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Two methods to improve the accuracy of target-strength estimates for horizontal beaming

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A high variability in fish's aspect, causing strong target-strength (TS) fluctuations, was observed in nase *Chondrostoma nasus* (L.) during upstream spawning migration through a horizontal, bottom-aligned beam in the Fischa River, a tributary of the Danube. Size estimates based on traditional mean target strength underestimated the total length of nase. Applying maximum TS from side-aspect detections overestimated size due to signal amplifications of up to 10 dB in the single-echo detections of tracked fish. Based on Lilja's simulations, the strong signal amplifications probably originated from flash-effects. Inhomogeneous sound-propagation due to cylindrical spreading and the maturity state of spawning nase probably contributed to signal amplification of up to 6 dB. In order to find better size estimators than the mean and max size estimator, we tested percentile estimators, and we developed a new statistical method—the Maximum Excess Test and Maximum Isolation Test (MET–MIT). This method links information from catch data with the TS-distribution from tracked fish in order to exclude outliers. The results show that both the MET–MIT and the percentiles gave reasonably similar results and that both were better size estimators than the traditional mean-target-strength estimator.

1. Introduction

The target strength (TS) of fish is highly variable. Even for the same fish, values are unlikely to be constant due to changes in behavioural, morphological, ontogenetic and physiological factors (Foote, 1980a; Ona, 1990; Simmonds and MacLennan, 2005). Air-filled swimbladders are the main reflector (up to 90%) of acoustic energy (Foote, 1980a). Moreover, condition and maturity state (Ona et al., 2001; Ona, 2003), length (Love, 1971, 1977; Foote, 1980b; Blaxter and Batty, 1990), tilt (Nakken and Olsen, 1977; Kubečka, 1994) and depth (Ona, 1990; Fleischer and Tewinkel, 1998; Gauthier and Rose, 2002) influence the shape or orientation of the swimbladder and considerably impact TS. Among the biological factors, pan and tilt are considered to play a key role in changing target strength (Hazen and Horne, 2003; McQuinn and Winger, 2003; Frouzová et al., 2005). Small behaviour-related changes in the aspect angle, and thus in the orientation of the body axis in relation to the vertical or horizontal sound beam, can significantly affect target strength; this occurs to a minor degree in the dorsal aspect (Hewitt and Demer, 1996; Horne et al., 2000; Rudstam et al., 2003) but to a high extent in the side-aspect (Love, 1969; Kubečka and Duncan, 1998; Frouzová et al., 2005). In side-looking applications the mean backscattering cross-section can differ by 10 dB or more for two fish of the same species and identical length (Fleischmann and Burwen, 2000). Hence, in shallow-water horizontal acoustics it is difficult to discriminate among species or even to attempt fish size estimates using TS alone (Burwen and Fleischmann, 1998; Horne et al., 2000). Burwen et al. (2003) suggested that the echo duration (i.e. the width of an echo measured at the half-power points) and the variability of echo duration are far better predictors of fish length and species discriminators than TS measurements for 200 kHz side-looking applications.

Accurate interpretation of acoustic data in estimating fish size requires knowledge of the scattering properties of fish (MacLennan and Simmonds, 1992).

Two recent publications have contributed to our understanding of the backscattering properties of *in situ* fish in shallow-water horizontal acoustics. Lilja et al. (2004) used numerical simulations to show that swimbladder bending severely influences TS measurements. Bending in the direction of the sonic beam caused strong fluctuation of the backscattering amplitudes, with a strong peak of TS in a narrow angular range near the full side-aspect. The

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TS simulations demonstrated that, just as reflecting light shows a quick flash in a particular direction, acoustic waves of sufficiently high frequency also exhibit similar behaviour. This was termed a 'flash-effect' (Lilja et al., 2004).

Burwen et al. (2007), by synchronizing a split-beam echo sounder with a high-resolution multibeam sonar (DIDSON; Blecher et al., 2001), confirmed earlier presumptions that, depending on the target orientation, other anatomical structures can contribute to the target backscatter and can influence the shape of the resulting echo.

The present study developed an empirical model based on advanced statistics (MET–MIT-percentile). The main focus is on an upper-tail-distribution analysis of the empirical normal distribution in order to handle high within-track TS variability. In addition, other size estimators like mean TS, pan corrected mean TS, maximum TS and TS-percentile were tested comparatively side-by-side. Traditional size estimators failed to size fish correctly, whereas the TS-percentile estimator was satisfactory. The new empirical model as well as the 95th TS-percentile enabled us to control individual target-strength fluctuations, to exclude signal amplifications (i.e. due to flash-effects) from total length estimates and to reliably estimate fish size in shallow-water horizontal acoustics.

2. Materials and methods

2.1. Study area

The Fischa River is a tributary of the Danube River east of Vienna. Recently, 36 fish species were identified here. In spring, the river is characterised by a sequence of single-species spawning events starting with pike *Esox lucius* L. and dace *Leuciscus leuciscus* (L.), followed by nase *Chondrostoma nasus* (L.), ide *Leuciscus idus* (L.) and barbel *Barbus barbus* (L.) (Rakowitz et al., 2008). Two nase spawning sites are located 4.5 km upstream the mouth, where the Fischa splits into several smaller branches, creating a local floodplain area (Fig. 1). Two of these branches contain riffles with high current velocity and are regularly frequented by the same nase individuals from year to year (Keckeis, 1998; Rakowitz et al., 2008). Individuals of this species occur in this river system only during spawning season, from March to early June (Keckeis, 1998).

2.2. Acoustic recording

The hydroacoustic investigation of the spawning migration of lithophilous nase into the Fischa River was conducted in the transition area at a site 4.0 km upstream of the river mouth. The cross-sectional riverbed topography here is well suited for fixed-location horizontal beaming: a triangular cross-section with a gently sloping right shore and steeply dropping left shore (Fig. 1). At average discharge, the river cross-section at the sampling site is 15.00 m wide with a maximum depth of 2.15 m near the left shore. The bottom consists of gravel and has an even gradient with small obtrusions. The site is located close to the spawning places of nase, with sufficient distance upstream of the mouth. This minimises bias caused by other Danubian fish species migrating into the lower stretch above the mouth.

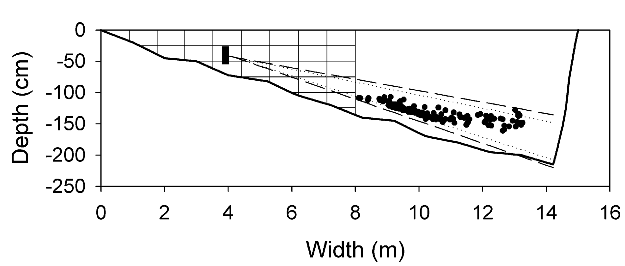

Fig. 1. Cross-section of the Fischa River at the hydroacoustic sampling site looking from downstream. A panel fence guided the migrating fish out of the transducers nearfield (4 m). Tested fish ($n = 184$) were bottom oriented, mainly recorded in the 3 dB beam (dotted line) and occasionally in the 6 dB beam (medium dashed line). Pan and tilt angles of the transducer were 13° downstream and 7.6° downwards, respectively.

From 30 March to 27 May 2004, hydroacoustic data were collected near-continuously with a portable 120 kHz digital echo sounder (Simrad, EK 60, Horten, Norway) and an elliptical (8.30° × 4.40°) splitbeam transducer. The transducer was mounted on a tetrapod-scaffold and aimed horizontally across the river from the right shore towards the left shore using a dual-axis, remote-controlled rotator (Sub-Atlantic, 1128-MAS, Aberdeen, Scotland). A deflection fence was placed downstream of the transducer to guide upstream-migrating fish out of the transducer's nearfield. The panel fence was manufactured from solid plastic tubes with a lattice spacing of 1.5 cm, fixed on the ground and equipped with floating bodies on the top. Prior to continuous echo sounding, beam mapping was conducted to adjust the horizontal beam as close to the bottom as possible. This allowed detection of bottom-oriented, upstream-migrating fish (Fig. 1). Hence, the beam was tilted downwards by 7.6° and panned downstream at 13.0° in order to see swimming direction as a function of range. Once properly oriented, the echo-sounder system was calibrated *in situ* using the tungsten-carbide standard-calibration sphere (Ø = 23.0 mm) with a nominal target-strength value of TS = −40.4 dB. The system was kept stationary for the whole sampling period. Basic information about the sound-propagation in the horizontal bottom-aligned beam is given by Rakowitz and Kubečka (2006). During monitoring, sound pulses were transmitted with 0.064 ms pulse width, 11.8 kHz bandwidth, a pulse repetition rate of 10–30 pings s^{-1} and 300 W power. Due to the short investigated range, the acoustic absorption was negligible. Studies in rivers with low signal-to-noise ratio (SNR, 10–15 dB) require less restrictive criteria for applying the echo sounder's single-echo detector than during vertical beaming. The sensitivity threshold of the detected echoes was set to −50.00 dB due to the background noise level. To increase the detectability in the horizontal bottom-aligned beam, the echo-length detector was set to 0.8–1.5 times the transmitted pulse duration; the maximum phase deviation was set to 1.2° and the maximum gain compensation was enhanced to 6.0 dB (one-way). Signals were automatically compensated for off-axis distance. The echo sounder was in operation for an average of 22.4 h·day^{-1} for 59 days. Field tests, transducer cleaning and defective power supply occasionally interrupted the monitoring for several hours. Analog data from the transducer were digitized in the echo sounder's GPT unit (General Purpose Transceiver), recorded on a laptop and stored on an external hard disk.

2.3. Acoustic analysis

For this study, a total of 33 days were analysed with Sonar5-Pro version 5.9.1 post-processing software (Balk and Lindem, 2000; Lindem Data Acquisition, Oslo, Norway), which was updated regularly (http://www.fys.uio.no/∼hbalk). After conversion of raw data, the acoustic analysis was carried out by single-echo detection followed by manual tracking. For single-echo detection we did not use the traditional detector based on echo length (Soule et al., 1997), but the alternative Crossfilter detector found in Sonar5 (Balk and Lindem, 2007). This detector improves track quality and reduces erroneous detections in data with low SNR (Balk, 2001). The detector consists of a suggestor obtaining trace candidates, an evaluator sorting out unwanted candidates, a SED former which defines the individual echo detections within a trace and an echo-quality estimator. The suggestor works with filters identifying the target's frequency