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Relationship between horizontal hydroacoustic stock estimates and gillnet catches of surface-oriented fish in shallow Lake Balaton (Hungary)

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ABSTRACT

Key-words:
gillnet,
side-looking
hydroacoustics,
comparability
of data,
Alburnus alburnus,
shallow lake

We examined whether gillnetting and hydroacoustics provide comparable relative fish density and fish size distribution estimates in the uppermost water layer of a shallow turbid lake and whether the inclusion of environmental and stock parameters could improve comparability of data between different gears. According to gillnetting, most fish shorter than 14 cm in total length were *Alburnus alburnus*, and most fish longer than 14 cm were *Pelecus cultratus*. Size distributions and median sizes obtained from gillnetting and acoustics differed. Pure acoustics-derived density estimates accounted for only <8.8% of the variation in the gillnet catch by number and no correlation was found in biomass indices. Most variances observed in the gillnet catch-per-unit-effort data were associated with water transparency, none of the other investigated variables had significant explanatory power. We conclude that the feasibility of establishing a powerful model describing the relationship between fish density estimates of gillnetting and acoustics is low in shallow and turbid habitats, and it might be successful only if the crucial sampling and environmental parameters affecting catch efficiency of gillnets and post-processing of acoustic data are considered. This study cautions again that gillnetting should be used carefully to analyse trends of fish abundance.

RÉSUMÉ

Relation entre les estimations horizontales hydroacoustiques du stock et les captures au filet maillant de poissons de surface en eaux peu profondes du lac Balaton (Hongrie)

Mots-clés :
filet maillant,
hydroacoustique
latérale,
comparabilité
des données,
Alburnus alburnus,
lac peu profond

Nous avons examiné si les filets maillants et l'hydroacoustique fournissent des données comparables de la densité des poissons et des estimations de distribution en taille des poissons dans la couche d'eau supérieure d'un lac peu profond trouble et si l'inclusion de paramètres environnementaux et du stock de poissons pourrait améliorer la comparabilité des données entre les différents engins. Selon la pêche au filet maillant, la plupart des poissons de longueur totale inférieure à 14 cm étaient *Alburnus alburnus*, et la plupart des poissons de plus de 14 cm étaient *Pelecus cultratus*. Les distributions de taille et les tailles médianes obtenues à partir des filets maillants et de l'acoustique sont différentes. Les estimations dérivées de la seule densité acoustique ne représentaient que moins de 8,8 % de la variation des captures au filet maillant en nombre et aucune corrélation

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n'a été trouvée dans les indices de biomasse. La plupart des variations obser-
vées dans les captures par unité d'effort des filets maillants ont été associées à
la transparence de l'eau, aucune des autres variables étudiées n'ont un important
pouvoir explicatif. Nous concluons que la possibilité d'établir un modèle puissant
décrivant la relation entre les estimations de la densité des poissons par pêche
au filet maillant et de l'acoustique est faible dans les habitats peu profonds et
troubles, et il ne pourrait être valable que si l'échantillonnage et les paramètres
environnementaux affectant l'efficacité de capture des filets maillants et le post-
traitement des données acoustiques sont considérés. Cette étude rappelle encore
une fois que les filets maillants doivent être utilisés avec précaution pour analyser
les tendances de l'abondance des poissons.

INTRODUCTION

The reliable estimation of biotic stock attributes is a fundamental requirement in both basic and applied research. A variety of fish sampling methods are available, which however differ in their applicability and selectivity (*e.g.* Murphy and Willis, 1996). With the globalization of research programs (*e.g.* the formation of the European Union Water Framework Directive), increasing attention has been turned to issues like the comparability of fish stock estimates over a wide range of habitats, and extended spatial and temporal scales (Holmgren and Appelberg, 2000; Mehner *et al*., 2005; Lauridsen *et al*., 2008; Deceliere-Vergés *et al.*, 2009; Erős *et al*., 2009a), and the comparability of results among sampling gears (Jackson and Harvey, 1997; Olin and Malinen, 2003; Erős *et al*., 2009b; Winfield *et al*., 2009; Emmrich *et al*., 2010).

In standing freshwaters, sampling by gillnetting is the most widely used technique to collect fish assemblage data. The most crucial proposition of gillnet sampling is to assess how catches relate to fish abundance and size distribution. In general, it is assumed that if they are taken in a standardized manner, gillnet catches (*i.e.* catch per unit effort; hereafter CPUE) appropriately monitor trends of fish assemblages both in time and space (*e.g.* Appelberg *et al*., 1995; CEN, 2005). However since gillnetting is a highly selective passive fishing gear, which efficiency varies with sampling circumstances and by fish species, the relationship between the CPUE data and the fish abundance is not universal, and typically, gillnet catches cannot directly be used as an accurate estimate of relative stock density (review: Hamley, 1975; and more recently Olin *et al*., 2004; Linløkken and Haugen, 2006; Pierce *et al*., 2010; Prchalová *et al*., 2011). Moreover, gillnetting is a highly destructive tool, causing high mortality in captured fish, and therefore, any methodological development encouraging reduced gillnet use would be favourable (see also Winfield *et al*., 2009).

Because of the problems associated with gillnet sampling, the complementary use of hydroacoustics has widely been suggested (Hansson and Rudstam, 1995; Mehner and Schulz, 2002; Mous *et al*., 2004; Guillard and Vergès, 2007; Winfield *et al*., 2009; Boswell *et al*., 2010). Hydroacoustics is an effective tool for assessing total abundance, size distribution and habitat usage of fish, but with the exception of special situations, it does not provide species-specific information (but see Elliott and Fletcher, 2001; Winfield *et al*., 2009).

The existence of a positive correlation between acoustics-derived abundance estimates and gillnet CPUE values seems to be ordinary, however its strength varies strongly, and often, it is weak (Hansson and Rudstam, 1995; Mehner and Schulz, 2002; Tátrai *et al*., 2008; Boswell *et al*., 2010; Dennerline *et al*., 2012). Since the catching efficiency of gillnetting varies due to environmental and technical factors, a comparison of data between different gears should consider these variables. For example, Hansson and Rudstam (1995) suggested that water transparency and temperature should be taken into account when comparing gillnet catches with results from other gears (*e.g.* acoustics), and recently Prchalová *et al.* (2011) proposed the "catchable biomass" model as a potential tool for improving gillnet data comparability by adjusting soak time related biases. Though only few attempts have been made so far to

incorporate such components into the models assessing the relationship between the data of different sampling protocols (see *e.g.* Hansson and Rudstam, 1995).

In this study, we tested whether gillnetting and acoustics provide comparable results on relative fish density and fish size distribution for the bleak *Alburnus alburnus* (L.) dominated surface water layer of shallow Lake Balaton. Sampling effort is usually not proportionally distributed across the characteristic habitats. In lakes, especially in shallow ones (*i.e.* water depth <10 m), the majority of the gillnetting effort is concentrated to the most diverse (*i.e.* more species rich) benthic fish assemblages, and surface-oriented fish are under-investigated (see *e.g.* CEN, 2005). Similarly, most acoustic surveys have concentrated on benthic and pelagic fish assemblages, but paid relatively little attention to surface-oriented fish mainly because of the technical limitations (*i.e.* near field zone, waves). However, recent studies have emphasised the importance of non-benthic fish in assessment of freshwater ecosystem processes in both deep (Kubečka and Wittingerova, 1998; Knudsen and Sægrov, 2002; Lauridsen *et al.*, 2008; Emmrich *et al.*, 2010) and shallow water monitoring (Olin and Malinen, 2003; Mous *et al.*, 2004; Specziár *et al.*, 2009). Although Lake Balaton is very shallow (mean depth is 3.2 m), its fish community presents a characteristic vertical gradient regarding the species occurrence, but inevitably not the fish biomass. Recent investigations showed that about one third of the fish biomass in the open water region of the lake is represented by the surface-oriented bleak (Specziár *et al.*, 2009).

The specific objectives of this study were to analyse how gillnet CPUE data relates to concurrent measurements from horizontal acoustic sampling in the uppermost 1.5 m deep water layer of Lake Balaton, and to investigate whether the inclusion of environmental parameters (*i.e.* water transparency, temperature and depth) and stock attributes (*i.e.* mean fish size and fish aggregation level) could improve comparability of data between different gears. If a strong correlation is identified, gillnet sampling could be reduced in the uppermost, species poor water layers and destructive sampling could be restricted mainly to diverse benthic and littoral fish assemblages.

MATERIALS AND METHODS

> STUDY AREA

Lake Balaton is the largest shallow lake (surface area: 593 km^2; mean depth: 3.2 m) in Central Europe, situated at 46° 42′–47° 04′ N, 17° 15′–18° 10′ E and 104.8 m above sea level. Its bottom is unstructured, mostly smooth, without significant fluctuation in water depth. The lake is meso-eutrophic with mean annual chlorophyll-a concentrations of 3.6–18.7 mg·m^{-3} (Istvánovics *et al.*, 2007). Forty-seven percent of the lakeshore is covered by reed grass, but submerged macrophytes occur sparsely in the littoral zone. The lake is slightly alkaline, it contains approximately 400 mg·L^{-1} of Ca^{2+} and $Mg^{2+}(HCO_3^-)_2$, its pH varies between 8.2 and 9.1, and has a conductivity of 550–671 μs·cm^{-1}. Although in exceptional cases (*e.g.* under ice cover) water transparency may reach 1.5–1.8 m, in general the lake is turbid with a Secchi depth varying between 0.2 m and 0.8 m. Thermal stratification do not develop in Lake Balaton, and the difference between the temperatures of the surface and the bottom water layers is always less than 2–3 °C (Herodek *et al.*, 1988). Oxygen deficiency has never been registered in the lake, and concentrations of pollutants are low or insignificant. Common bream *Abramis brama* (L.), razor fish *Pelecus cultratus* (L.) and *A. alburnus* are characteristic fish species of the Lake and most abundant in biomass along with the introduced hybrid Asian carps *Hypophthalmichthys*. There are several reviews on the limnology (*e.g.* Herodek *et al.*, 1988; Istvánovics *et al.*, 2007) and the fish fauna (*e.g.* Bíró, 1997; Specziár 2010) of Lake Balaton, which can serve as a source of further information.

Table I
Survey dates, environmental parameters and basic acoustics-derived characteristics (at target strength ⩾−55 dB) of the fish stock in the uppermost 1.5 m water layer of Lake Balaton.

Trial	Date	Water depth (cm)	Secchi depth (cm)	Water temperature (°C)	Single echoes (%)	Mean acoustic L (cm)	Mean A_{Tot} (fish 1000·m⁻³)
1.	19.04.2007	450	47	14.0	85.8	15.4	19.1
2.	11.05.2007	335	66	18.6	61.6	18.5	6.4
3.	31.05.2007	415	54	18.6	52.7	16.4	32.1
4.	20.09.2007	425	45	14.6	2.2	16.2	54.1
5.	21.09.2007	390	44	15.1	70.2	12.9	39.9
6.	26.09.2007	400	100	16.2	48.0	8.4	17.2
7.	15.04.2009	470	85	13.0	35.9	20.9	0.9
8.	21.07.2009	415	68	23.6	47.9	10.2	10.7
9.	23.07.2009	460	77	24.5	50.5	10.1	12.1
10.	27.07.2010	330	38	19.9	89.6	14.6	10.3
11.	28.07.2010	400	46	19.9	62.7	18.7	18.3
12.	29.07.2010	460	54	21.1	74.2	16.4	5.1
13.	30.07.2010	410	48	21.1	47.6	19.1	3.8
	Mean ± SD	412 ± 44	59 ± 19	18.5 ± 3.7	60.7 ± 15.9	15.2 ± 3.9	17.7 ± 15.6

L: total length; A_{Tot}: volumetric acoustic abundance based on the amplitude-echogram.

> DATA SAMPLING AND PROCESSING

Thirteen gillnetting and concurrent acoustic surveys were conducted in the uppermost 1.5 m water layer during the day-time in 2007, 2009 and 2010 in the open water area of Lake Balaton (Table I). Sampling trials were distributed in time and space to provide useful gradients of both fish density and environmental circumstances. In order to exclude effects of diel changes in fish behaviour (*i.e.* activity, diel vertical migration), all samplings were initiated at 8 a.m. conforming also to the diel activity pattern of bleak. Unlike most other temperate freshwater fish, bleak is more active at day-time than at night-time, especially in waters with low transparency (Olin and Malinen, 2003; Prchalová *et al.*, 2010; but see Vašek *et al.*, 2009 for a more transparent habitat). Considering the high sensitivity of horizontal acoustics to the stability of the beam orientation and the signal-to-noise ratio, all samplings were carried out on windless days.

For the experiments, surface-set multimesh gillnets (Nippon Verkko oy, Finland) were used. Gillnets were made according to the European standard EN 14 757 (CEN, 2005) for benthic gillnets but with a modified buoyancy line enabling the surface setting of the net. They composed of 12 different mesh-sizes ranging from 5 to 55 mm (knot to knot) and were 1.5 m deep. The order of the panels of different mesh-sizes was fixed as 43, 19.5, 6.25, 10, 55, 8, 12.5, 24, 15.5, 5, 35 and 29 mm. Each mesh panel was 2.5 m long and mounted on a 30 m long buoyancy line (linear density in water 31 g·m⁻¹) and a 33 m long lead line (linear density in air 22 g·m⁻¹). The hanging ratio was 0.5 for all mesh-sizes.

In each trial, three surface-set gillnets were positioned linearly with one net length gap between them. In order to avoid the saturation of nets with fish and the related biases (Olin *et al.*, 2004; Prchalová *et al.*, 2011), soak time must be kept short in Lake Balaton (Erős *et al.*, 2009b; Specziár *et al.*, 2009). Therefore, we used sampling intervals of two hours.

Catches from each net were processed separately. Captured fish were identified, counted by species, measured to the nearest millimetre total lengths (*L*), and weighted to the nearest gram wet mass (*M*). Gillnet catches were expressed in both NPUE (number of fish captured per one hour per net) and BPUE (mass of fish captured per one hour per net).

Concurrent horizontal acoustic measurements were carried out by means of a SIMRAD EK60 split-beam echo sounder with 120 kHz operating frequency and equipped with an E120-7C transducer (circular beam with a nominal beam angle of 7° × 7°). The transducer was mounted

on a pole fixed to the bow of a boat, 0.4 m under the water surface and aimed perpendicular to the sailing route. The axis of the beam was tilted 3.5° below horizontal as the upper margin of the sound beam run approximately parallel with the water surface. The system's operating power was 100 W, the pulse duration 0.128 ms, the ping rate 10 ping·s^{-1}, the bandwidth 10.92 kHz and the recording threshold –100 dB. Based on the results of Godlewska *et al.* (2011), short pulse duration was chosen to enable target separation in the densely populated uppermost water layer of Lake Balaton. The echosounder system was calibrated before each trial with a 23 mm copper calibration sphere with reference target strength (*TS*) of –40.4 dB at 120 kHz. In each trial, three consecutive acoustic measurements, each lasting for approximately 10 min, with 15 min gaps between them were made along an approximately 1200 m long elliptical route (with a major radius being approx. 280 m long and coinciding with the axis of the nets; and the minor radius being approx. 50 m long and being perpendicular to the nets) around the gillnets, measuring outwards. First acoustic measurement started 15 min after the set of the nets. Second and third acoustic runs followed the same route set during the first run based on GPS navigation.

Acoustic raw data was converted and analysed using Sonar5-Pro post-processing software (Balk and Lindem, 2007). To enable a more detailed statistical analysis (*i.e.* the comparison of three consecutive measurements for each trial), each acoustic measurement (*i.e.* data of one lap along the 1200 m long route around the nets) was divided into five elementary distance sampling units (EDSU) of equal length (*i.e.* 240 m). For this study, acoustic data were processed to 12 m distance from the transducer (excluding the near-field range of the transducer) corresponding to the uppermost 1.5 m water layer. Sonar-5-Pro's cross-filter detector (CFD) was used to reduce noise related bias in the single echo detection (SED) echograms and to improve the quality of the data (Balk, 2001; see also Rakowitz *et al.*, 2009; Tušer *et al.*, 2009). Both the height and the width of the CFD's foreground filter was set to 1; the background filter height was between 23–29, the width between 1–13, and the offset was +6 dB. Volumetric fish abundance (*A*) and biomass (*B*) was assessed by the S_v/*TS* scaling method (A_{Tot}, B_{Tot} from the amplitude-echogram and A_{SED}, B_{SED} from the SED-echogram, respectively) (Balk and Lindem, 2007). Linear volume reverberation (S_v) and mean *TS* (calculated in the linear domain) were determined based on SEDs for each EDSU (15 EDSUs per trial). Since the records were relatively noisy, *TS* threshold was set to –55 dB (equivalent to a L = 2.5 cm fish at side aspect; Frouzová *et al.*, 2005). Suitability of conditions for a reliable *TS* estimation was checked by the Sawada index; and its value proved to be less than 0.1 in each case. Target strength values of single echoes recorded at random aspects were converted to side aspect *TS* values using the deconvolution method of Kubečka *et al.* (1994), and then to L according to the lateral aspect regression for European freshwater species by Frouzová *et al.* (2005). For calculating *B*, mean L (cm) of each 1 cm acoustic L groups were converted to *M* (g) according to the corresponding relationships for bleak ($M = 0.00720 \, L^{3.102}$) and razor fish ($M = 0.00576 L^{3.041}$) determined from gillnet catches, and then multiplied with the estimated *A* of the given L group. All targets with an estimated L up to 14 cm were considered to be bleak, and all larger targets were considered to be razor fish (see results).

Water temperature (°C) measured at 0.5 m under the water surface, depth (cm) and transparency measured as Secchi depth (cm) were recorded at each trial. It is well known that the accuracy of acoustic density estimates depends upon the detectability of individual fish as single targets, which however is a function of distance between fish in the shoal. Hence, we characterized the "aggregation level" of fish based on the ratio of $A_{Tot} \, A_{SED}^{-1}$, which is the converse of the ratio of S_v from single echoes and the total S_v in the sampled volume calculated by the Sonar5-Pro post-processing software. Finally, since the efficiency of gillnets varies with fish size, we also considered mean acoustic L as a potential explanatory variable for the model assessing the relationship between the density estimates of gillnetting and acoustics.

> STATISTICAL ANALYSIS

Since fright reaction of fish can bias the results of acoustics (Draštic and Kubečka, 2005; Godlewska *et al*., 2009), and surface-oriented fish, like bleak, are supposed to be especially sensitive for the presence of the survey boat (Janáč and Jurajda, 2005), thus first it was examined whether avoidance of the survey boat by fish could influence results of the acoustics. It was hypothesized that if the boat frightens fish, then their density and size distribution should change in the sampling area during the continuous disturbance. Therefore, results of the three consecutive rounds (data of five EDSUs for each) of the acoustic sampling were tested for significant differences in A_{Tot}, A_{SED} and mean acoustic L with analysis of variance (ANOVA) performed on $\log_{10}(x + 1)$ transformed data, both for each individual trial and for the whole study.

Total length distributions derived from gillnetting and acoustics were compared with non-parametric Kolmogorov-Smirnov two-sample test and Mann-Whitney U-test separately for each individual trial. Comparisons were made over both the whole fish size range represented in the gillnet catches (L = 5–35 cm) and the size range of bleak (L = 5–14 cm) only.

Relationship between the gillnet catches (dependent variable) and the acoustics-derived density estimates, and other explanatory variables were investigated with multiple linear regression analysis using the forward stepwise variable selection procedure (at $p < 0.05$). Other parameters examined were the water temperature, Secchi depth, water depth and aggregation level and mean acoustic L of fish. Prior to analyses gillnet CPUE data and acoustic fish density estimates (A and B) were $\log_{10}(x + 1)$ transformed and other variables were $\log_{10} x$ transformed. Explanatory variables were largely independent, except the relationship between the Secchi depth and aggregation level of fish (Pearson's correlation, $r = 0.730$, $p < 0.005$). Latter two variables were therefore investigated separately.

A comparison between gears was attempted for both abundance (*i.e.* NPUE *vs.* A_{Tot} or A_{SED}) and biomass (*i.e.* BPUE *vs.* B_{Tot} or B_{SED}) related estimates using data over both the whole fish size range represented in the gillnet catches (L = 5–35 cm) and the size range of bleak only (L = 5–14 cm). Where it was relevant, regression analyses were completed with variation partitioning procedure to quantify the contribution of each explanatory variable to the explained variance in the gillnet CPUE data.

All statistical analyses were performed in Statistica 8.0 (StatSoft, Inc.).

RESULTS

> GILLNETTING

Altogether 4889 fish belonging to five species were captured during the 13 trials (39 gillnet sets) in the uppermost 1.5 m water layer of Lake Balaton at 3.3–4.7 m water depth (Table II). In gillnet catches, bleak dominated in both number (mean: 98.7%) and biomass (mean: 83.5%). Other fish captured were razor fish and as singletons roach *Rutilus rutilus* (L.), asp *Aspius aspius* (L.) and pikeperch *Sander lucioperca* (L.). Except three specimens, all $L < 14$ cm fish caught were bleak; and except two all $L > 14$ cm fish were razor fish. Catch per unit effort values varied within the ranges of 2.2–177 (62.7 ± 55.7; mean ± SD) fish·h^{-1}·net^{-1} and 11.6–1666 (588 ± 556) g·h^{-1}·net^{-1} in NPUE and BPUE, respectively.

> HYDROACOUSTICS

Acoustic abundance estimates varied over the 13 trials in the range of 0.9–54.1 (17.7 ± 15.6) fish 1000·m^{-3} (ANOVA, $F_{12,180} = 71.7$, $p < 0.001$) and 0.3–33.7 (11.2 ± 10.1) fish 1000·m^{-3} (ANOVA, $F_{2,180} = 83.0$, $p < 0.001$) for A_{Tot} and A_{SED}, respectively. However, acoustic abundance estimates, based either on A_{Tot} or A_{SED}, did not differ among the three consecutive measurements in 11 out of the 13 trials (ANOVA, $p > 0.05$; Table III), as well as for the

Table II
Number (N) and mass (M, g) of fish captured, their mean total length (L, cm), and mean catch per unit effort values by number (NPUE, fish·h^{-1}·net^{-1}) and biomass (BPUE, g·h^{-1}·net^{-1}) in gillnet samples in the uppermost 1.5 m water layer of Lake Balaton.

Species	Sample size		L	NPUE	BPUE
	N	M	Mean ± SD (min.–max.)	Mean ± SD	Mean ± SD
Rutilus rutilus	1	324	25.8 ± 0 (25.8–25.8)	0.02 ± 0.06	5.09 ± 18.3
Aspius aspius	1	242	29.1 ± 0 (29.1–29.1)	0.01 ± 0.04	2.48 ± 8.95
Alburnus alburnus	4823	38 282	9.0 ± 1.8 (5.0–13.6)	61.8 ± 55.5	491 ± 511
Pelecus cultratus	63	6942	23.0 ± 5.6 (9.5–32.5)	0.80 ± 0.93	89.0 ± 113
Sander lucioperca	1	11	10.2 ± 0 (10.2–10.2)	0.01 ± 0.05	0.15 ± 0.53
Total sample	4889	45 826		62.7 ± 55.7	588 ± 556

Table III
Results of the ANOVA statistics of horizontal acoustics-derived fish abundance estimates from the amplitude-echograms (A_{Tot}) and single echo detection echograms (A_{SED}), and total length (L) during the three consecutive acoustic measurements (each divided into five subsamples, EDSU) of 13 surveys in the uppermost 1.5 m water layer in Lake Balaton.

Trial	df.	A_{Tot}		A_{SED}		L	
		F	p	F	p	F	p
1.	2.12	0.42	0.664	0.80	0.470	1.45	0.272
2.	2.12	3.47	0.064	1.41	0.281	3.77	0.054
3.	2.12	8.75	0.005*	7.53	0.008*	0.12	0.884
4.	2.12	0.53	0.599	0.82	0.463	0.36	0.703
5.	2.12	0.28	0.762	0.36	0.705	1.28	0.314
6.	2.12	0.21	0.812	2.15	0.159	0.10	0.908
7.	2.12	2.36	0.136	0.66	0.537	0.28	0.759
8.	2.12	0.85	0.451	0.68	0.525	0.00	0.996
9.	2.12	1.20	0.334	1.67	0.228	0.92	0.425
10.	2.12	5.37	0.022*	5.53	0.020*	2.45	0.128
11.	2.12	2.80	0.100	0.35	0.712	1.50	0.262
12.	2.12	1.26	0.319	2.41	0.132	0.73	0.504
13.	2.12	1.32	0.304	1.72	0.221	0.04	0.964

* Note that the differences are not significant ($p > 0.05$) if the Bonferroni correction of significance level for multiple comparisons is considered.

whole study (Figure 1). Mean acoustic L ranged from 8.4 to 20.9 cm (15.2 ± 3.9) and differed significantly among (ANOVA, $F_{12,180} = 27.8$, $p < 0.001$) but not within trials (Table III and Figure 1). Correspondingly, it is likely that research boat induced avoidance reaction of fish was insignificant.

> *RELATIONSHIP BETWEEN GILLNETTING AND HYDROACOUSTICS*

For the entire fish size range (L = 5–35 cm) investigated, gillnetting and acoustics provided different fish size distribution estimates for most of the individual trials and the global samples pooled over the 13 trials (Table IV). The most obvious difference between the two gears was that gillnetting underestimated the share of larger (*i.e.* L > 14 cm) fish compared to acoustics. When only the L = 5–14 cm fish (*i.e.* bleak) were considered, consistency between the estimates of the two gears improved, but they still often differed significantly. Due to their low representation in the gillnet catches, size distribution of L = 14–35 cm fish could be compared for pooled samples only, which proved also to be different (Kolmogorov-Smirnov two-sample test, $p < 0.025$; Mann-Whitney U-test, $Z = -2.57$, $p = 0.010$). In gillnet catches, this size range was represented by four separate size classes of razor fish peaking at 15, 21, 27 and 29 cm L, which were however not identified by the acoustics (Figure 2).
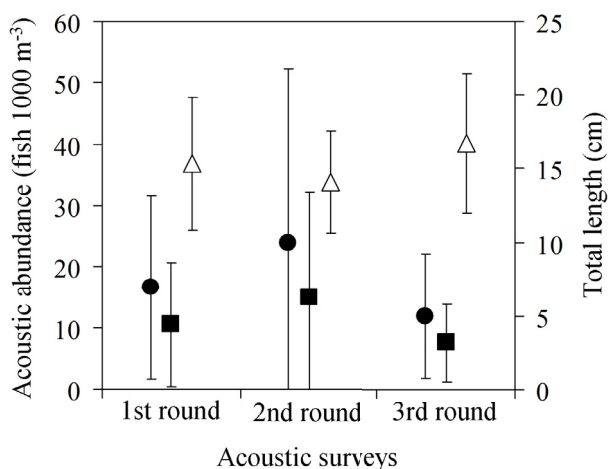
Figure 1

Changes (mean ± SD) of horizontal acoustics-derived fish abundance estimates from the amplitude-echograms (filled circles) and single echo detection echograms (filled squares), and total length (empty triangles) during three consecutive acoustic measurements of 13 surveys in the uppermost 1.5 m water layer in Lake Balaton. Neither variables differed among the three consecutive acoustic measurements (each divided into five subsamples, EDSU) at the level of the whole study (ANOVA, $F_{2,180}$ = 1.9–2.54, p = 0.084–0.153), and in general, the same result was obtained at the level of individual trials (for statistics, see Table III).

Regression analyses showed that gillnet catches were only weakly related to acoustics-derived density estimates, and just for abundance data (*i.e.* NPUE *vs.* A_{Tot} and A_{SED}) (Figure 3). Moreover, of the investigated complementary variables only water transparency (measured as Secchi depth) correlated with the gillnet CPUE data. The negative correlation between the Secchi depth and the gillnet CPUE was strong ($R^2_{adj.}$ = 0.770–0.825, $p < 0.001$) (for $L = 5$–35 cm see also Figure 4). Established multiple linear regression models predicted gillnet NPUE and BPUE well, and explained 77% to 86% of the total variance in these variables (Table V, Figure 5). Variance partitioning showed that most of the explained variance was associated with the water transparency, and acoustics-derived fish density had only minor separate influence ($\leqslant 8.8\%$ of the total variance) on gillnet catches. However, the shared effect of water transparency and acoustics-derived fish density was also substantial in NPUE (Table V).

DISCUSSION

In accordance with other studies (Hansson and Rudstam, 1995; Boswell *et al.*, 2010; Dennerline *et al.*, 2012), we found that gillnet catches hardly correlated with fish density estimates obtained from an acoustic survey, which is the most widely suggested complementary tool to improve and calibrate gillnet data. Pure acoustics-derived density estimates accounted for <8.8% of the variation in the gillnetting NPUE data, but they contributed insignificantly to regression models describing BPUE. Analyses showed that most of the variance in the gillnet CPUE data was associated with water transparency. Moreover, because of the absence of a meaningful relationship between the gillnet catch and acoustics-derived fish density, even the relevance of gillnet data for monitoring trends of fish abundance seems to be problematic.

Gillnet CPUE correlated negatively with water transparency, indicating a higher catchability of fish under poor visibility. Hansson and Rudstam (1995) found a similar but less strong correlation in Baltic Sea herring *Clupea harengus* L. and sprat *Sprattus sprattus* (L.). They also reported that a regression model including both acoustic abundance and water transparency explained an extra 10% (altogether 38%) of variance in the gillnetting NPUE data compared to the model based solely on acoustic data. Water transparency can influence gillnetting

Table IV

Results of Kolmogorov-Smirnov two-sample test (K-S test) and Mann-Whitney U-test (M-W test) for comparing total length (L) distribution and median L of fish in gillnet samples and hydroacoustic recordings for size ranges of L = 5–35 cm (both bleak and razor fish) and L = 5–14 cm (bleak only) in the uppermost 1.5 m water layer of Lake Balaton.

| Trial	L = 5–35 cm					L = 5–14 cm				
	L (cm; mean ± SD)		K-S test	M-W test		L (cm; mean ± SD)		K-S test	M-W test	
	Gillnet	Acoustic	p	Z	p	Gillnet	Acoustic	p	Z	p
1.	9.8 ± 3.2	14.0 ± 6.8	<0.001	−4.38	<0.001	9.4 ± 1.8	9.5 ± 2.8	>0.100	0.06	0.956
2.	10.6 ± 4.1	15.8 ± 6.9	<0.001	6.72	<0.001	9.6 ± 1.0	10.5 ± 2.7	<0.001	2.68	0.006
3.	9.4 ± 3.6	14.1 ± 5.4	<0.001	−8.00	<0.001	8.8 ± 1.8	10.9 ± 1.9	<0.001	−5.99	<0.001
4.	9.2 ± 1.9	15.5 ± 5.6	<0.001	−8.75	<0.001	9.2 ± 1.9	1.0 ± 2.5	<0.001	−4.41	<0.001
5.	9.9 ± 2.0	12.1 ± 5.8	<0.001	−1.75	0.080	10.0 ± 2.0	9.2 ± 2.9	<0.050	1.92	0.055
6.	7.2 ± 1.8	8.1 ± 3.5	>0.100	0.79	0.430	7.2 ± 1.8	7.4 ± 2.5	>0.100	0.10	0.922
7.	8.9 ± 1.4	17.6 ± 7.6	<0.001	8.38	<0.001	8.9 ± 1.4	9.6 ± 3.0	<0.050	0.94	0.346
8.	9.8 ± 2.6	9.8 ± 4.3	<0.005	1.74	0.080	9.5 ± 1.7	8.7 ± 2.6	<0.001	2.99	0.003
9.	8.3 ± 3.3	9.6 ± 4.1	>0.100	−2.21	0.026	7.9 ± 2.4	8.5 ± 2.6	>0.100	−1.50	0.133
10.	9.0 ± 1.4	12.6 ± 6.5	<0.001	−3.52	<0.001	9.0 ± 1.4	9.1 ± 2.6	>0.100	0.33	0.741
11.	9.0 ± 1.4	15.9 ± 7.5	<0.001	−7.08	<0.001	9.0 ± 1.4	9.7 ± 2.5	<0.025	−1.37	0.173
12.	9.1 ± 1.5	13.9 ± 7.3	<0.001	−4.62	<0.001	9.1 ± 1.5	9.2 ± 2.7	>0.100	0.15	0.881
13.	9.8 ± 2.4	15.2 ± 6.6	<0.001	−6.97	<0.001	9.8 ± 2.4	10.6 ± 1.8	<0.050	−3.13	0.001
Pooled data	9.2 ± 2.6	13.4 ± 6.7	<0.001	−16.4	<0.001	9.0 ± 1.8	9.4 ± 2.7	<0.001	−2.30	0.022
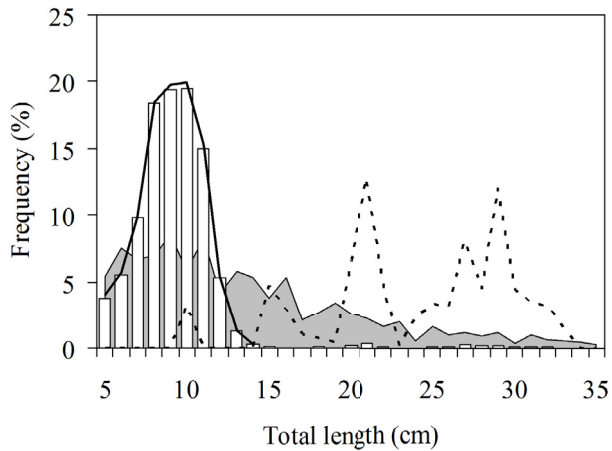
Figure 2

Average relative total length (L) distribution of fish assessed by gillnetting (empty bars) and horizontal acoustics (grey shaded area) for the size range of L = 5–35 cm in the uppermost 1.5 m water layer of Lake Balaton. Size distributions of bleak (continuous line) and razor fish (broken line) in the gillnet catches are also indicated. For between gear statistics, see Table IV.

efficiency at least in two ways. Firstly, in turbid water the probability that a fish observes the net before being entangled is lower than in clear water. Secondly, activity of most fishes is influenced by light intensity, being highest at low light but not in complete darkness (Gjelland *et al*., 2004 and references therein). In Lake Balaton, the transparency of the water may vary between 0.2 and 1.8 m measured as Secchi depth, depending on the instantaneous biomass of planktonic algae and the winds. Since Lake Balaton is a large but shallow lake, a wind over 1 to 4 m·s^{-1} disturbs the loose sediment and disperses the solid particles in the whole water body (Herodek *et al*., 1988). Consequently, even day-to-day or site-to-site variation in the water transparency may be considerable, and thus, it can bias gillnet-based fish density indices even at these scales, at least in the uppermost water layer. Accordingly, variations in the water transparency should be considered when comparing gillnet data over sampling sites or dates, and with results of other methods.

Water temperature is undoubtedly one of the most important factors influencing the activity and behaviour of fish. Fish activity and swimming speed supposedly increase with water temperature, and accordingly the efficiency of gillnetting is expected to increase as well (Linløkken and Haugen, 2006). In contrary to the above hypothesis, but in accordance with the observations of Hansson and Rudstam (1995), we did not identify a significant temperature effect in gillnet catches.

Corresponding to other observations (Mehner and Schulz, 2002; Boswell *et al*., 2007, 2010), size distribution and median size estimates obtained from gillnetting and acoustics differed. It is well known that gillnetting is a highly size selective gear, and in general, it underestimates the presence of small fish (Hamley, 1975; Olin and Malinen, 2003; Prechalová *et al*., 2009). On the contrary, we found a higher share of small fish in gillnet catches than estimated by acoustics. Since we performed our surveys at day-time, therefore it could be a logical explanation that gillnetting overestimated the share of small-sized day-time foragers like bleak, and underestimated larger fish, which may however be active only at twilight or complete darkness. Based on gillnet catches, the sole species occurring regularly in the uppermost water layer within the L = 14–35 cm size range was razor fish. This species is also active during the day-time and can be captured effectively, especially in water layers somewhat deeper than investigated here (Specziár *et al*., 2009; Specziár, 2010). Razor fish represented in gillnet catches in discrete size classes that were however not mirrored in acoustic data. Similar phenomenon was observed by Boswell *et al*. (2007) in very shallow estuarine habitats in Louisiana. There are several formulas in use, which were developed on theoretical basis to adjust gillnet catches for size selectivity. However, these indirect techniques do not take into
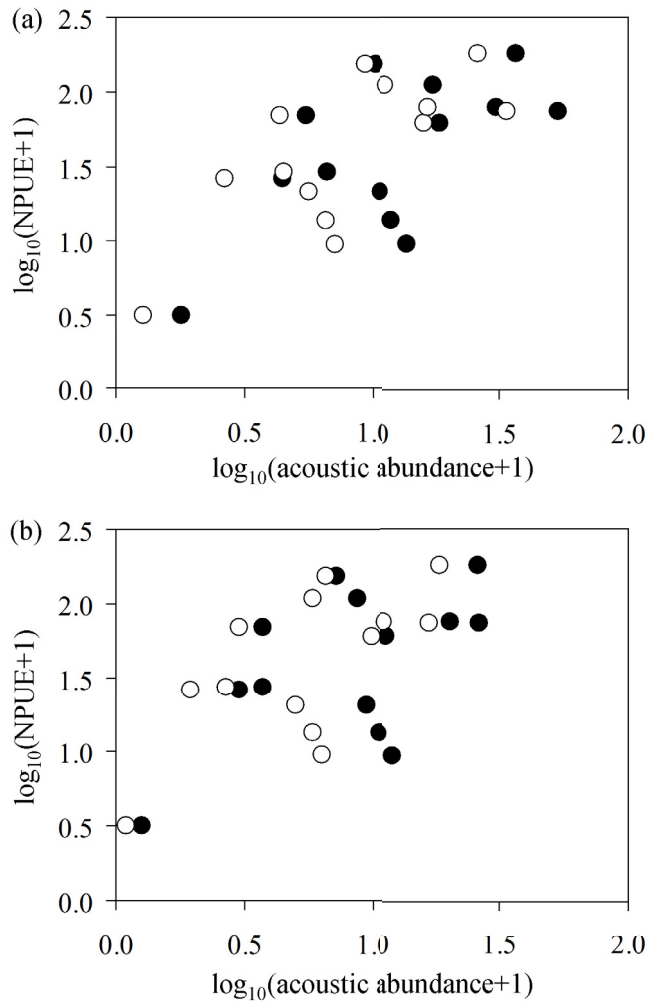
Figure 3

Relationship between hydroacoustic fish density estimates based on the amplitude-echograms (A_{Tot}, fish $1000 \cdot m^{-3}$; filled circles); and single echo detection echogram (A_{SED}, fish $1000 \cdot m^{-3}$; empty circles), and gillnet catch per unit effort by abundance (NPUE, fish $\cdot h^{-1} \cdot net^{-1}$) for fish total length (L, cm) ranges of (a) L = 5–35 cm (both bleak and razor fish) and (b) L = 5–14 cm (bleak only) in the uppermost 1.5 m water layer of Lake Balaton. Note that data are $\log_{10}(x + 1)$ transformed; and all relationships were insignificant for biomass data. Linear regression statistics: (a) $\log_{10}(NPUE+1) = 0.82 \log_{10}(A_{Tot}+1)+0.70$, $R^2_{adj.} = 0.361$, p = 0.018; $\log_{10}(NPUE+1)=0.95 \log_{10}(A_{SED} + 1) + 0.74$, $R^2_{adj.} = 0.500$, p = 0.004; (b) $\log_{10}(NPUE+1)= 0.74 \log_{10}(A_{Tot} + 1) + 0.91$, $R^2_{adj.} = 0.253$, p = 0.046; $\log_{10}(NPUE+1) = 0.95 \log_{10}(A_{SED} + 1) + 0.88$, $R^2_{adj.} = 0.387$, p = 0.014.

account species-specific behavioural and activity patterns, and therefore provide ambiguous results (Millar, 2000; Prechalová et al., 2009). Since size-specific processes were assumed to occur, we tested whether the inclusion of the mean acoustics-derived fish size would gain more explained variance in gillnet catches, but it did not.

Most of the discrepancies between the estimates of the two gears studied could undoubtedly be explained by the highly selective nature of gillnetting, but not necessarily only by that. The accuracy of acoustics in estimating fish density and size distribution is theoretically high, and for the assessment of pelagic fish stocks, the acoustic technique is at least as good as, and probably better than any other (Simmonds and MacLennan, 2005). Yet, there are some sources of potential biases that may influence acoustic estimates, too. Mobile acoustic equipments are operated from vessels, which may induce a fright reaction in fish, and thereby affect fish density and size distribution estimates (Draštic and Kubečka, 2005; Godlewska
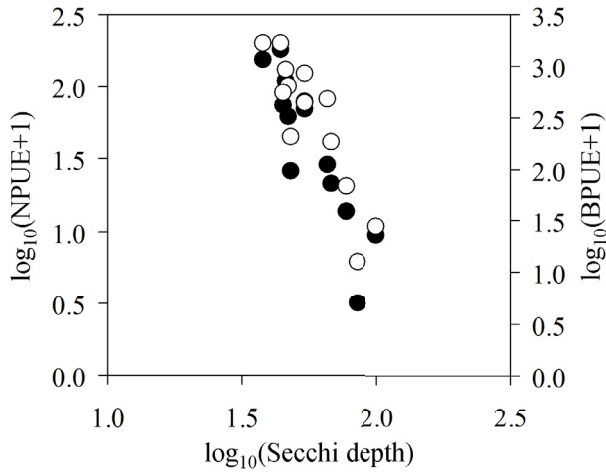
Figure 4

Correlation between Secchi depth (cm), gillnet catch per unit effort data by number (NPUE, fish·h^{-1}·net^{-1}; filled circles) and biomass (BPUE, g·h^{-1}·net^{-1}; empty circles) for fish total length (L) range of L = 5−35 cm (both bleak and razor fish) in the uppermost 1.5 m water layer of Lake Balaton. Note that data are logarithmic transformed. Linear regression statistics: $\log_{10}$(NPUE+1) = −3.59 $\log_{10}$(Secchi depth)+7.90, $R^2_{adj.}$ = 0.770, p < 0.001; $\log_{10}$(BPUE+1) = −4.61 $\log_{10}$(Secchi depth)+10.57, $R^2_{adj.}$ = 0.771, p < 0.001.
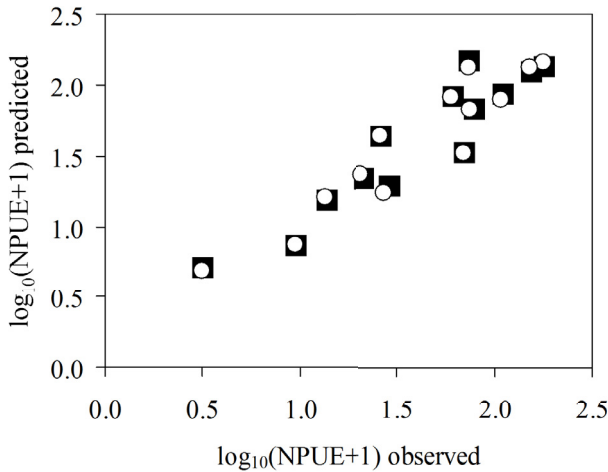

Figure 5

Correlation between observed and predicted gillnet catch per unit effort data by number (NPUE, fish·h^1·net^{-1}) for fish total length (L) ranges of L = 5−35 cm (both bleak and razor fish) (filled squares) and L = 5−14 cm (bleak only) (empty circles) in the uppermost 1.5 m water layer of Lake Balaton. Multiple linear regression models are based on Secchi depth (cm) and acoustics-derived volumetric abundance estimates obtained from the amplitude-echograms (A$_{Tot}$, fish 1000·m^{-3}). Regression models and their statistics are given in Table V. Note that data are $\log_{10}$(x + 1) transformed.

et al., 2009). However, we did not identify any significant difference in the acoustics-derived fish density and mean fish size over consecutive measurements by trials, suggesting that fish avoidance could not be a serious problem in this case. More specific studies with horizontal beaming agreed with the present observations and concluded that in Central European waters, including Lake Balaton, fish avoidance generally has only a minor importance, and some effect was found only in the smallest fish (TS < −40 dB) close (<10 m) to the boat (Draštik and Kubečka, 2005; Godlewska et al., 2009).

Further criterion of an accurate acoustic survey is that fish should sufficiently be dispersed enabling their detection mostly as individual targets (single echoes). In this study, the mean share of single echoes was more than 60% that is quite a useful ratio (see e.g. Mehner and

Table V

Parameters (b) and statistics of models derived from multiple linear regression analysis with forward stepwise variable selection procedure to predict gillnet catches by number (NPUE, fish·h⁻¹·net⁻¹) and biomass (BPUE, g·h⁻¹·net⁻¹) based on acoustic abundance (A, fish 1000·m⁻³) and biomass (B, kg 1000·m⁻³) and environmental variables in the uppermost 1.5 m water layer of Lake Balaton. Models were built for both L = 5–35 cm (both bleak and razor fish) and L = 5–14 cm (bleak only) total length (L) ranges. Relative roles of the retained predictor variables were assessed by variation partitioning. Note that models are based on logarithmic transformed data.

Gillnet data	L range	Variables in the model		Regression parameters			Variance partitioning			Model statistics			
		Acoustic data	Environmental retained	$b_{acoustic} \pm SE$	$b_{Secchi} \pm SE$	$b_{intercept} \pm SE$	Acoustic (%)	Secchi (%)	Shared (%)	$R^2_{adj.}$	F	df.	p
NPUE	5–35 cm	A_{Tot}	Secchi	0.42 ± 0.16	-3.03 ± 0.49	6.47 ± 0.95	8.2	49.1	27.9	0.852	35.6	2.10	<0.001
NPUE	5–35 cm	A_{SED}	Secchi	0.47 ± 0.17	-2.80 ± 0.52	6.10 ± 1.01	8.8	35.8	41.2	0.858	37.1	2.10	<0.001
BPUE	5–35 cm	B_{Tot}	Secchi	–	-4.61 ± 0.72	10.57 ± 1.26	–	77.1	–	0.771	41.3	1.10	<0.001
BPUE	5–35 cm	B_{SED}	Secchi	–	-4.61 ± 0.72	10.57 ± 1.26	–	77.1	–	0.771	41.3	1.10	<0.001
NPUE	5–14 cm	A_{Tot}	Secchi	0.42 ± 0.15	-3.20 ± 0.46	6.83 ± 0.86	8.6	60.6	16.7	0.859	37.5	2.10	<0.001
NPUE	5–14 cm	A_{SED}	Secchi	0.48 ± 0.17	-3.00 ± 0.48	6.50 ± 0.92	8.7	47.3	30.0	0.860	37.9	2.10	<0.001
BPUE	5–14 cm	B_{Tot}	Secchi	–	-4.58 ± 0.60	10.44 ± 1.06	–	82.5	–	0.825	57.5	1.10	<0.001
BPUE	5–14 cm	B_{SED}	Secchi	–	-4.58 ± 0.60	10.44 ± 1.06	–	82.5	–	0.825	57.5	1.10	<0.001

$A_{Tot.}$ and $B_{Tot.}$: acoustic abundance and biomass based on amplitude-echogram; A_{SED} and B_{SED}: acoustic abundance and biomass based on single echo detection echogram.

Schulz, 2002) concerning also the robust number of single targets detected and that in horizontal beaming the probability of overlapping targets is higher compared to vertical beaming. For all that the share of single echoes (35.9–89.6%) varied considerably among trials, multiple linear regression models based on the data from either amplitude-echograms (A_{Tot}) and SED-echograms (A_{SED}) gave similarly good predictions on the gillnet NPUE. Moreover, the variable "aggregation level" did not have a significant contribution to the regression model assessing the relationship between the density estimates of the two gears.

In horizontal acoustics, a further problem is that the records are often relatively noisy, which makes the identification of small fish difficult and may result their underestimation (Draštík *et al.*, 2009). According to our preliminary studies, if the amplitude of waves exceeds about 10 cm, horizontal beaming in the uppermost water layer of Lake Balaton becomes problematic and the echograms practically are unprocessable because of the low signal-to-noise ratio (*i.e.* bubbles, disturbed sediment particles and reverberation from the water surface). Though all sampling trials were performed under waveless conditions, records were yet noisy (probably because we measured very close to the surface of the water, some bubbles and surface reverberation might be presented even under calm weather conditions) and post-processing filtering was needed. Moreover, in horizontal acoustics the *TS* of small fish recorded from a head/tail aspect is as low that generally they are filtered out during the post-processing (Draštík *et al.*, 2009; Kubečka *et al.*, 2009). For example, in the present case the post-processing *TS* threshold was increased to −55 dB due to the noisy environment. This *TS* threshold corresponds to $L = 2.5$ cm in side aspect but to $L = 25.6$ cm in head/tail aspect. This means that how much shorter the fish is to 26 cm *L* the higher the probability that it will be filtered out together with the noise. Consequently, it is likely that the underestimation of small fish by acoustics may partly be a post-processing error. Further, we observed that in most cases bleak were entangled in highest density in the uppermost 20 cm of gillnets, this water layer is however un-investigable with acoustics.

Length and biomass of fish cannot directly be derived from acoustic data; these metrics are calculated via sophisticated procedures including parameter estimations (*i.e.* acoustic *TS* and *A*) and subsequent conversions (*i.e.* converting *TS* to *L*, *L* to *M* and then, *A* and *M* to *B*), which relationships however vary by fish species and may change with sampling circumstances (Didrikas and Hansson, 2004; Boswell *et al.*, 2008; Godlewska *et al.*, 2012). Accordingly, the accuracy of acoustics-derived size distribution and biomass data can be variable, and generally, it is unknown. Further, as typically we do not know the orientation of fish relative to the sound-beam axis, fish size assessment is even more problematic in horizontal acoustics. Since we had robust numbers of single echoes detected and there was not any indication on that fish were not randomly oriented, we used the de-convolution procedure to convert *TS* values to *L* values (Kubečka *et al.*, 1994; Godlewska *et al.*, 2012). However, if a deviation from the randomness of the orientation of the fish occurs, estimated *L* distribution and perforce, the assessed biomass will be biased as well. Additionally, *TS* distribution can be biased if echoes from two or more fish are overlapping and misidentified as a single fish echo. In sight of these, it is not surprising that the weak correlation observed here between acoustics and gillnetting based abundance indices could not be retained in biomass metrics. Conversion of horizontally detected *TS* to *L* data may be improved by using a catch basket obtained from a representative catch (Kubečka *et al.*, 2009), which criterion is however can not be met by the strongly size selective gillnetting.

Insomuch as gear related problems generally have species-specific aspects, thus it is evident that disentangling and adjusting processes that influence comparability of results between gears should be more complicated for species rich assemblages (*i.e.* benthic and littoral assemblages) than for stocks comprised by one or few species (*i.e.* pelagic or surface oriented fish assemblages). However, the comparison of data obtained from gillnetting and hydroacoustics seems to be problematic even for homogeneous stocks. Though the same areas were sampled in the same time with the two gears, and there were only two dominant fish species with completely separated size ranges, no consistency between the estimates of gillnetting and acoustics was found. Similar, experiences were reported for example for

pelagic herring and sprat in the Baltic Sea (Hansson and Rudstam, 1995); for smelt *Osmerus eperlanus* (L.) in Lake Vesijärvi (Peltonen *et al.*, 1999) and vendace *Coregonus albula* (L.) in Lake Stechlin (Mehner and Schulz, 2002).

To conclude, we found that neither of the gears studied provided a representative picture about the fish assemblage inhabiting the uppermost water layer of Lake Balaton, thus gillnetting and acoustics should be used parallel to complement each other. However, the feasibility of establishing a powerful model describing the relationship between fish density estimates of gillnetting and acoustics is low in shallow and turbid habitats, and it might be successful only if the crucial sampling and environmental parameters affecting catching efficiency of gillnets and post-processing of acoustic data are also considered. This study cautions again that gillnet CPUE should be used carefully to analyse trends of fish abundance, and it is strongly advisable to avoid gillnetting-based abundance metrics when high accuracy is of utmost importance, for example, when critical conservation or management decisions will be based upon the conclusions. Nevertheless, gillnet samples retain their indispensable advantage over acoustics in providing information on species composition and other assemblage metrics such as growth rate, condition and diet of fish.

ACKNOWLEDGEMENTS

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