



# Testing *in situ* avoidance reaction of vendace, *Coregonus albula*, in relation to continuous artificial light from stationary vertical split-beam echosounding

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**Abstract** The *in situ* avoidance reaction of vendace, *Coregonus albula* L., in relation to continuous artificial light in terms of a scaring device was tested by split-beam echosounding. The tests were carried out in the mesotrophic Bigge Reservoir (Germany) in November 2007 and 2008 using a Simrad EK 60 echosounder (120 kHz). An underwater lamp with light turned on and off was lowered to 30 m water depth at four sampling sites. No reaction of vendace was observed for the sampled references (light off), but strong avoidance behaviour by swimming mainly downwards was observed when the light was turned on. The light avoidance reaction was confirmed by the volume backscattering strength ( $S_v$ ) and calculated fish densities (fish ha<sup>-1</sup>). The mean fish densities for the samples carried out with light turned on were lower (268 fish ha<sup>-1</sup>,  $\pm 409$  SD,  $n = 32$ ) than for the references with light turned off (5028 fish ha<sup>-1</sup>,  $\pm 2317$  SD,  $n = 56$ ). The related median values (33 and 3726 fish ha<sup>-1</sup>, respectively,  $n = 88$ ) differed significantly (Mann–Whitney test,  $P = < 0.001$ ). In conclusion, artificial light has great potential to scare pelagic vendace from areas near the bottom outlets of reservoirs to prevent entrainment losses.

**KEYWORDS:** avoidance behaviour, bottom outlets, entrainment loss, hydroacoustics, reservoir.

## Introduction

Light is a primary stimulus for fish, and many species have well-developed visual systems (Königson, Fjälling & Lunneryd 2002). Light can be used to attract fish (Wickham 1973) or their larvae (Klein 1998), to repel fish from specific areas (Königson *et al.* 2002) and to guide their passage, e.g. at hydropower dams (Schilt 2007). Work has also been carried out to investigate the avoidance behaviour of fish mainly concerning guidance and protection, e.g. Nemeth &

Anderson (1992) studied the response of juvenile coho salmon *Oncorhynchus kisutch* (Walbaum) and chinook salmon *Oncorhynchus tshawytscha* (Walbaum) in relation to strobe and mercury vapour lights to influence the behaviour of migrating smolts at fish bypass systems.

During the 26th symposium of the American Fisheries Society on behavioural technologies for fish guidance in 1999, several authors contributed studies about the responses of fish to strobe lights. The reactions of American eel, *Anguilla rostrata* (Lesueur),

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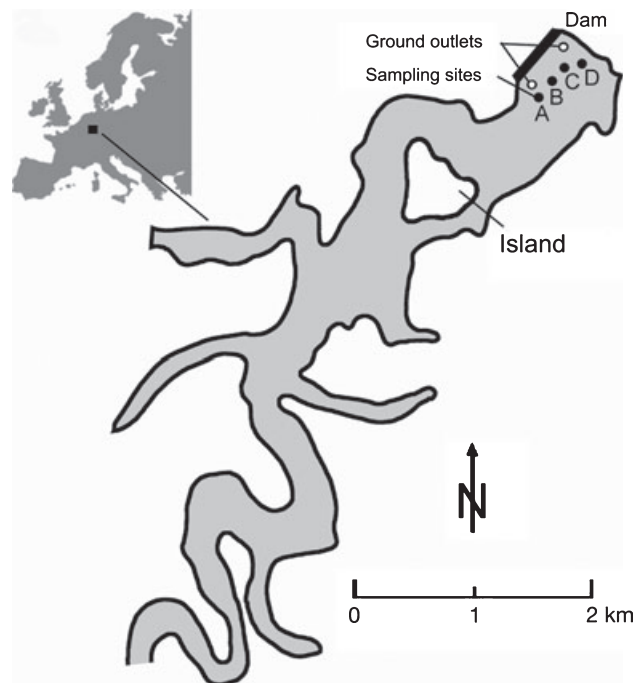
to strobe light were described by Patrick, Poulton & Brown (2001), and Johnson, Goetz & Ploskey (2001) evaluated strobe lights for vertical displacement of juvenile salmon near water intakes using echosounding to estimate fish densities. The response of free-ranging kokanee, *Oncorhynchus nerka* (Walbaum), to strobe light to reduce entrainment losses through large hydroelectric facilities was investigated by Maiolie, Harryman & Ament (2001) using mobile vertical hydroacoustics in lakes. Ploskey & Johnson (2001) and Mueller, Neitzel & Amidan (2001) tested the effectiveness of strobe light in relation to the avoidance reaction of juvenile salmon and char.

In addition to these studies dealing with riverine fish species, Königson *et al.* (2002) performed field (enclosure) and aquarium experiments on the avoidance of whitefish, *Coregonus lavaretus* (L.), to strobe light, and McKinstry, Simmons, Simmons & Johnson (2005) used a statistical approach based on log-linear models on hydroacoustic split-beam tracking data to assess fish behaviour.

All these studies were carried out in the marine or estuarine environment, investigated the behaviour of riverine fishes (especially salmonids) or were conducted under experimental or laboratory conditions. With the exception of Maiolie *et al.* (2001) and McKinstry *et al.* (2005), little focus was on the avoidance behaviour of fishes in relation to light in large and deep inland waters (like lakes and reservoirs) under natural conditions. Hence, there is a need for detailed studies in this field.

Several reservoirs in the catchment of the River Ruhr, West Germany support dense populations of pelagic vendace, *Coregonus albula* (L.) (Schmidt, Gassner & Meyer 2005). During flood events, the water is released by dam bottom outlets. High mortalities of vendace (mainly caused by pressure decrease) are observed when fish are entrained and passing the outlets in times of high and rapid water discharge (Kühlmann 1997; Schmidt, Gassner, Kühlmann & Meyer 2007). The risk of high mortalities increases with aggregation of fish in the dam area. Aggregation is caused by thermal stratification during the late summer (Schmidt *et al.* 2005) and the spawning season in early winter (Schmidt *et al.* 2007).

Based on the relevance described above and the assumption of Schmidt & Gassner (2006) that underwater light of scuba divers may trigger avoidance reaction of vendace in such reservoirs, the aims of this study were: (1) to test the ability of stationary vertical hydroacoustic data acquisition to assess light avoidance of fish in pelagic waters of a reservoir and (2) to monitor the avoidance reaction of vendace to light



**Figure 1.** Map and site of Bigge Reservoir and the sites of the experimental series A–D in the dam basin to test light avoidance of vendace.

under natural conditions to assess the potential of light to reduce entrainment losses.

## Materials and methods

### Study area

The study was carried out in the mesotrophic Bigge Reservoir, part of the Bigge and Lister reservoir system located in the south-eastern Germany in Northrhine-Westphalia (region Sauerland), at 7°53′ E and 51°06′ N (Fig. 1). The altitude is 308 m. Its catchment area is dominated by forestry and agriculture. The reservoir has a maximum surface area of 7 km<sup>2</sup>, a mean depth of 20.0 m and a maximum depth of 49.5 m. It is thermally stratified during the summer.

The reservoir was considered appropriate because it supports fish densities up to 37 000 fish ha<sup>-1</sup>, especially dense aggregations of vendace in the dam basin during spawning time (Schmidt *et al.* 2007). High fish densities are required to increase the likelihood of clear avoidance behaviour of fish (Maiolie *et al.* 2001; Schmidt & Gassner 2006). Other species present include eel *Anguilla anguilla* (L.), roach *Rutilus rutilus* (L.), bream *Abramis brama* (L.), tench *Tinca tinca* (L.), carp *Cyprinus carpio* L., brown trout *Salmo trutta f. lacustris* (L.), pike *Esox lucius* L., perch *Perca fluviatilis* (L.) and pikeperch *Sander lucioperca* (L.).

### Sampling procedure

The experiments were carried out during daytime in November 2007, and replicated with modifications in November 2008. The light device was lowered down with light on and off, while the effect on the fish was monitored with a split-beam echosounder. In 2008, the light device could be switched on and off from the surface.

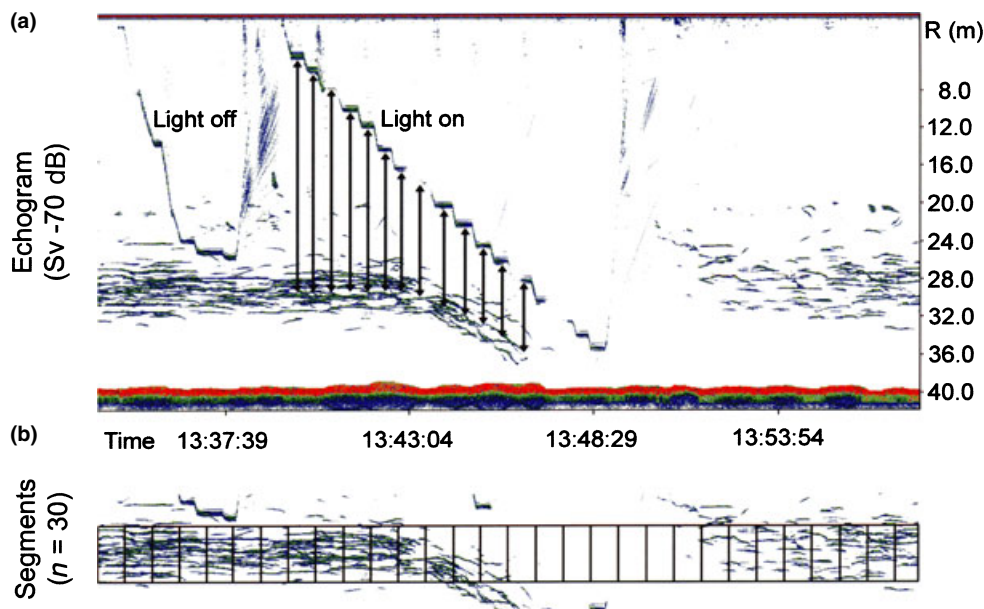
In 2007, the experiment was conducted on 28 and 29 November. Consecutive surveys were carried out at four different sites; A and C on 28 November and B and D on 29 November (Fig. 1). The sites were close to the bottom outlets in the dam area of Bigge reservoir. The distance between the two experimental sites sampled per day was approximately 150 m. This was selected to avoid fish reactions at sites C and D being influenced by the previous testing at sites A and B, respectively. The maximum water depth of the four sampling sites was 40 m, the water temperature decreased from 8.5 °C at the surface to 6 °C at 30 m water depth; the Secchi transparency was 3.6 m.

An underwater halogen lamp (Type: Hartenberger Maxi Compact with 50 W) with non-flashing light was used to test light avoidance of vendace. Hydroacoustic data acquisition was obtained with a Simrad EK 60 scientific split-beam echosounder equipped with an ES-120 kHz  $7\times 7^\circ$  split-beam transducer. The transducer

was mounted at the bow of a 6.5 m long boat (permanently moored to buoys at the four sampling sites) 0.4 m below the surface, aimed vertically downwards. Electric transmit power was set to 100 W. Pulse duration was 0.064 ms, and the pulse repetition rate was set to 0.1 (equivalent to 10 pings  $s^{-1}$ ).

The hydroacoustic system was calibrated with a standard copper sphere before the surveys. The underwater lamp (fixed to a rope and pointing downwards) was lowered down along the acoustic transducer axis. First, the reference state was sampled with light turned off. The underwater lamp was lowered down until it reached the top of the fish layer at 26 m water depth (Fig. 2a). The lamp was then raised to the boat, the light was turned on, and lowered again in steps of 2 m every 15 s through the whole water column (i.e. directly through the fish layer, see Fig. 2a). The lamp was then removed again from the water, while acoustic data were recorded until the fish showed a similar spatial distribution to that recorded prior to the tests. The experiment was repeated identically for each of the four sampling sites.

In 2008, a replica experiment was carried out on 25 November at sampling site C. The environment conditions matched those in 2007, except for a lower reservoir water level resulting in a maximum water depth of 26 m at this location. A modified light device (50 W) with an on/off switch was used to (1) scrutinize



**Figure 2.** Amplitude echogram ( $S_v -70$  dB) showing the experimental setup to test the light avoidance of vendace (a) and echogram zoom of the fish layer with 30 evenly distributed segments used for data analysis (b) shown for the experimental site D.

whether avoidance reactions were triggered by the light and not by the lowering of the light devices and (2) to control whether the avoidance behaviour during periods of illumination was continuous. The experimental setup and performance of the hydroacoustic system were similar to 2007, except that the lamp was lowered directly to the middle of the fish layer and that the light could be turned off after it was positioned.

#### Data analysis

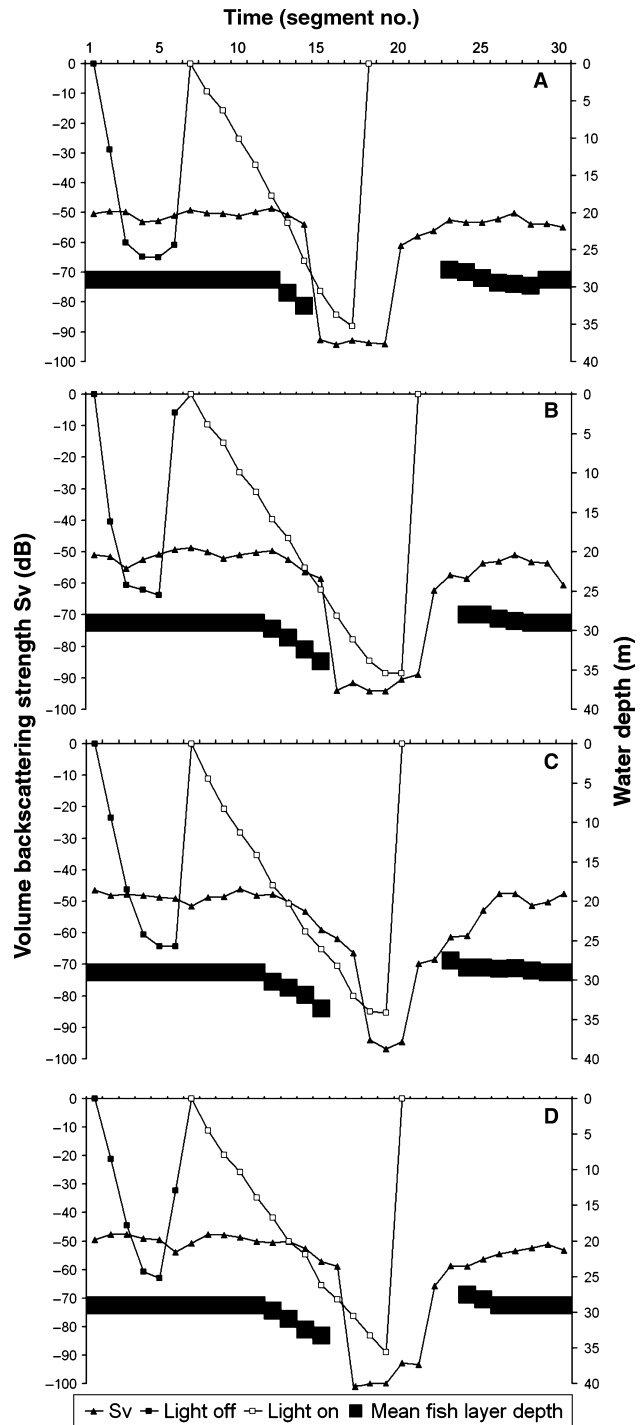
The acoustic data were analysed with Sonar5-Pro post-processing software (Balk & Lindem 2004) and MS Excel. Echoes from the underwater lamp were first removed from the echograms with the Sonar5 noise erasing tool to avoid bias in the analysis. The eraser was set to remove entirely echoes marked by the mouse so that these echoes did not contribute to the backscattering energy in terms of average echo integrals and TS size distribution (see Fig. 2a, b). To separate fish from background noise, a threshold of  $-70$  dB was applied to the volume backscattering strength ( $S_v$ ).

The Sonar5 single echo detector based on echo length was applied to isolate single fish echoes. The detector was set to accept echoes with minimum target strength (TS) of  $-58$  dB. Minimum and maximum echo length was set to 0.8 and 1.2, respectively, relative to the transmitted pulse length. Only echoes within the half power beam were accepted and maximum sample angle standard deviation was set to  $0.8^\circ$ . Echoes with multiple peaks were excluded.

The acoustic data were divided in a number of equal sized analysis segments surrounding the fish layer to evaluate the fish reaction. Based on the observed fish density, lamp lowering speed, and fish reaction time, the individual cell thickness was set to 6.0 m from 26.5 to 32.5 m water depth. Segment width (Elementary Sampling Time Unit) was set to 50 s (Fig. 2). Average  $S_v$  and abundance based on  $S_v$ /TS scaling (abundance by echo integration and *in situ* single echo detection, Bodholt 1990 and Balk & Lindem 2004) was estimated for each analysis cell by Sonar5, exported to MS Excel and plotted against the distance of the light source from the fish layer (Fig. 3).

The segments of all four sampling sites were grouped into three different classes [segments 1–14 ( $n = 56$ ) = references with off-turned light, segments 15–22 ( $n = 32$ ) = light avoidance test, and segments 23–30 ( $n = 32$ ) = after the light was removed and fish returned to the sampling site] for statistical analysis.

Mean  $S_v$ -values and fish density of the groups were calculated from the segments. Differences in estimated



**Figure 3.** Volume backscattering strength ( $S_v$ ) and distance of the light source (light off and on) in relation to the mean fish layer depth as a function of time for the experimental series A–D.

fish densities were tested for significance using the Mann–Whitney Rank Sum Test (Sigma-Stat Software). For this analysis, fish densities ( $n \text{ ha}^{-1}$ ) from group one and three (light off and removed, respec-

tively) were pooled, and the median value was tested against group two (light on).

The *in situ* target strength (dB) distribution in relation to fish total length (TS–TL relationship) was calculated for the dorsal aspect of vendace using the formula of Mehner (2006) for 120 kHz [ $TS = 25.5 \log(TL) - 70.9$  dB]. The fish lengths obtained from hydroacoustic data were compared with sub-samples from pelagic pair-trawling carried out regularly on Bigge Reservoir each winter season in November and December (M. Mühlmann, personal communication; Schmidt *et al.* 2007).

Additionally, the avoidance reaction was assessed by studying the vertical movement of fish. This was measured from the distance (range in m based on the echograms) between the light source and the visually observed mean fish layer depth during the second lowering of the lamp (light on) at every 2-m step (see Fig. 2a). The distance at which the fish showed the first avoidance response in relation to the approaching light was measured (range in m) between the echo of the lamp and the mean fish layer depth of the related segment. The duration between the first avoidance response until the fish returned to the sampling site was calculated based on the time interval (segment start time) for segments 22 and 30 of each sampling site. Supplementary tracking analysis was carried out for 28 single fish (14 under light off and 14 under light on conditions) to assess the individual swimming behaviour. The distance (m) between the first and last single echo of each track along the *z*-axis (range or water depth, respectively) was calculated by the software to obtain small-scale information about the vertical movement of the fish under both conditions. The results were tested for significance (Mann–Whitney Test).

For the 2008 experiment, volume backscattering levels ( $S_v$ ) were analysed based in four depth layers and 30 segments per layer (= 120 cells). The  $S_v$ -values were calculated separately for each analysis cell to allow a consecutive comparison of volume backscattering levels of both, the light device (light off/on) and surrounding segments (fish/no fish).

## Results

The main outputs were that vendace strongly avoided the light under the described conditions, that the avoidance was persistent over time (if the light was kept on), and that they quickly returned to the area when light was turned off.

Based on the echograms (Figs 2 and 7) and related analyses, a strong avoidance reaction was observed in

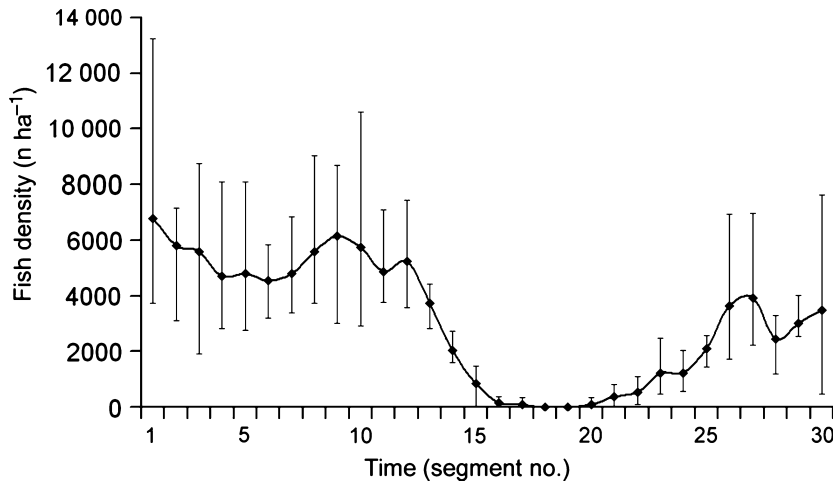
the dense and layered distributed vendace in relation to the approaching light source. The average  $S_v$ -value from the grouped segments of the reference samples was  $-50.1$  dB ( $\pm 1.0$  SD,  $n = 56$ ) and dropped down to  $-80.6$  dB ( $\pm 2.7$  SD,  $n = 32$ ) during the lowering of the lamp with light turned on. After the light was removed, the mean  $S_v$ -value increased to  $-53.8$  dB ( $\pm 1.2$  SD,  $n = 32$ ). Figure 3 shows the results based on the mean volume backscattering strength in relation to the approaching underwater lamp with light turned off and on, respectively.

The average fish densities from grouped segments based on echo-integration data confirmed these results and were calculated as  $5028$  fish  $ha^{-1}$  ( $\pm 2317$  SD,  $n = 56$ ) for the reference state and  $268$  fish  $ha^{-1}$  ( $\pm 409$  SD,  $n = 32$ ) for the light avoidance test. Fish densities increased again to  $2632$  fish  $ha^{-1}$  ( $\pm 1783$  SD,  $n = 32$ ) after the light was removed. The median value of the grouped segments 1–14 and 23–30 (light off and removed, respectively,  $n = 88$ ), was about  $3726$  fish  $ha^{-1}$  and was significantly different from the median value of  $33$  fish  $ha^{-1}$  for the grouped segments 15–22 (light on,  $n = 32$ ,  $P < 0.001$ ) (Fig. 4).

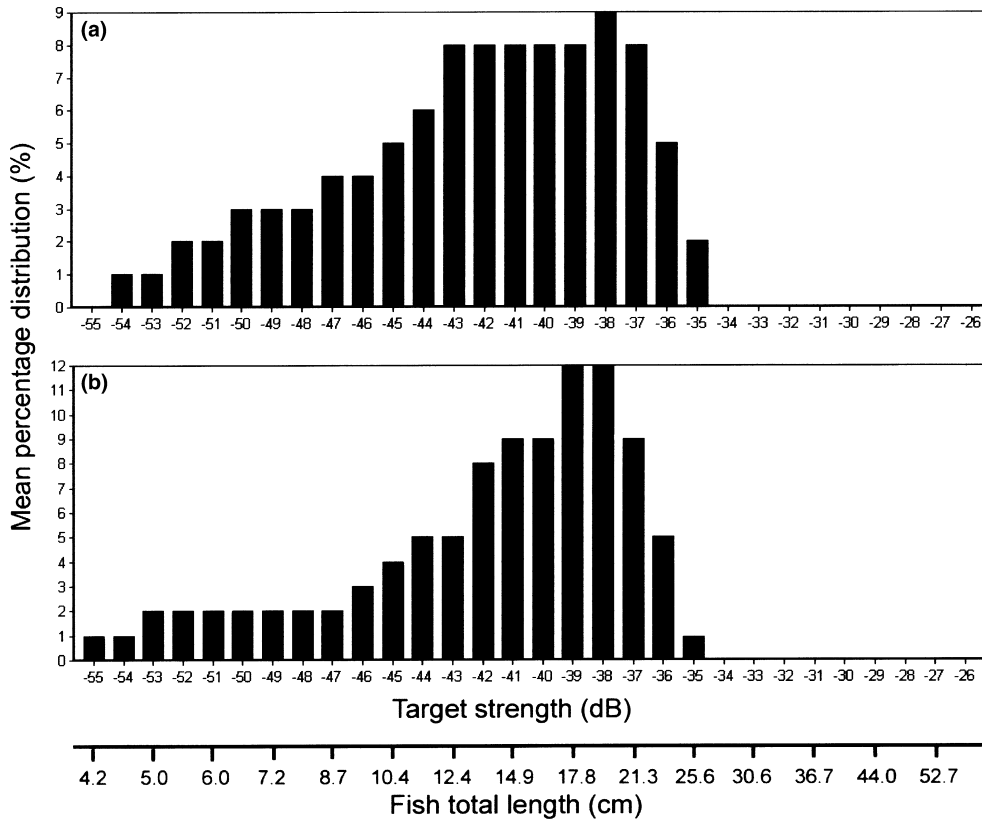
The observed *in situ* target strength distributions showed continuous peaks around  $-39$  and  $-38$  dB corresponding to fish total lengths ranging from 17.8 to 19.5 cm (Fig. 5) and were consistent with the results of subsamples from trawl catches of vendace with total lengths ranging from 14 to 21 cm and a mean length of 18 cm in November and December 2007.

Based on the echograms and measured distances between the approaching light source and the mean fish layer depth, vendace avoided the light by a directed movement in the opposite direction, i.e. by swimming downwards to the reservoir bottom (Fig. 3). The fish returned to the sampling sites from approximately the same depth as the mean fish layer depth observed prior to the tests (29 m, see Fig. 3). No upwards swimming was observed. The mean distance at which vendace showed a first avoidance response in relation to the approaching light was 12 m ( $\pm 1$  SD,  $n = 4$ ). The mean time interval until the fish showed the same spatial distribution as observed during the reference samples was 6 min 12 s ( $\pm 36$  s SD,  $n = 4$ ).

The tracking analysis underlined that undisturbed fish (light off) generally showed horizontal swimming behaviour (Fig. 6a). Fish that avoided the light showed downwards swimming with slightly lateral movements resulting in a zig-zag pattern (Fig. 6b). The mean changes in range (i.e. water depth) were 0.06 m ( $\pm 0.05$  SD,  $n = 14$ ) for the fish tracked under light off conditions and 0.57 m ( $\pm 0.18$  SD,  $n = 14$ ) for the fish tracked during illumination (Fig 6c). The differences in



**Figure 4.** Mean fish densities (based on  $S_V/TS$  scaling) with related minimum and maximum values as a function of time for the experimental series A–D.

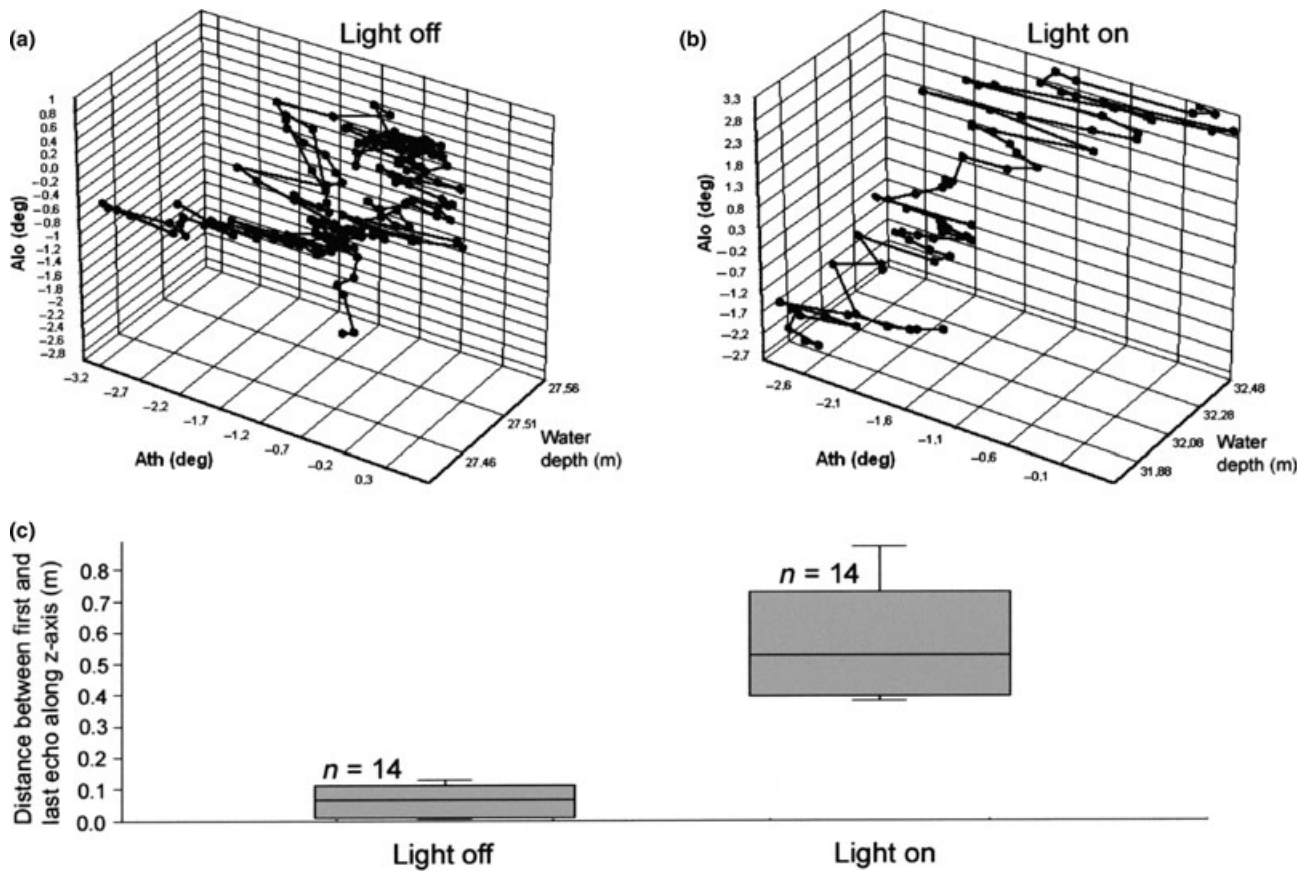


**Figure 5.** Mean percentage target strength distribution based on single echo detections and corresponding fish total length based on Mehner (2006) for the sampled references with the light device positioned but light turned off (a), and for the period after the light device was removed and fish returned to the sampling site (b).

the median values of both groups were statistically significant ( $P \leq 0.001$ ).

The November 2008 experiment and the related echogram showed that the fish avoided the light and

not the light device (Fig. 7a). The  $S_V$ -values decreased when the lamp was lowered to the middle of the fish layer with the light on, but as soon as the light was turned off,  $S_V$ -values increased again and confirmed



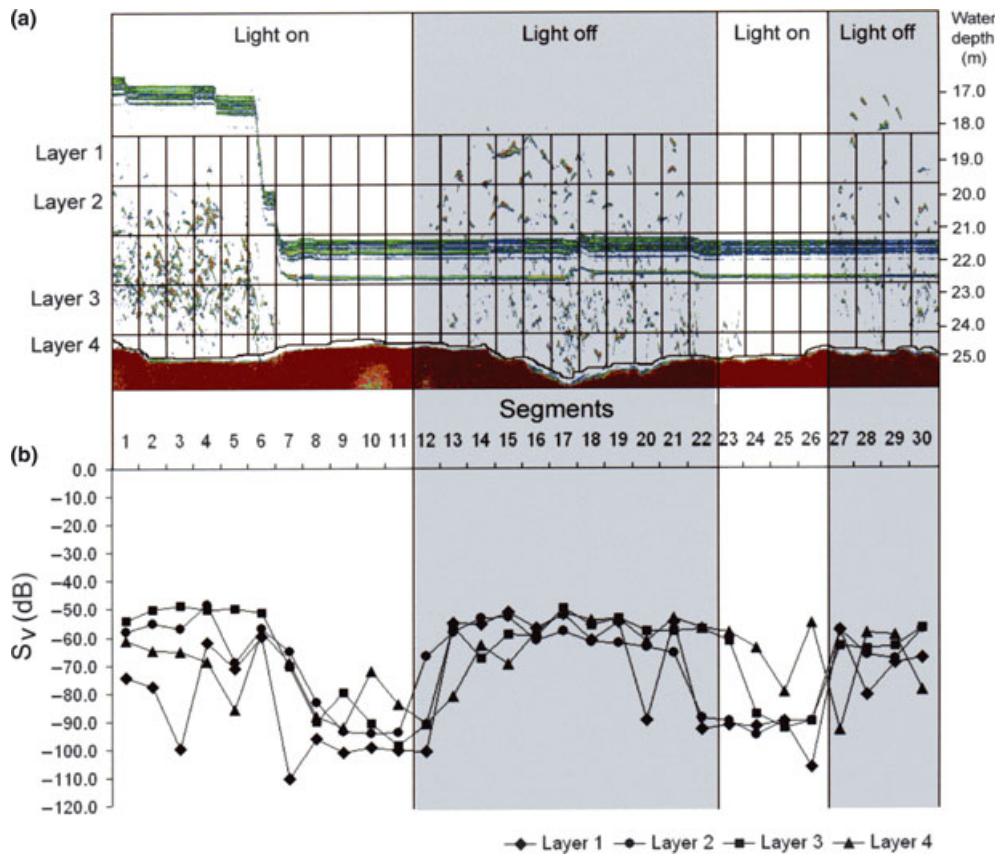
**Figure 6.** 3D-tracking analysis of two single fish (a and b) and distance between first and last tracked echo along z-axis for 28 tracked fish (c). Note the different scaling in (a) and (b) depending on the *in situ* 3D distribution of tracked single echoes.

the return of the fish to the sampling site (Fig. 7b). The avoidance reaction was persistent for more than 20 min and no acclimation of the fish to the light was observed during the periods of illumination (Fig. 7).

**Discussion**

The results suggest a strong avoidance reaction of the fish to artificial light. This confirmed the assumption of Schmidt & Gassner (2006) that underwater light triggers avoidance behaviour of pelagic vendace in Bigge Reservoir. Although it cannot be excluded that other species inhabit the fish layer under observation, the good correspondence with the TS–TL relationship of Mehner (2006) between acoustics and catch data, suggest that the observed fish were exclusively vendace (see also Schmidt & Gassner 2006 and Schmidt *et al.* 2007). Recent investigations also showed that this relationship proved to be appropriate for the vendace population in Bigge Reservoir (Schmidt 2009).

The majority of studies about freshwater fish and their behaviour in relation to underwater light confirm these avoidance responses for both continuous and strobe light. Although only constant light was used during the tests in Bigge Reservoir, it can be assumed that the use of strobe lights would lead to comparable results. Nemeth & Anderson (1992) found avoidance behaviour of salmon smolts to both flashing (strobe) and non-flashing (mercury vapour) light. They also observed a slight attraction response of Chinook smolts to dim mercury light when fish were adapted to darkness and assumed that the responses to light are complex depending on a variety of conditions involving both the fish and its environment (e.g. day and night time conditions). This statement is also valid for American eels because Patrick *et al.* (2001) found strong avoidance reactions to strobe light depending on size-classes. While juveniles avoided the light immediately, the adult eels showed marked avoidance only after several minutes of exposure to the light source. No acclimation was observed for either



**Figure 7.** Amplitude echogram ( $S_v -70$  dB) from the 2008 experiment (a) with corresponding volume backscattering strength analysis below (b). Note that the layer with both light device and fish echoes was excluded from analysis.

juveniles or adults. By contrast, this study found strong avoidance of adult vendace while Klein (1998) found larvae of another coregonid species (whitefish) to be attracted by underwater light in shallow waters of a natural lake.

The use of hydroacoustics to assess avoidance behaviour of fish was confirmed by Johnson *et al.* (2001) and Maiolie *et al.* (2001). Johnson *et al.* (2001) found significantly lower densities of juvenile salmon (calculated from 420 kHz single-beam data) near a filling culvert intake when fish were exposed to a strobe light. They observed displacements of 3–7 m from the light source. Similarly, Maiolie *et al.* (2001) using vertical mobile split-beam surveys at 120 kHz, found kokanees exposed to a strobe light at Secchi transparencies ranging from 2.8 to 17.5 m in the open water of two natural lakes with depths ranging from 20 to more than 100 m moved an average of 30–136 m away from the flashing lights depending on conditions. Consequently, the authors stated that strobe lights have high potential to reduce the numbers of fish near turbine intakes at dams.

Königson *et al.* (2002) found avoidance reactions of adult whitefish to a strobe light array using ultrasonic transmitters in field-enclosure and aquarium experiments. The fish responded by a distinct turn and a change in swimming direction away from the light (as observed at Bigge reservoir in 2007). Surprisingly, even fish above the (downwards pointing) light source showed avoidance behaviour during the 2008 experiment (see Fig. 7a at time 11:56). Synchronized behaviour based on visual census due to the introduced light could be a possible explanation. The mean distance of 0.65 m at which whitefish showed avoidance response in the study of Königson *et al.* differed considerably from the mean distance (11.6 m) observed for vendace at Bigge Reservoir. This may be explained by different conditions, e.g. the field enclosure experiment was carried out at night. Also different water transparency and species-specific behaviour have to be considered.

In conclusion, artificial light has the potential to scare vendace from areas in the hypolimnion of reservoirs and thus protect them from being entrained into bottom outlets, e.g. by using ring-shaped light

arrays around these technical structures. In practice, it would be effective to use such scaring device only short-term, just before the outlets are opened. Although only a non-flashing light source was tested, both constant and flashing light has promise for fish protection and, respectively, passage and guidance (Schilt 2007). Also many other aspects of light avoidance behaviour of fish (e.g. spectrum-specific differences, light polarity, background and contrast; see Schilt 2007) remain to be explored. With respect to background light and contrast, this study was carried out during daytime, and it is likely that lower light intensities (i.e. increasing contrast) during the night would lead to similar or even stronger avoidance behaviour, although it should be noted light intensities in the hypolimnion of the mesotrophic Bigge Reservoir during the day were low.

Generally, the use of hydroacoustics appears a good method to assess fish behaviour to light sources. The split-beam approach used here proved to be highly effective but more research is needed to discover additional information about fish behaviour and related practical setups.

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