.

Perch growth (dl/dt) estimated from survey and commercial catches were related to mean length in a Gulland and Holt (1959) plot. The slope and the intercept of the regression were used to estimate the Von Bertalanffy (1934) growth parameters K and L_∞.

Table 1. Total catch ($n \times 1\,000$), mean landing size (mm), standard deviation (mm), *c.v.* and distribution skewness of the 1985 perch cohort in the commercial catch.

Year	(Group)	Catch $n \times 10^3$	Length mm	(*S.D.*)	*c.v.* %	Skewness
1987	(2)	20	200	(17)	8.5	0.85
1988	(3)	370	260	(20)	7.7	– 1.18
1989	(4)	1 160	280	(19)	6.8	0.01
1990	(5)	180	290	(21)	7.2	0.36

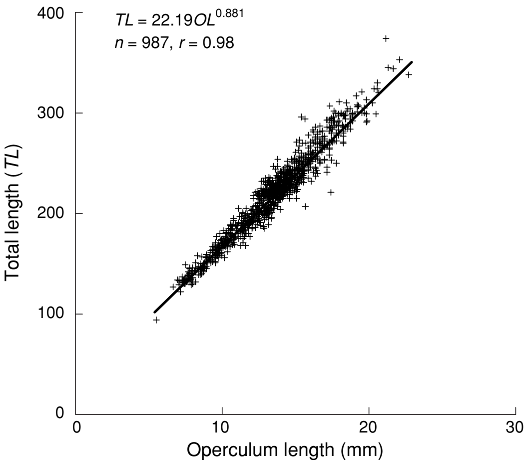

Fig. 2. Perch length (total length, *TL*) in relation to operculum length (*OL*).

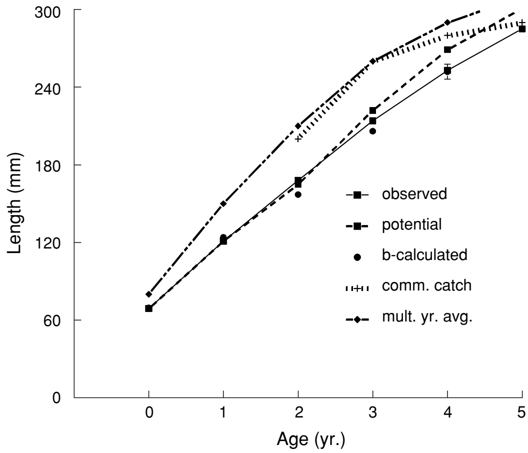

Fig. 3. Mean length at age (mm) for the 1985 perch cohort for observed and backcalculated operculum readings in the population. Also shown is the multi-year average and the length at age in the commercial catch. Reconstructed length is also shown.

3. Results

The size distribution at age for the 1985 cohort, in November of each year is given in Fig. 1. Mean length at age varied from 69 mm to 285 mm for the age-0 and age-5 groups respectively. The coefficient of variation ranged from 8.3% for group 1 to 11.9% for group 2. The Wilk-Shapiro statistic indicated non-normality of the size distributions. All distributions, except the age-4 group were positively skewed. Average length at age, determined by Willemsen (1977), was higher: the mean length at age was 80 mm for age-0 group and 310 mm for the age-5 group for the period 1966 to 1976.

Mean length and abundance of the 1985 cohort in the commercial catch is given in Table 1. The catch of age 4 fish in 1989 was highest. Approximately 65% of the total perch landings in this year originated from the 1985 cohort. Mean length was higher compared with the mean length of the corresponding age groups of the 1985 perch cohort in the trawl survey catch (see Fig. 1).

Regression of operculum radius on total fish length for the 1985 cohort perch from Lake IJssel is shown in Fig. 2. The relation found showed no significant differences between sexes and were combined.

Back-calculated total lengths and total lengths from the November bottom trawl surveys of different year-classes of the 1985 perch cohort, are shown in Fig. 3 and Table 2. Actual measurements of length were not available for the separated sexes, except for 4 group perch in November 1989. Back-calculated mean length was smaller than measured length for 4, 3 and 2 groups. The difference amounted 1, 8 and 11 mm for group 4, 3 and 2 respectively, all being significant (Student's *t*-test) except group 2. For 1-group and 0-group perch the back-calculated length was larger (3 respectively 0.5 mm) than the measured length.

Correlation between size at age in the previous year and actual length attained at catch was significant ($r = 0.95$). The correlation coefficient for back-calculated length at age – 2, – 3 and – 4 from the catch age reduced to 0.8, 0.5 and 0.3 (*n.s.*) respectively.

Observed growth, estimated from survey and commercial, was compared with the potential growth in a Gulland and Holt (1959) plot (Fig. 4). The resulting von Bertalanffy (1934) growth pa-

Table 2. Total length (mm) estimations from the back-calculations of the operculum samples and observed length of the 1985 perch cohort combined, and males and females separated. Standard deviation (*S.D.*) of total length is given between brackets. (– = missing value).

Year class	Back-calculation (mm)	(*S.D.*)	♀	♂	Measured (mm)	(*S.D.*)	♀	♂
4	252	(22)	248	259	253	(27)	240	266
3	206	(24)	196	220	214	(25)	–	–
2	157	(20)	148	164	168	(20)	–	–
1	124	(11)	121	126	121	(10)	–	–
0	69.5	(7)	–	–	69	(7)	–	–

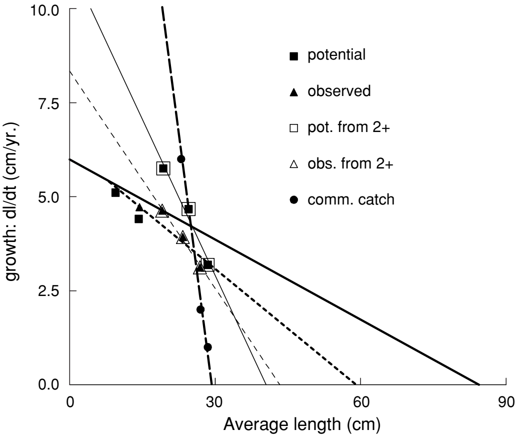

Fig. 4. Gulland and Holt (1959) plot for direct population observations and reconstructed growth from back calculations. The growth estimates from the commercial catch are also shown.

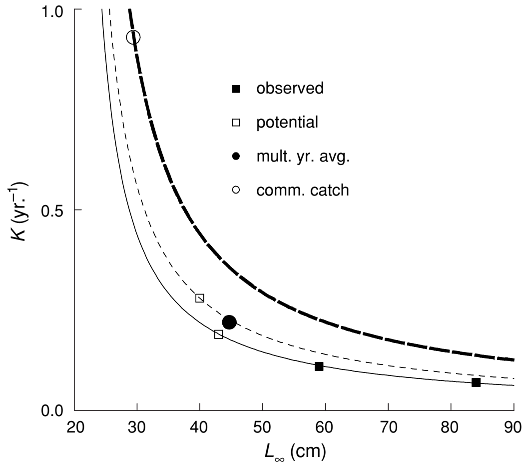

Fig. 5. Plot of the Von Bertalanffy (1934) growth- function parameter K on L_∞ for the various estimations. Growth isopleth for a 20-cm sized perch are also drawn for comparison.

rameters K and L_∞ are presented in Table. 3. The Gulland and Holt plot shows that growth is relatively low during the first two years. Therefore the K and L_∞ were also estimated from group 2 onwards. Although the resulting estimates show a wide range of values for both K (0.07–0.93) and L_∞ (29–84) growth for a 20 cm perch is similar for the estimates from direct observations and the back-calculated growth, when all observations were included. The different K and L_∞ values were plotted in Fig. 5. Growth estimated from the samples from the commercial catch for a 20 cm perch was highest, while the back-calculated estimate from group 2 onward gave an intermediate result, similar to the estimates from a 10-year average (Willemsen 1977) where K was 0.22 and L_∞ was 45.

Table 3. Estimates of the Von Bertalanffy growth parameters of the 1985 perch cohort, using commercial catch data, trawl survey data and operculum back calculations.

Observations		L_∞	K	(r)
Commercial catch		29.4	0.93	(0.99)
Direct observations population	all ages	58.9	0.11	(0.94)
	from 2+	46.3	0.19	(0.99)
Reconstructed from back-calculations population	all ages	84.4	0.07	(0.57)
	from 2+	40.5	0.28	(0.98)

(r) = coefficient of correlation of Guland and Holt (1959) regression.

4. Discussion and conclusion

In this study, size-selective mortality due to exploitation was identified for group 2, 3 and 4 perch of the 1985 cohort. The average length of these groups in the commercial catch, caught with 101 mm gillnets was larger then the average length of the perch groups in the population. The growth history, derived from back-calculated length at the most recent annuli, suggested that individuals that had survived the winter gillnet exploitation had attained a smaller length in the previous year, causing a reduction of the average length of the group. According to Ricker's (1969) estimation method, the differences in average instantaneous mortality rate between the smaller and the larger half of an age-group, amounted 0.10, 0.40, – 0.74, – 0.43, – 0.05 for group 0, 1, 2, 3 and 4 respectively.

Without this size selective mortality the length achieved by group 4 would be 14 mm larger than the actual length found in the exploited population. The resulting systematic underestimation of growth parameters (– 20%) affects results from management models. Back calculated length from the most recent annuli were used in this study. The correlation between final length and size of earlier annuli reduced considerably. Moreover, Vaughan and Burton (1994) showed that the use of back calculated length at formation of all annuli can lead to relatively large bias in the estimates of the growth parameters, which should be avoided by using the most recent annuli only.

In comparison with the estimates from the 10-year average, based on Willemsen (1977), size at age and growth estimates of the 1985 cohort are low. It is likely that the average length estimates from the 1985 cohort are biased, due to its high abundance. Back-calculated length of more cohorts are necessary to reveal unbiased average growth of exploited perch in Lake IJssel. Such information will also give some indication of the year to year variation in growth and growth parameters. This study suggests a considerable variation in individual growth of a particular perch cohort, independent from the year to year variation, affected by environmental factors.

Higher mortality rates for the smaller individuals from group 0 and 1 might be related to selective predation of smaller individual from these groups and the onset of piscivory after two years. The growth abruptly increases after two years.

The selective removal of the large fish of a cohort could have an effect on the genetic composition of the perch stock when growth is heritable. The slow growing part of the population could be in advantage. There are no real world examples of a genetic change induced by size selective fisheries (Chambers 1994). Management should consider the biased estimates of length at age and on a long-term basis the possibility of adaptive genetic changes in the exploited stocks.

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