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Fisheries Research 72 (2005) 219–228
FISHERIES RESEARCH
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Fish avoidance of acoustic survey boat in shallow waters

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Received 27 April 2004; received in revised form 4 October 2004; accepted 27 October 2004

Abstract

The avoidance reactions of fish with respect to a survey vessel were studied during horizontal acoustic applications of a Simrad EY500 split-beam echosounder (120 kHz) in two lakes (Wallersee, Balaton) and two reservoirs (Orlík, Římov). Three methods were used to assess the avoidance reaction of fish to the survey vessel: (1) comparison of acoustically detected fish biomass at different distances, (2) determination of the fish direction vector (echogram slope) with respect to the transducer and (3) direct acoustic observation of fish behaviour in front of the moving vessel. Comparing acoustic biomass in order to demonstrate avoidance reactions is limited. All fish were divided in two groups according to the slope of their movement: with a positive value of slope (fish swimming away from the transducer) and with a negative slope (fish swimming towards the transducer). Fish avoidance caused higher slope values. Most avoidance behaviour was found with small fish (target strength, TS < −40 dB, 22 cm) at distances under 10 m. Only in the clear lake Wallersee were some indications of avoidance up to a distance of 15 m from the survey boat. There were no significant indications of fish avoidance in the Czech reservoirs. Much less avoidance behaviour was found with fish larger than TS > −40 dB. At distances over 10 m, the avoidance of small boats (5–6 m long, 15–25 HP two-stroke engine) appears not to be a serious problem in shallow waters.

Keywords: Fish behaviour; Avoidance; Echogram slope; Acoustic biomass; Echosounder

1. Introduction

Fish avoidance behaviour could be a serious problem in fisheries acoustics since fish avoiding boats could bias the results of acoustic stock assessments. Fisheries management needs a precise estimate of fish stocks in order to obtain unbiased estimates of fish biomass and distribution (MacLennan and Simmonds, 1992). A number of papers have focused on fish avoidance in the marine environment (Olsen, 1990; Ona and Godø, 1990; Gerlotto and Fréon, 1992; Soria et al., 1996; Vabø et al., 2002; Handegard et al., 2003). The avoiding shoals of fish swimming away from the approaching boat, either horizontally or vertically, are exposing less reflective parts of the body to the sonar beam. The intensity of avoidance behaviour varies

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0165-7836/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.fishres.2004.10.017

among fish species (Misund, 1990; Olsen, 1990). Only a few authors have dealt with freshwater fish avoidance behaviour (Mous and Kemper, 1996; Lucas et al., 2002) although it has been shown that routine acoustic surveys performed with marine research vessels suffer from fish avoidance (Mitson and Knudsen, 2003) and the vessel noise makes fish avoid at tens or hundreds of meters. Acoustic surveys in freshwaters are carried out by relatively small vessels beaming over short distances (usually 15–50 m) suggesting both greater (short distances, visual stimuli) and less (lower vessel size and noise intensity) avoidance. Three different approaches have been taken in this paper in an attempt to quantify the effects of potential bias, due to fish avoidance, upon surveys of shallow waters by horizontal sonar. Avoidance at different distances from the survey boat, and by different fish sizes, was considered. Routine acoustic surveys and experiments with observations of fish in front of a moving vessel were carried out in two reservoirs and two lakes with different hydrobiological characteristics, in order to evaluate fish avoidance behaviour. All four localities have some limited boat traffic, so the fish would have had some previous contacts with motorboats.

2. Materials and methods

2.1. Study area

Hydroacoustic studies of Lake Balaton, Wallersee and Orlík reservoir were chosen for analysis and direct fish avoidance experiments were carried out at Římov reservoir. Lake Balaton is a shallow eutrophic lake in Hungary with a water surface area of 600 km^2, an average depth of 3.5 m and a maximum depth of 11 m. The night survey was performed during 7–9 September 1997. The most abundant fish species were bream (*Abramis brama*), roach (*Rutilus rutilus*), bleak (*Alburnus alburnus*), rudd (*Scardinius erythrophthalmus*), and white bream (*Blicca bjoerkna*) (Bíró et al., 2003). Orlík reservoir is a deep eutrophic dam in Czech republic with a water surface area of 27 km^2, an average depth of 26 m and a maximum depth of 80 m where the fish stock mainly consisted of roach, perch (*Perca fluviatilis*), bream and bleak (Kubečka, pers. commun.). The survey was carried out during 28–30 June 1997. Wallersee is a relatively shallow meso/eutrophic lake in Austria with a water surface area of 6 km^2, an average depth of 12.5 m and a maximum depth of 22 m where the fish stock mainly consisted of bream, carp (*Cyprinus carpio*), pike (*Esox lucius*) and corregonids (Coregonidae) (Gassner and Wanzenböck, pers. commun.). The daytime survey was performed during 24–25 August 1996. Římov reservoir is a deep meso/eutrophic dam in Czech republic with a water surface area of 2 km^2, an average depth of 16 m and a maximum depth of 43 m. The fish avoidance experiments were performed during 21–23 August 2000 and 3 July 2002. The fish stock consisted of roach, bream, perch and bleak (Vašek et al., 2003). The surveys were done at night in Balaton and during the daytime in Wallersee, Orlík and Římov.

2.2. Data collection and analysis

A Dory 13 boat powered with a 15 HP combustion engine mounted outboard and with a special transducer frame mounted on the front end of the boat, enabling horizontal beaming, was used (Kubečka and Wittingerová, 1998). We have assumed only horizontal avoidance because of the shallowness (Balaton) or strong water column stratification of the lakes and reservoirs (fish seem to be very unwilling to dive to cold deoxygenated waters; Kubečka and Wittingerová, 1998). The sonar system consisted of a Simrad EY 500 split-beam echosounder operating on 120 kHz frequency. An ES-120 elliptical split-beam transducer with nominal angles of 4.3 and 9.1° was beaming perpendicularly to the direction of the boat. The transducer was about 70 cm deep and tilted 2–3° downwards. The pan of the transducer was close to perpendicular with respect to the boat movement. The whole sonar system was calibrated using a 32 mm tungsten-carbide standard target. The gain of the echosounder was calculated according to Foote et al. (1987). Statistical assessment was done in STATISTICA (data analysis software system), Version 5.5 (StatSoft, Inc., 2001). One-way or two-way ANOVA tests were used for both acoustic biomass and echogram slope analysis.

Three different approaches were used for the assessment of avoidance behaviour:

1. Acoustic biomass approach: the comparison of an acoustic measure of fish biomass, volume scattering coefficient (s_v, m^2 of backscattering cross sections

r_e m^3 of volume), was made at different distances with respect to the position of the boat. The data records for acoustic biomass were obtained during acoustic surveys on Balaton and Orlík. The distances used for comparison of acoustic biomass differ between reservoirs due to various sampling conditions. Eight layers (4–6, 6–8, 8–10, 10–12, 12–15, 15–20, 20–25 and 25–30 m) were used in the case of Orlík, where greater distances were available. Ten layers from 3 to 18 m (each 1.5 m thick) were used in the case of the shallow Lake Balaton. The analysis was made in EP 500 post-processing software (Simrad, Norway).

2. The comparison of echogram slope was used as a more direct method. Echogram slope values were calculated as a ratio between the difference in distance (ΔR) between the first and the last echo and the number of pings that recorded a particular fish (Δn, Fig. 1). Avoiding fish increased their distance from the boat (positive values). Negative values indicate decreasing distance, as the fish was swimming towards the boat. A zero value indicates no change in distance i.e. no reaction, in terms of distance, to the passing boat. For extracting fish tracks, Sonar 5 software (Balk and Lindem, 2003), was used. Parameters for automatic tracking were a minimal track length (MTL) and a maximum ping gap (MPG). MPG was set to 1 at all the reservoirs. MTL was set to 4 in the case of Balaton. At Orlík and Wallersee two layers were defined: MTL was set to 4 for close and middle distances 4–15 m; MTL was set to 8 for greater distances 15–30 m (Δn is likely to be longer for greater distances). Two thousand four hundred and forty three fish were tracked at Balaton, 348 fish at Orlík and 2135 fish at Wallersee. All tracks were controlled manually after the automatic tracking to avoid suspicious echoes. Tracks were divided into several groups according to the distance and TS. Comparisons distance strata are given in Table 1. Two subgroups, according to TS distribution, were recorded as follows: “big” fish (bigger than −40 dB) and “small” fish (smaller than −40 dB). It has been shown that TS of −40 dB could correspond to a 22 cm long fish recorded

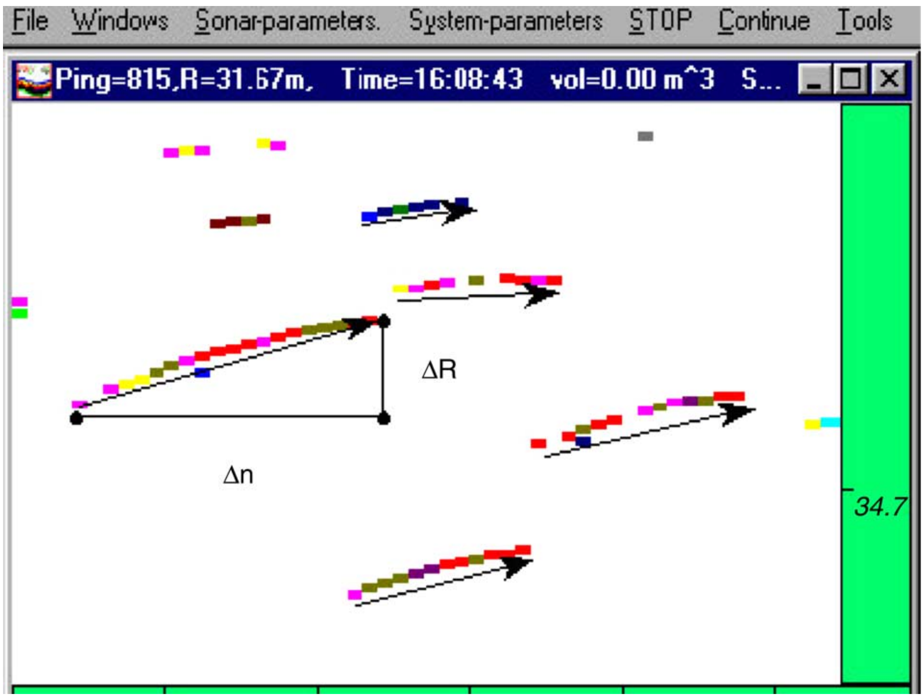

Fig. 1. The definition of the echogram slope. Number of pings is on the x-axis, distance R (m) is on the y-axis. The echogram slope is counted as a ratio of ΔR and Δn.

Table 1
Comparison of echogram slopes of fish populations recorded in different distance strata from the transducer at three localities

Fish size	Range (m)				Mean slope (m ping^{-1})				ANOVA
	Near	Middle 1	Middle 2	Far	Near	Middle 1	Middle 2	Far	
Orlík									
All	5–10	10–15		25–30	−0.008	−0.005		−0.010	NS
Small (< −40 dB)	5–10	10–15		25–30	0.013	−0.014		−0.021	NS
Big (> −40 dB)	5–10	10–15		25–30	−0.014	0.001		−0.006	NS
Wallersee									
All	5–10	10–15		15–30	−0.014	−0.015		−0.020	10^{-6}
Small	5–10	10–15		15–30	−0.013	−0.015		−0.021	10^{-6}
Big	5–10	10–15		15–30	−0.021	−0.017		−0.017	NS
Balaton									
All	5–10	10–15	15–20	20–25	−0.003	−0.005	−0.006	−0.006	10^{-6}
Small	5–10	10–15	15–20	20–25	−0.002	−0.005	−0.007	−0.007	10^{-6}
Big	5–10	10–15	15–20	20–25	−0.003	−0.005	−0.006	−0.006	0.03

The last column gives the significance level of the overall dependence of the fish slope upon distance (NS: nonsignificant).

from an unknown aspect (Kubečka and Duncan, 1998).

3. Direct observations of fish avoidance behaviour were carried out at the Římov reservoir on the 21–23 August 2000, from 16.30 till 21.30 and on 3 July 2002, from 12.40 till 19.40. The boat with the echosounder system was anchored at a fixed point beaming horizontally in the open water. Another 5 or 6 m long boat, powered with a 15 or 25 HP combustion engine, was running perpendicularly to the acoustic beam at a distance of 25–60 m from the transducer, at the usual survey speed of 1.5 m s^{-1}. It was possible to observe the exact time and distance of the boat's passage on the echogram saved for post-processing. Fish densities and trajectory slopes were measured on both sides of the boat's position before, during and after the passage. Positive values of ΔR, according to Fig. 1, mean increasing distance from the boat passage distance (both sides). There were approximately 15–30 min breaks between subsequent passages of the disturbing boat to allow fish to return, or the whole experiment was moved approximately 100 m away from the previous one. Twenty-three such experiments were carried out. Analysis of acoustic biomass and echogram slope were performed in EP 500 post-processing software and Sonar 5, respectively. Several minutes of recording before the passage of the disturbing boat were tested against 20–30 s of recording during and immediately after the boat passage.

3. Results and discussion

3.1. Biomass approach

The biomass approach was based on the assumption of a constant fish biomass level in the ensonified water to the side of the boat. This assumption is correct if fish are distributed randomly in open water. Lower biomass within close range should indicate fish avoidance. Avoiding fish may either leave the close distances of the acoustic beam or expose less reflective aspects of their body (Arnold et al., 1990). Comparing acoustic biomass within different distances requires a random vertical distribution of fish in the water column, which was more or less the case in Balaton and Orlík. No significant difference in acoustic biomass was found among all ranges in Lake Balaton and Orlík reservoir (Fig. 2) and in both there was approximately the same value of biomass irrespective of distance. Such a distribution does not suggest any signs of fish avoidance. The results from Orlík reservoir did, however, show lower fish biomass at the greater distances, although it was not statistically significant. This observation may be consistent with including layers deeper than the epilimnion in the side scanning sonar beam (Fig. 3). Layers deeper than about 4 m are often empty in eutrophic reservoirs due to summer stratification (Unger and Brandt, 1989; Kubečka and Wittingerová, 1998) whereas, in the well-mixed and homogeneous Balaton, the distance had no influence on the biomass. The distribution of fish in

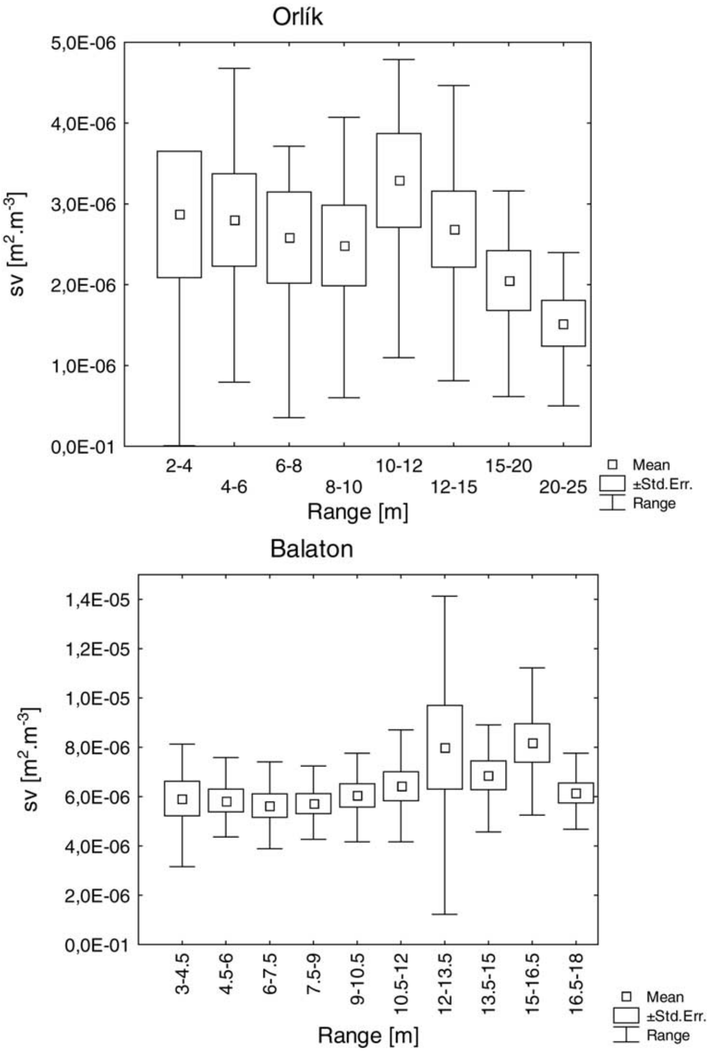

Fig. 2. Acoustic biomasses (s_V) at different distances (ranges) from the transducer.

Wallersee was found to be more complicated, and the biomass approach was not suitable in that situation.

3.2. Fish slope

Comparison of echogram slopes indicates differences among various distances (Table 1) and the shape of the slope–frequency distribution also differs between lakes (Fig. 4a and b). In Orlík the mean slopes were not significantly different among all three distances. More detailed analysis by Tukey post-hoc comparison revealed that, at Wallersee, two distances were different: the near and middle distance average slopes have significantly more positive echogram slopes than from greater distances ($F_{(2,2123)} = 39.6$, $P < 10^{-6}$). The same significant difference was found in the group of small fish ($F_{(2,1716)} = 74.6$, $P < 10^{-6}$). Slopes from the near and middle distances were not significantly different. Surprisingly, no significance was found in the group of big fish (Table 1) which could be caused by the small overall density of big fish within close range in Wallersee, or by less avoidance by big fish. The slope frequency distribution of all Wallersee records is shown in Fig. 4a. The nearest fish have the most positive

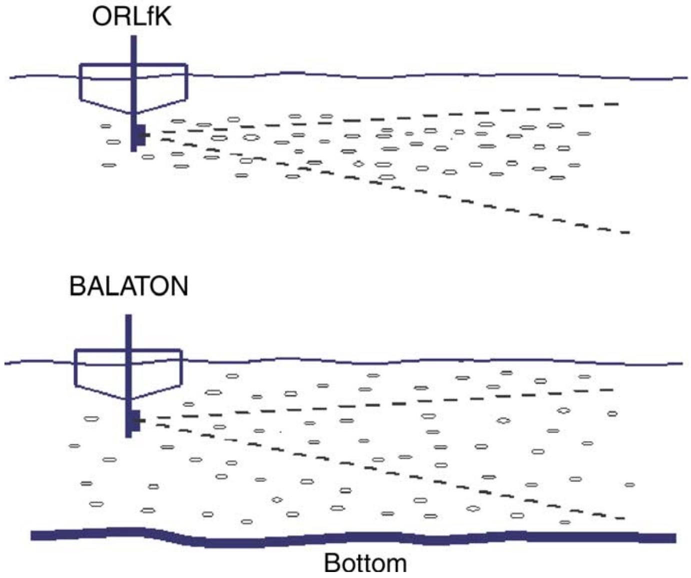

Fig. 3. Likely fish distribution in the Lake Balaton and Orlík Reservoir. The decrease of s_v at greater distances in Orlík may be consistent with the inclusion of empty metalimnetic layers in the sampling volume at greater distances.

echogram slopes which suggests most avoiding behaviour. The boundary between avoiding and non-avoiding fish could have been about 10–15 m from the boat in this relatively transparent subalpine lake. Underwater visibility could play an important role in fish avoidance behaviour, especially in clear waters (Arnold et al., 1990). Visual cues cause an increase in minimum approach distance towards a predator (Brown and Magnavacca, 2003), which was not observed in low light levels, suggesting that visual orientation is limited to a sufficient light levels. Higher avoidance might be expected in oligotrophic waters with high transparency.

The shift of slope frequency distributions in Balaton had a similar character (Fig. 4b). Fish from short distances had more positive echogram slopes than more distant fish. There were no significant differences between the Middle 1, 2 and Far distance strata. With all fish and small fish, the nearer distance appears to be significantly different from all more distant strata ($F_{(3,2439)} = 13.1$, $P < 0.001$; resp. $F_{(3,1187)} = 11.3$, $P < 0.001$). Big fish differed significantly only in the near and middle 2 distances (Table 1). In lake Balaton, there was no difficulty with tracking sufficient numbers of large fish and the results are based on robust numbers (1246 large and 1191 small tracked fish). The results from both Balaton and Wallersee support the notion that mostly the small fish are avoiding the survey boat, while big fish are ignoring it. Small fish may exhibit much stronger avoidance than large fish as part of anti-predation behaviour. Larger individuals of rainbow trout, exposed to predation, had a significantly weaker tendency to avoid a fish predator than the smaller fish (Johnsson, 1993).

3.3. Direct study of fish avoidance

Acoustic biomass (s_v, $m^2 m^{-3}$) was compared before, during and after boat passage at different distances from the passing boat. We considered 10 different strata within the distance of 2–20 m from the point of boat passage (Fig. 5). The acoustic biomass at closer distances was slightly smaller during and after the boat passage than before, although this difference is not statistically significant. At further distances from the disturbing boat, the biomass had similar values both before, during and after passage of the boat. The two-way ANOVA test was used to make a comparison among the different strata but no significant differences were found between before, during and after passage of the boat and among all distances, also in the interaction between them. There was only a weak indication of fish avoidance found at close range (4–8 m from the

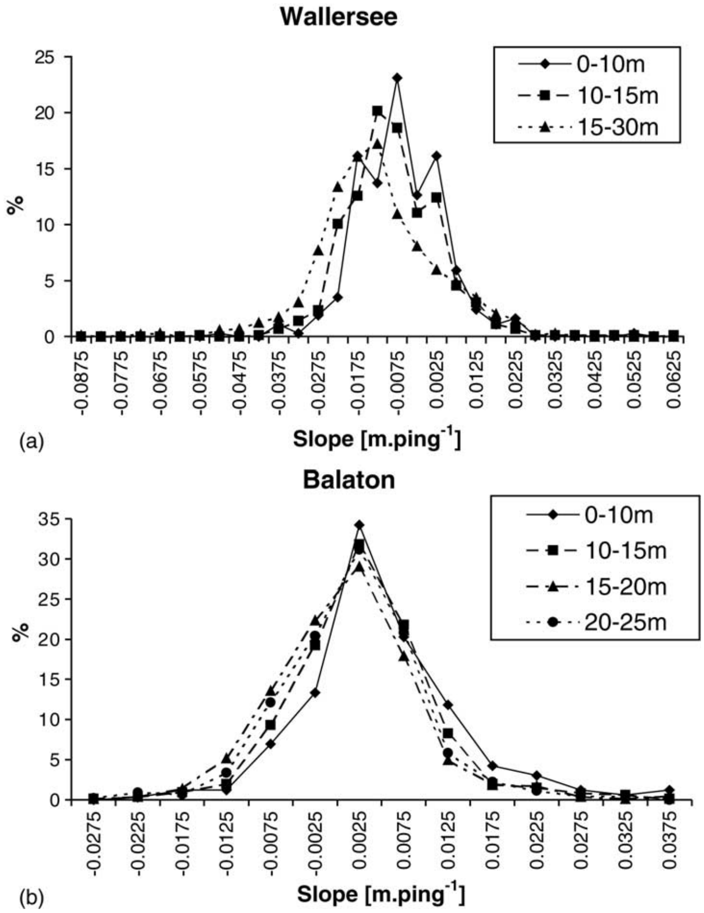

Fig. 4. Echogram slope distribution from Wallersee and Balaton lakes for “all fish” at different distances.

boat). Two strata, 0–10 and 10–20 m, were defined for evaluation of echogram slope but the slope analysis performed using the two-way ANOVA test did not show any significant differences (Table 2). Slope frequency distributions show that at closer range (<10 m, Fig. 6a) the slopes during and after passage of the boat show some tendency to more positive values. However, the difference is not significant and greater distances lack this trend completely (Fig. 6b).

Table 2
Comparison of slope–frequency distributions of fish populations recorded in two distance strata from the point of boat passage before and immediately after the passage of the survey boat

	Range (m)		Mean slope (m ping^{-1})		ANOVA
	Near	Far	Near	Far	
Before	0–10	10–20	0.0003	0.005	NS
During and after	0–10	10–20	0.006	0.0005	NS

In the presence of an acoustic survey vessel, fish may react to different sources of stimulation that might cause avoidance behaviour. Visual cues play a role only in sufficiently light conditions, especially in clear waters, which could cause a part of the avoidance behaviour observed in the oligotrophic Lake Wallersee. Small fish may have anti-predator reactions when the visibility is high (Brown and Magnavacca, 2003). Visual cues as an explanation of avoidance by small fish failed in Balaton where a night survey was performed. In waters where transparency is a problem (eutrophic reservoirs) the noise of the vessel is the most probable explanation of fish avoidance. The noise is produced

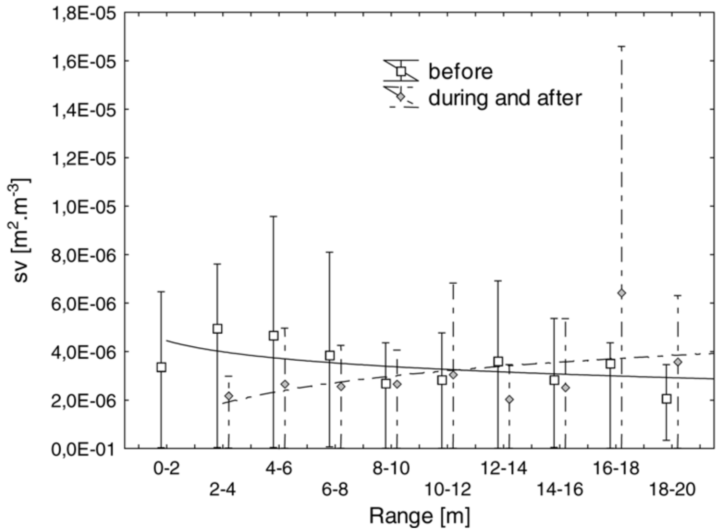

Fig. 5. Acoustic biomass (s_v) at different distances (*x*-axis) from the boat from observations of direct fish avoidance. Trendlines are before boat passage (solid line), during and after boat passage (dashed line). Whiskers indicate minimum and maximum values.

by movement of the propeller and vibration of the hull caused by the engine (MacLennan and Simmonds, 1992). Fish hearing begins at several hertz (Karlsen, 1992; Knudsen et al., 1993, 1997) and is usually restricted up to 2 or 3 kHz (Mann et al., 1997; Popper, 2003); the noise frequencies of vessels lie within this spectrum (Mitson and Knudsen, 2003). The range of hearing frequencies of fish common in studied lakes is not known. We suggest that most of the fish avoidance we observed was caused by vessel noise, although a small survey vessel emits noise at a much lower intensity than marine ships. Unfortunately we had no opportunity to measure sound field of the noise radiated by our outboard two-stroke engine. Nevertheless the direct experiments at Římov reservoir did not reveal any signs of fish avoidance such as that observed with marine survey vessel experiments (Olsen, 1990; Handegard et al., 2003).

Table 3
Summarized results of individual analyses with respect to avoidance behaviour

Method	Locality	Range intervals (m)						
		4–6	6–8	8–10	10–12	12–15	20–25	25–30
Biomass	O	–	–	–	–	–	–	–
	W	?	?	?	?	–	–	–
	B	–	–	–	–	–	–	–
Mean slope all fish	O	–	–	–	–	–	–	–
	W	+	+	+	+	+	–	–
	B	+	+	+	–	–	–	–
Mean slope small fish	O	–	–	–	–	–	–	–
	W	+	+	+	+	+	–	–
	B	+	+	+	–	–	–	–
Biomass	R(D)	?	?	–	–	–	–	–
Mean slope	R(D)	–	–	–	–	–	–	–

O = Orlík, W = Wallersee, B = Balaton, R(D) = direct observation of boat avoidance in Římov; –: no indication offish avoidance, ?: difficult to decide, +: positive indication of fish avoidance.

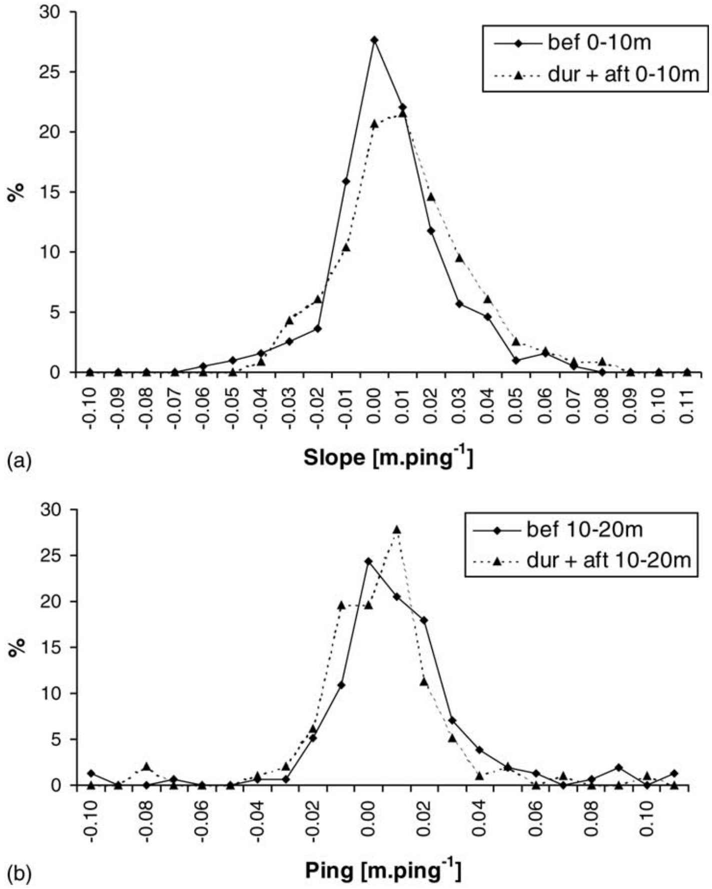

Fig. 6. Echogram slope distribution for: (a) near (0–10 m) and (b) greater distances (10–20 m) from direct observation of fish avoidance. "Bef" stands for the time before boat passage, "dur + aft" stands for the time of during and after boat passage.

3.4. Comparison of the three approaches

The results of the three approaches used here show that it is possible to find some indications of fish avoidance within short distances of a survey boat. Table 3 attempts to summarize the results of individual analyses with respect to avoidance behaviour. In most cases, we believe that the distances greater than 10 m appear safe from this potential source of bias. At closer range, avoidance was sometimes found, or not. The greatest avoidance was found in a clear subalpine lake, the lowest in the Czech reservoirs. Larger boats used on larger waters (lakes and the sea) may stimulate much greater avoidance reactions (up to 20 m in Lake IJsselmeer as reported by Mous and Kemper (1996); up to hundreds of meters as shown by Pitcher et al. (1996) and Soria et al. (1996)). A small research vessel appears to be advantageous for surveying where possible.

4. Conclusions

All three approaches (biomass—with restrictions, track slope statistics and direct observations of passage events) were found to be suitable for the assessment of fish avoidance behaviour. The vertical distribution of fish plays an important role in interpreting the information from the biomass approach. Fish avoidance causes higher values of the slope of an echogram trace with respect to the boat at closer ranges. Most avoidance behaviour was found with small fish (TS < −40 dB, 22 cm) at distances less than 10 m. Only in the clear lake Wallersee, were some indications of avoidance found up to 15 m from the survey boat; in Czech reservoirs no significant indications of fish avoidance were found. Greater distances appear to be safe from fish avoidance bias; at distances over 10 m, the avoidance of small boats (5–6 m long, 15–25 HP two-stroke engine) appears not to be a serious problem in shallow waters.

Acknowledgements

The authors would like to thank Martin Čech, Zdeněk Prachař and Georg Rakowitz for field assistance during the acoustics surveys and Jarka Frouzová, Marie Prchalová and Helge Balk for useful discussions. We thank also anonymous reviewers. The work was supported by the projects No. A6017901, S6017004 and Z6017912 of the Czech Academy of Sciences and MSM123100004 of Czech Ministry of Education.

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