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Changes of acoustic target strength during juvenile perch development

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Abstract

Dependence of acoustic size (target strength—TS in dB) on body length of juvenile perch (*Perca fluviatilis* L.) was studied. Perch larvae were reared in a laboratory tank from spawning to the age of 89 days. Fish length and TS were measured during 3, 7, 15, 22, 45 and 89 days of life. TS was measured using a Simrad 500 EY split-beam echosounder with the frequency 120 kHz and a BioSonics Model 101 dual-beam echosounder with the frequency 420 kHz in down-looking, horizontal and up-looking directions. Range of fish body length 7–41 mm corresponded with a TS range from −69 to −53 dB. Differences between TS of different aspects were not found in young fish larvae. TS in ventral and dorsal aspects appears to grow faster than in the side aspect for fish 15–30 mm long. With perch larger than 40 mm, vertical and side aspects reach similar values. This paper provides regressions for the size identification of acoustically detected fish targets. The results indicate that the TS/length relationship of early life stages of perch is not too different from general fish TS/length relationship.

Keywords: Perch; Larvae; Juveniles; Target strength; Growth; Scattering

1. Introduction

Small fish assessment is extremely important for understanding fish population dynamics. Fish with acoustic size smaller than −50 dB are usually neglected during hydroacoustic surveys of fish stocks (Trevorrow, 1998; Rudstam et al., 2002) due to problems with acoustic detection limit of small individuals. Difficulties occur with their separation from background noise and various small non-fish objects (e.g., air bubbles, water insects and crustaceans), that may have similar acoustic size (MacLennan and Simmonds, 1992; Kubecka et al., 2000). Despite significant effort aimed to calibrate acoustic and real sizes of adult fish under various conditions (Love, 1977; Kubecka, 1994), data for small freshwater fish are rare (Ponton and Meng, 1990; Rudstam et al., 2002). The objective of this study was to describe relationships between acoustic and real body size of perch (*Perca fluviatilis* L.) larvae during larval development.

The perch was selected for this study for several reasons. It is a common European fish that is abundant in almost all types of water bodies. It is a very close relative to the yellow perch (*Perca flavescens*) that is a morphologically and ecologically very similar fish in North America (Craig, 2000). The perch also serves as a model fish in many ecological studies. Larval perch have an ichthyoplankton stage in their life cycle, when

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they inhabit open water of lakes (Craig, 2000). According to our experience in several European lakes and reservoirs it is possible to detect perch larvae at this developmental stage using hydroacoustics. The first larger series of echosounding of perch larvae was carried out during the work of Wanzenbock et al. (1997). Another extensive survey was conducted by Duncan et al. (1998) on Dutch Lake Maarsseveen. A very similar series of results was reported by Rudstam et al. (2002). These previous studies were missing direct observations of juvenile perch as a verification of targets observed. The ability to survey perciform ichthyoplankton acoustically would greatly facilitate the study of their distribution and behaviour.

2. Material and methods

Fertilised perch eggs were collected from a reservoir and put in a small tank with proportions about 2 m × 1.5 m × 2 m (Fig. 1). After hatching, the fish larvae were fed by *Artemia salina* nauplii and observed by echosounder in particular size stages of their ontogeny, on 3, 7, 15, 22, 45 and 89 days of life (corresponding average total length of 5, 7, 10, 12, 25 and 41 mm). The abundance of the smallest fish in the tank numbered hundreds but we were not able to count the exact number of fish larvae without damaging them. In the course of the experiment the number of fish decreased due to natural mortality and also removal by sampling. At the end of the experiment there were 70 fish that averaged 41 mm. During the monitoring we carefully disturbed fish that had a tendency to stay near walls or bottom, outside of the beam. This practice also reduced the possibility of counting the same fish many times. Fish were subsequently monitored from three directions: ventral, dorsal and lateral (side) body aspects (Fig. 1).

Two systems were used:

(1) Simrad EY 500 split-beam echosounder operated with a frequency of 120 kHz, and a nominal beam angle of the circular split-beam transducer of 7.1°. The diameter of the transducer face is 11 cm (transducer type ES120-7G). The settings of the echosounder were as follows: pulse duration was 0.1 ms, pulse repetition rate 10 Hz, wide frequency bandwidth (12 kHz), the duration of single echoes were allowed within the interval 0.7

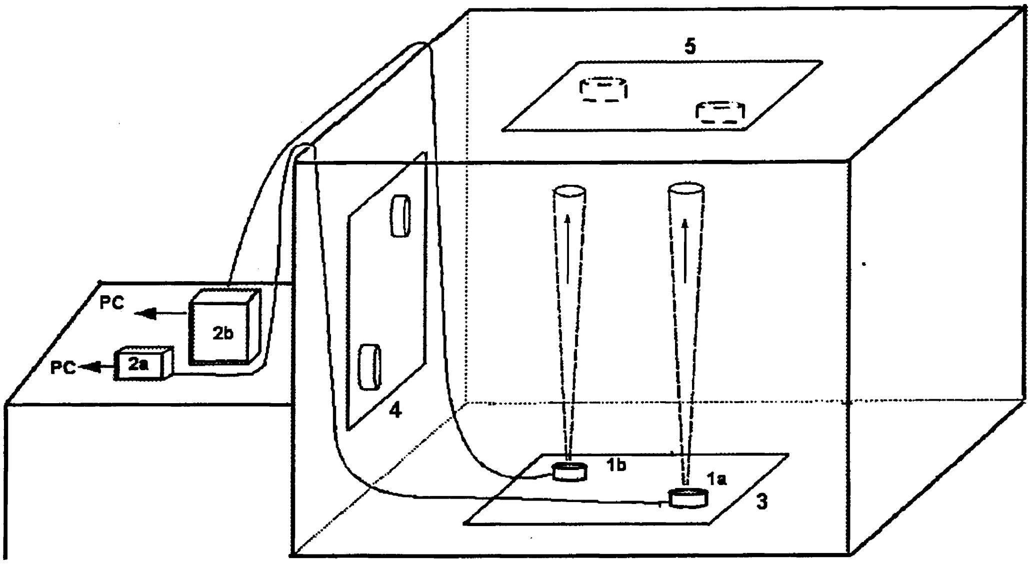

Fig. 1. Experimental set-up with two sonar systems observing perch juveniles in an experimental tank: 1a—transducer 120 kHz, 1b—transducer 420 kHz, 2a—Simrad EY 500, 2b—BioSonics 101, 3—position of the transducer frame for the observation of ventral aspect (up-looking beam), 4—position of the transducer frame for the observation of side aspect (side-looking beam), 5—position of the transducer frame for the observation of dorsal aspect (down-looking beam).

and 1.6 times the duration of transmitted pulse, TS noise threshold −75 dB, maximum allowed off axis distance (gain compensation) 4 dB, maximum phase deviation (measure of electrical phase jitter) 10 steps.

(2) BioSonics, Model 101 dual-beam echosounder operated with a frequency of 420 kHz, and nominal beam widths of 6° and 15°. Echosounder settings were as follows: pulse duration 0.3 ms, pulse repetition rate 10 Hz, frequency bandwidth 10 kHz. Pulse duration measurements were disabled as they were unreliable for the pulses shorter than 0.4 ms (Kubecka, 1995) and the noise threshold was about −70 dB.

Table 1
Summary TS of average σ_{bs} and TS means for individual fish age categories, for 120 and 420 kHz[a]

Age of fish (days)	7	15	22	45	89
Stage of larval development	II	III–IV	V	VII	Juvenile
n	56	39	100	100	70
TL mean (mm)	7.0	10.3	12.4	25.2	41.4
S.D.	0.62	0.75	1.26	2.90	3.46
20 kHz (side aspect)					
n	23	25	39	27	29
TS of average σ_{bs} (dB)	−68.35	−66.53	−63.03	−61.20	−51.64
TS mean (dB)	−68.85 a–v	−67.19 ab–v	−63.89 a–x	−62.69 a–x	−54.98 a–y
S.D.	2.05	2.18	2.90	4.08	6.24
Model of TS average of σ_{bs} (dB)	−69.11	−65.72	−64.16	−58.04	−53.73
420 kHz (side aspect)					
n			20	20	78
TS of average σ_{bs} (dB)			−60.78	−55.12	−51.17
TS mean (dB)			−61.18	−58.75	−53.36
S.D.			1.67	3.16	4.84
Model of TS average of σ_{bs} (dB)			−60.79	−55.13	−51.18
120 kHz × 420 kHz			S	S	NS
120 kHz (dorsal aspect)					
n		24	25	20	27
TS of average σ_{bs} (dB)		−66.24	−63.02	−56.34	−53.48
TS mean (dB)		−66.61 a–v	−63.87 a–x	−57.57 b–y	−54.54 a–z
S.D.		1.82	2.80	3.62	3.61
Model of TS average of σ_{bs} (dB)		−65.32	−63.69	−57.29	−52.79
420 kHz (dorsal aspect)					
n			14	13	18
TS of average σ_{bs} (dB)			−61.62	−56.61	−54.16
TS mean (dB)			−62.03	−56.40	−55.53
S.D.			1.6	3.87	3.78
Model of TS average of σ_{bs} (dB)			−61.44	−57.03	−53.92
120 kHz × 420 kHz			S	NS	NS
120 kHz (ventral aspect)					
n	19	15	28	25	
TS of average σ_{bs} (dB)	−68.43	−67.71	−61.91	−55.56	
TS mean (dB)	−68.85 a–v	−68.05 b–v	−62.37 b–x	−56.17 b–y	
S.D.	1.52	1.85	2.23	2.46	
Model of TS average of σ_{bs} (dB)	−69.41	−65.21	−63.28	−55.71	

[a] Homogenous groups are marked by the same letter behind values: the letters a, b, c, d, mark homogenity for different aspects of the same age, the letters v, x, y, z, for the same aspect but different ages ($P < 0.05$, ANOVA, LSD test). TL—total body length of fish, S.D.—standard deviation, TS—target strength. Stages of juvenile perch development are marked by Spanovskaya and Grygorash (1977, according to Konstantinov, 1957). For comparison of 120 and 420 kHz TS means was used *t*-test for independent samples ($P < 0.05$).

Table 2
Summary of regression models of the dependence between TS of average σ_{bs} (dB) and total fish length (mm)

	$TS = a + b \times \log(TL)$	R	P	The data are valid for the total fish body in the range (mm)
120 kHz				
Side aspect	$TS = -85.8826 + 19.87735 \times \log(TL)$	0.9491	0.014	7–41
Dorsal aspect	$TS = -86.4128 + 20.79234 \times \log(TL)$	0.9870	0.013	10–41
Ventral aspect	$TS = -90.1587 + 24.5918 \times \log(TL)$	0.9568	0.043	7–25
420 kHz				
Side aspect	$TS = -80.8172 + 18.33617 \times \log(TL)$	0.9999	0.001	12–41
Dorsal aspect	$TS = -77.1536 + 14.36867 \times \log(TL)S$	0.9954	0.062	12–41

Near field of both transducers was 90–97 cm, which was calculated from transducer face dimension and verified by the standard target. Both systems were calibrated using tungsten-carbide standard targets (MacLennan and Simmonds, 1992). The echosounders were driven by personal computers and all data were stored on the hard disc of the PC for subsequent processing.

One hundred and twenty kilohertz data were processed by using a fish tracking function in Simrad EP 500 V. 5.2 postprocessing software, 420 kHz data by the BioSonics ESP—Echogram (V. 3.1) software. Only fish echoes further than 1 m from the transducer (for exclusion of near field) and not more than 2° from the centre of the beam were accepted. Targets changing the distance from the transducer were rejected as they were considered to have unknown aspect with respect to the transducer. Only fish tracks with at least five hits were accepted.

Excel 97 and Statistica software were used for data processing. Average TS values were used to test the significance of differences between different aspects (Table 1) while the TS equivalents of average backscattering cross-section (σ_{bs}) (MacLennan et al., 2002) were used for least square regressions between TS and log length (Table 2).

3. Results

Development stages of perch (according to Konstatinov, 1957 as given by Spanovskaya and Grygorash, 1977) during our experiment are given in Table 1. At ages of 3 and 7 days, no larvae had gas in their swim bladders. Filling of the swim bladder started with 15-day-old fish (10 mm long). All 22-day-old fish had swim bladders filled with gas. Generally, all the relationships between body length and acoustic size expressed as TS can be described by a logarithmic function (Table 2). The largest deviation from the linear model was found with the side aspect of fish 25 mm long (120 kHz, Fig. 2a), which appears weaker than predicted (the regression has lower R).

120 kHz. Fish smaller than 7 mm were not detectable by the single echo detection algorithm of EY500 sounder. In 3-day-old fish, 5 mm long, only occasional traces were recorded which were mostly indistinguishable from background noise. These fish had no air in their swim bladders and their TS did not exceed −80 dB. In fish longer than 7 mm, acoustic size increased steeply as the fish grew larger (Figs. 2a and 3, Table 1). Table 1 gives two ways of averaging of TS data: the target strength of average backscattering cross-section (antilogarithmic equivalent of TS averaged in linear domain) and simple arithmetic average of TS recorded (average of log-transformed data). The differences between the two ways of expressing average acoustic size were low except for the biggest juvenile group.

No significant differences in average TS values were found between individual aspects in particular observation of 7 mm long fish. With 10 mm perch, the dorsal aspect was the strongest and significantly different from the ventral (Table 1). The situation changed with 12 mm long fish when the TS of the ventral aspect (and with 25 mm long fish dorsal aspect too) was significantly higher than the side aspect. With the biggest fish (41 mm) the side aspect became similar to the dorsal and ventral ones. It was not possible to measure the ventral aspect of these fish since they did not swim

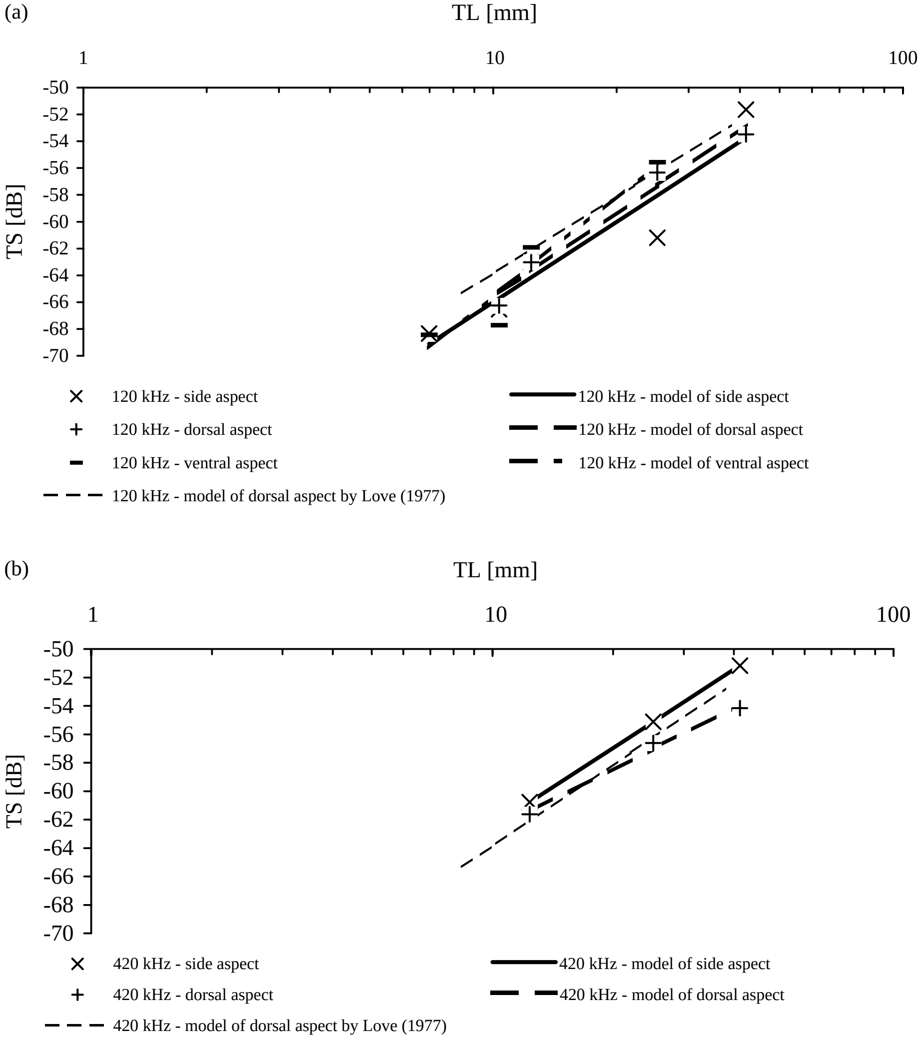

Fig. 2. The course of regression models for all aspects of TS of average σ_{bs} (TS—target strength, TL—total body length of fish): (a) for 120 kHz, (b) for 420 kHz.

over the field of the transducer located on the bottom of experimental tank.

The frequency distribution of total body length of the test fish was normal and symmetric in all cases (tested by χ^2-test, $P < 0.05$). As the age of fish increased the distribution of total length became more flat because the variability of length increased in absolute terms. Also TS distribution had symmetric, normal distribution (χ^2-test, $P < 0.05$). The only exception was 89-day-old fish that had a negatively skewed TS frequency distribution.

420 kHz. Similarly to 120 kHz values, TS values increased with fish body length, but in contrast to them a significant difference between individual aspects was not found (*t*-test for independent samples, $P < 0.05$). Unfortunately 420 kHz data for the youngest perch categories were lost due to hard disk problems and comparison between 120 and 420 kHz was not complete. With smaller larvae (12–25 mm), the TS of 420 kHz records appear significantly higher than 120 kHz. This difference became non-significant with the largest size group of juveniles, where TS reach similar values.

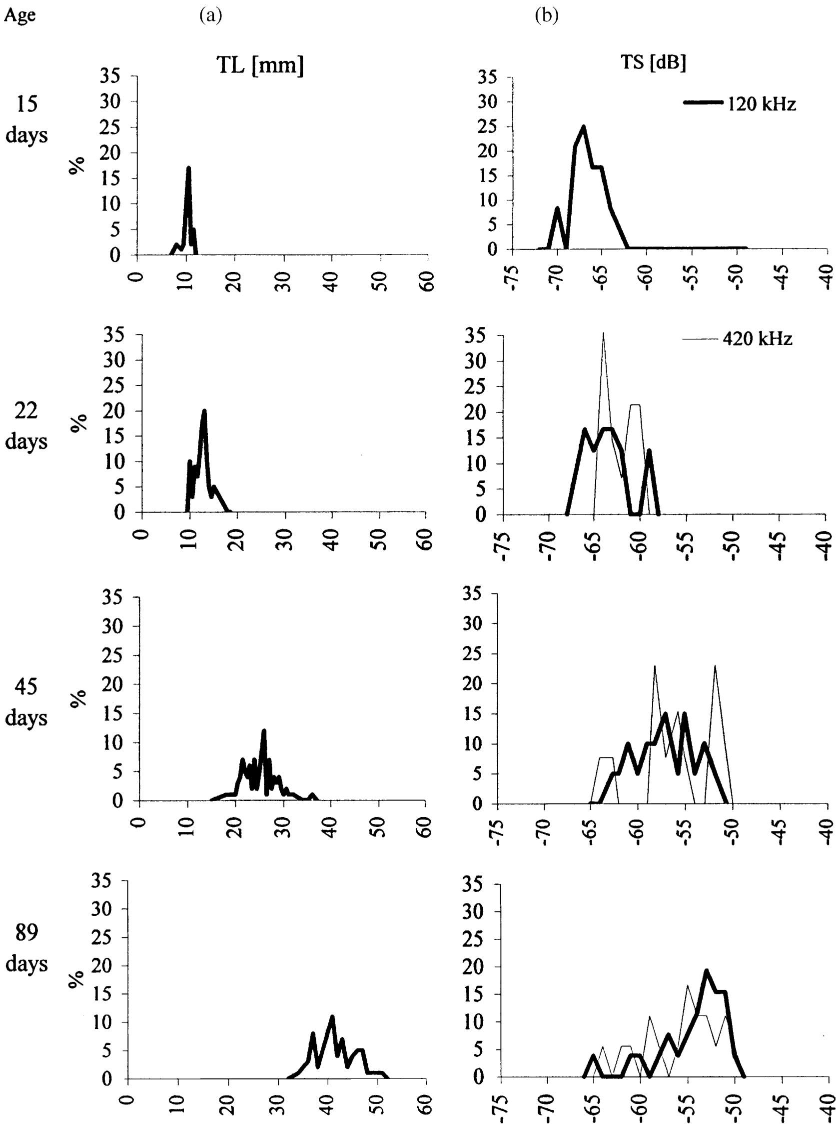

Fig. 3. Percentage distribution of: (a) total body length of fish (TL), (b) target strength (TS) in individual fish ages for dorsal aspect.

4. Discussion

The detection threshold for fish larvae in this study was between 5 and 7 mm, which is close to half of the wavelength (6 mm) that represents the reliable theoretical detection threshold (Uric, 1975) for 120 kHz. The TS of fish at length 7–40 mm ranged from −69 to −53 dB. Concerning the fish that are close to the detection threshold, we have found no data in the literature about the TS of fish of similar size. Similar acoustic size, about −70 dB was reported with planktonic invertebrates crustacean and insects (Pauly and Penrose, 1998; Kubecka et al., 2000). Also, some interference like ambient noise and air bubbles gave similar or higher TS values (Trevorrow, 1998; Frouzova et al., 1998). Keeping in mind the relatively low TS of perch larvae, it is clear that reliable detection requires low noise acoustic conditions. Fortunately, the TS of ambient noise is often below −75 dB in vertical surveys of freshwater lakes and reservoirs with given frequencies. Rudstam et al. (2002), found rather similar TS ranges for a fish larval assemblage 5–15 mm long (modal length 9 mm corresponded to TS of −68 dB) and 15–30 mm (modal length 20 mm corresponded to TS of −58 dB). TS of juvenile fish 40 mm in size was in the range of −56 to −50 dB. Similar acoustic size was also given by other authors for fish 20–50 mm in length (Trevorrow, 1996, 1998; Ponton and Meng, 1990).

In contrast to adult fish in which the side aspect gives the strongest echo (Love, 1977; Kubecka, 1994), TS in all aspects seem to be similar in small fish up to 12 mm. With fish 25 mm long the TS in both vertically oriented aspects was stronger than in side aspects. Only with the oldest investigated fish (41 mm) and 420 kHz, the side aspect becomes strongest similarly to adult fish. With 120 kHz the difference is not significant. We can assume that this corresponds to changes in fish larvae morphology during development. During the yolk sac period of ontogeny the body cross-section becomes slimmer as the larva resorbs the yolk. This may correspond to the period when vertical aspects exceed horizontal ones. Later the fish body becomes flattened laterally and this corresponds to a relative increase of side aspect. Also, the development and morphological changes in size and distribution of gas-containing tissue, namely gut and swim bladder, may support this phenomenon.

Fig. 2 shows the comparison of our data with the general TS/length relationship published by Love (1977). It is interesting to see that general model derived from much larger fish only slightly overestimates TS of 120 kHz records and overlaps with 420 kHz data. Our findings support the notion that Love's general model is a reasonable approximation for TS/length relationship down to early juveniles.

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