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Discriminating the diel vertical migration of fish and *Chaoborus flavicans* larvae in a lake using a dual-frequency echo sounder

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Abstract – The diel vertical migration of fish and larvae of the phantom midge *Chaoborus flavicans* was studied using a combined 38 and 200 kHz echo sounder. Multi-mesh gill net was used to sample fish, and a Schindler-Patalas trap to sample *Chaoborus*. Oxygen and temperature profiles were also recorded. At 38 kHz, only fish were detected, without considerable interference from *Chaoborus* echoes. At 200 kHz, both fish and *Chaoborus* were detected and echoes from *Chaoborus* almost completely masked all fish echoes at night. During the day, *Chaoborus* remained hidden in an oxygen-poor refuge near the bottom. Tracks of fish diving into the *Chaoborus* refuge were observed on several occasions. At the onset of dusk, *Chaoborus* started to rise and by the time it was dark they were occupying the whole water column. Fish were found in patches in midwater during the day. In the dark, the fish were dispersed throughout the water column. Results suggest that a dual-frequency approach can be used to discriminate between fish and *Chaoborus* and to provide a rapid method for their selective monitoring.

Key words: Multifrequency acoustics / Freshwater fish / Phantom midge / *Chaoborus* / Species discrimination

Résumé – La migration verticale de poissons et de larves de l'insecte Diptère *Chaoborus flavicans* est étudiée sur une période de 24 h, en utilisant un échosondeur combiné de 38 et 200 kHz. Un filet maillant est utilisé pour échantillonner les poissons, et un collecteur Schindler-Patalas pour échantillonner *Chaoborus*. Les profils d'oxygène et de température sont enregistrés également. A 38 kHz, seuls les poissons sont détectés sans interférence considérable avec les échos provenant de *Chaoborus*. A 200 kHz, à la fois poissons et *Chaoborus* sont détectés et la nuit, les échos de *Chaoborus* masquent presque complètement tous les échos de poissons. Durant le jour, *Chaoborus* reste caché près du fond, une zone pauvre en oxygène. Des suivis de poissons plongeant dans ce refuge sont observés à plusieurs reprises. Au crépuscule, *Chaoborus* commence à remonter puis avec la nuit occupe toute la colonne d'eau. Les poissons sont trouvés en patches à mi-profondeur durant le jour.
La nuit, les poissons se dispersent sur toute la colonne d'eau. Les résultats suggèrent qu'une approche bifréquentielle peut être utilisée pour distinguer less poissons des *Chaoborus* et pour fournir une méthode rapide d'analyse sélective.

1 Introduction

Larvae of the phantom midge (*Chaoborus flavicans*) are abundant in many lakes throughout the year. The larva possesses two pairs of air-sacs and is a strong acoustic scatterer at the echosounder frequencies traditionally used in freshwater (Northcote 1964; Eckmann 1998; Wagner-Döbler and Jacobs 1998; Malinen et al. 2001, 2005; Knudsen et al. 2006). When they co-occur with fish, *Chaoborus* display a diel vertical migration, where they are found in the sediments or in the hypolimnion during the day and ascend into the epilimnion to feed in the evening (Malueg and Halser 1966; Nilsen 1974; Voss and Mumm 1999). Fish display a similar vertical migration, and both fish and *Chaoborus* can be interspersed in open water at night (Teraguchi and Northcote 1966; Pope et al. 1973), in some lakes even during the daytime hours (Liljendahl-Nurminen et al. 2002; Malinen et al. 2005). Since the most favorable conditions for acoustic fish surveys are often at night, when the fish are dispersed in the open water, *Chaoborus* may cause errors in fish estimates. *Chaoborus* is by far the most important lake predator among the insects (Zaret 1980) and it shapes the zooplankton community in competition with fish (Carpenter and Kitchell 1993). *Chaoborus* is both an attractive prey for most fish and a competitor for the zooplankton. Therefore, an echosounder that can be able to discriminate between fish and *Chaoborus* would be a useful tool when studying fish-plankton interactions in understanding the biological dynamics in lakes.

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Methods based on thresholding have been suggested as a means of solving the *Chaoborus*-fish separation problem (Eckmann 1998; Malinen et al. 2001, 2005), but none have considered the possibility of using multiple frequencies to distinguish fish from *Chaoborus*. The acoustic scattering from *Chaoborus* is dependent on echosounder frequency (Jones and Xie 1994; Knudsen et al. 2006). Knudsen et al. established the acoustic frequency response of *Chaoborus* at six echosounder frequencies (38, 70, 120, 200, 364 and 710 kHz), and found that *Chaoborus* spanned the transition from Rayleigh (nondirectional) to geometric (directional) scattering with a resonance peak at 200 kHz. At 38 kHz, backscattering was weak and it was suggested that a low echo-sounder frequency could be employed to avoid the error caused by *Chaoborus* in acoustic fish estimates.

At traditional echo sounder frequencies, the acoustic wavelength is usually less than the length of fish; scattering is geometrical and would be flat with frequency if the fish had no directivity. However, fish are directive acoustic sources, whose backscatter main lobe becomes sharper as frequency rises (Foote 1985; Furusawa 1991) leading to a slight decrease in total backscattering from swimbladder fish *in situ* (Pedersen et al. 2004; Kaartvedt et al. 2005; Jurvelius et al. 2008; Rudstam et al. 2008b). Since the frequency dependent backscatter signals from fish and *Chaoborus* are different, it should be possible to separate them acoustically by using more than one frequency. McKelvey and Wilson (2006) used 38 and 120 kHz echo sounders for species classification of pacific hake and euphasiids based on overall mean volume backscattering difference (ΔS_v) at the two frequencies. Everson et al. (2007) adopted the same approach to separate northern krill from other scatterers in a Swedish fjord. Several similar experiments have been made in the marine environment (Cochrane 1993; Everson et al. 1993; Miyashita et al. 1997; Kang et al. 2002; Korneliussen and Ona 2002; Fernandes et al. 2006), while little work has been done on freshwater species (Jurvelius et al. 2008; Rudstam et al. 2008b).

Establishing a methodology capable of providing accurate fish and *Chaoborus* estimates when they co-occur would be of great value. Indirect methods are available (Eckmann 1998; Malinen et al. 2001, 2005), but routine acoustic surveys would benefit from direct and rapid methods. This is also in line with recent EU freshwater directives that aim to establish routines for effective and non-invasive monitoring of all components of the freshwater ecosystem.

The aim of this study was to determine whether using a low echo sounder frequency would eliminate the potential error caused by *Chaoborus* in fish estimates. We also wished to find out whether a combination of low and high frequencies could be used to separate and selectively monitor fish and *Chaoborus* during the diel vertical migration.

2 Materials and methods

2.1 Location

The study took place in Lake Borrevann, 100 km southwest of Oslo (N59°24′:E10°25′) in September 2007. Lake Borrevann is eutrophic with marked oxygen depletion in the hypolimnion during the summer. The most common fish species are roach (*Rutilus rutilus*), bleak (*Alburnus alburnus*), bream (*Abramis brama*) and rudd (*Scardinius erythrophthalmus*). The non-cyprinid species perch (*Perca fluviatilis*) and pike (*Esox lucius*) are also present, but are less abundant than the cyprinids. The only large pelagic invertebrate in Lake Borrevann is the insect larva *Chaoborus flavicans* (Økland 1964). The smaller crustacean zooplankton is dominated by *Bosmina longirostris, Daphnia cucullata, D. cristata, Cyclops strenuus* and *Megacyclops gigas* (Bishnu Prasad Regmi, unpublished).

2.2 Echosounders

A new echosounder (EY60 combi-wide) with a transducer housing both 38 and 200 kHz single-beam frequencies and with wide opening angles was used. The instrument was validated by comparison with a traditional scientific echosounder operating at 200 kHz. The dual-frequency single-beam echosounder (combi-wide) was employed to collect scattering data from fish and *Chaoborus*. The echosounder has a 3 dB beam angle at both 38 and 200 kHz close to 32°. It was calibrated according to the single-beam calibration procedure in the Simrad EK500 manual (Simrad, Horten, Norway) and Foote (1982, 1987), using a standard target (38.1 mm tungsten carbide sphere with cobalt binder, www.ballbiz.com) with nominal TS of –42.3 dB at 38 kHz and –39.5 dB at 200 kHz (speed of sound: 1470 m s^{-1}). The transducer near-fields of both frequencies are less than 0.5 m. However, the 38 kHz transducer rings (ring-down) and masks echoes at ranges of up to 3 m from the transducer face. The echo sounder was run from a ruggedized laptop interfaced with a USB-GPS in order to provide accurate position and speed readings. Since this echosounder has not been used for quantitative work before it was validated by comparison with a traditional EY60 200 kHz split-beam echosounder with a 7° beam angle transducer (200-7C) in a separate test. This echo sounder was also calibrated according to standard procedures (Foote et al. 1987). At both echosounders the pulse duration was 256 μs, pulse interval 0.3 s and power was 100 W.

The wide-beam echosounder transducer was installed at the end of a pole and mounted at the side of a 4 m-long boat with its centre at a depth of 70 cm. The boat was rowed 7 times along the same transect both during the day and at night, at a speed of 0.2 m s^{-1}. The transect length was 350 m, with a maximum water depth of 15 m. Once during both day and night the boat was anchored at the deepest part of the transect for simultaneous acoustic and zooplankton sampling. Gill-nets were set just prior to the zooplankton sampling.

In the echosounder validation test the 200 kHz transducers (combi-wide and 200-7C) were mounted side by side with alternating transmissions as the boat was rowed once along a 300 m transect. The sampling volume of the wide-beam transducer is 21 times greater than the narrow beam. The comparison was made in the evening when fish had ceased schooling and *Chaoborus* had started to ascend, in order to obtain the most even distribution of targets in the water. The echosounder validation test did not include 38 kHz because the equivalent 7° split-beam transducer at 38 kHz frequency weighs 40 kg and was not practical for portable use.

2.3 Fish and zooplankton sampling

Multimesh gill net was used to sample the fish. Two 5 m × 30 m multimesh gill nets (Nordic survey nets, Appelberg et al. 1995) were used simultaneously to sample from the surface to near the bottom. Each nets was divided into 12 panels (5 × 2.5 m) with mesh sizes of 5, 6.25, 8, 10, 12.5, 15.5, 19.5, 24, 29, 35, 43, 55 mm (randomly distributed). The nets were set for two hours during the day and one hour at night.

Zooplankton samples were taken using a Schindler-Patalas (Schindler 1969) zooplankton trap (25 L) at depth of 1, 4, 7 and 13 m both during the day and at night. Five parallel samples were taken at each depth. The zooplankton trap position was monitored by the echo sounder, and the horizontal distance between the echo sounder transducer and the trap was about 1 m. The samples were filtered through a 90 μm plankton net and preserved in 4% formaldehyde. The zooplankton samples were counted and measured using a stereomicroscope and presented as individuals m^{-3} (mean ± SD) and length in mm. Daphnids and copepods were also found in the samples, but since they do not contribute acoustically at these frequencies (Knudsen et al. 2006), they were not considered.

Oxygen and temperature profiles were recorded using an YSI (YSI, Yellow Springs, Ohio) sensor at each 1 m water depth during daytime.

2.4 Analysis

The acoustic recordings were analyzed using the Sonar5 software package (Balk and Lindem Data Acquisition, Oslo, Norway). The acoustic terminology used is defined in MacLennan et al. (2002).

The volume backscattering strength (S_v, dB re m^{-1}) at 38 and 200 kHz were compared in areas with only fish and in areas with only *Chaoborus*, and a mean ΔS_v ($S_{v38kHz} - S_{v200kHz}$) was calculated to establish the frequency response of fish and *Chaoborus*.

To establish and index for fish density a mean nautical area scattering coefficient (NASC ± SD, $m^2 nmi^{-2}$) from seven complete transect recordings at 38 kHz was made both during the day and at night within the depth range 6–12 m (corresponding to the bottom gill net) and with a S_v threshold of –70 dB re m^{-1}. No comparison was made with the surface gill net due to the ring-down of the 38 kHz transducer. Catch per unit effort (CPUE) for the gill net was expressed as fish catch per hour.

Volume backscattering at 200 kHz was established for each zooplankton sampling depth. The sampler was seen in the echogram and about 100 pings within a 1 m high layer (±0.5 m of the sampling depth) immediately prior to the actual sampling point were selected for analysis of S_v. The 38 kHz recording was used to verify that the selected area was without fish. The correlation between the volume backscattering (linear volume backscattering, s_v, m^{-1}) and the mean *Chaoborus* count at each sampling depth was studied with the Pearson correlation coefficient.

In mobile night-time surveys *Chaoborus* was mixed with fish, and backscattering from fish at 200 kHz had to be removed before establishing an index of *Chaoborus* abundance. The echo energy from fish was removed by identifying fish tracks in the 38 kHz recordings and constructing a mask to eliminate them from the 200 kHz recordings (Jurvelius et al. 2008; Rudstam et al. 2008b). The eliminated sections were not considered when the scattering from *Chaoborus* was being estimated from the 200 kHz recording. Since there is no ring-down on the 200 kHz transducer, data analysis started 0.5 m from the transducer (outside the transducer near-field). A NASC was estimated as the mean ± SD of seven recordings made both during the day and at night. S_v threshold was –90 dB re m^{-1}. The seven daytime transects were analyzed directly at 200 kHz since no fish was mixed with *Chaoborus*.

NASCs were compared in the water column (2–12 m) across the new wide-beam and traditional split-beam echosounders with 200 kHz frequency. The 300 m transect was analyzed in five depth layers, each being 2 m high, and each layer was divided into ten subsegments (30 m). A NASC (mean ± SD) was calculated for each layer. The total NASC for the whole water column over the full length of the transect was also calculated.

3 Results

Echograms from the mobile recordings made during the day and at night are shown in Figure 1, with a 20 log time-varied gain (TVG) and a lower volume backscattering strength (S_v) threshold of –70 dB re 1 m^{-1}. At this threshold, echo energy from *Chaoborus* at 38 kHz was nearly absent ($S_v < -69$ dB re m^{-1}). During the day, echoes from individual fish and patches of fish could be seen in the lower part of the water column at both frequencies. The 38 kHz recording shows that fish stopped aggregating at night and dispersed throughout the water column. All the fish caught by the gill nets were bleak and roach (Table 1), except for one bream and one perch in the upper gill net at night. More fish were taken at night, particularly by the upper gill net. Near the bottom a scattering layer could be detected at 200 kHz during the day, but not at 38 kHz. Zooplankton sampling showed high densities of *Chaoborus* in this layer (Table 2). At 200 kHz the scattering layer started to ascend at dusk and at night it occupied the whole water column more or less masking all fish echoes. At 38 kHz the scattering layer could not be seen whereas clear fish tracks can be detected, both during the day and at night. Zooplankton sampling confirmed that the scattering layer was caused by *Chaoborus*. Oxygen concentration and temperature were almost stable from the surface down to 10 m (Fig. 2). Thereafter, both declined rapidly and oxygen concentration approached 0 mg L^{-1} near the bottom where the *Chaoborus* congregate during the daytime (Fig. 2). Tracks of targets diving into the low-oxygen *Chaoborus* refuge were occasionally observed on the daytime echograms from stationary recordings (Fig. 3). The tracks were observed in the low-oxygen layer ($O_2 < 1$ mg L^{-1}) for periods of up to 30 s, suggesting some fish predation on *Chaoborus* during the day.

The frequency response of fish and *Chaoborus* was determined on the basis of the daytime echogram (Fig. 1). The ΔS_v ($S_{v38kHz} - S_{v200\,kHz}$) was –25 dB for *Chaoborus* and 7 dB for fish. The actual S_v for the *Chaoborus* aggregating near bottom at the 38 kHz recording was less than –69 dB re m^{-1}. This is

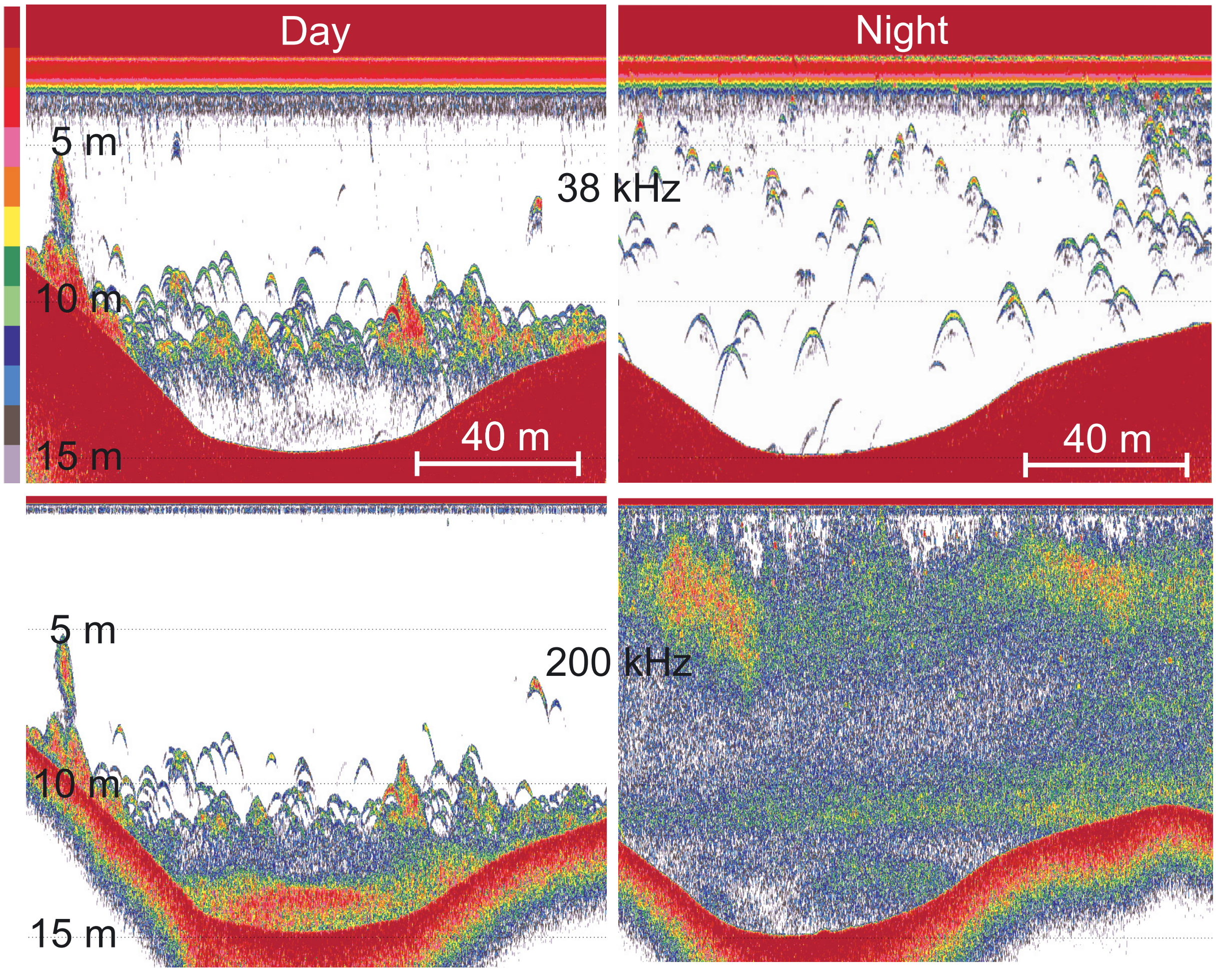

Fig. 1. Echograms showing the vertical distributions of fish and *Chaoborus* at 38 and 200 kHz during the day and at night. Only fish are detected at 38 kHz, while at 200 kHz both fish and *Chabor*us are detected. The color bar represents echo strength from weak (grey) to strong (brown). S_v threshold is –70 dB re m^{-1}.

Table 1. CPUE (fish h^{-1}) and mean length (L, cm) of fish caught in the upper (0–6 m) and lower (6–12 m) multimesh gill nets and the corresponding NASC (± SD), m^{2}nmi^{-2}, for the lower gill net during the day and at night. One perch and one bream were also caught at night in the upper gill net.

	Depth (m)	CPUE Bleak	L Bleak	CPUE Roach	L Roach	Total	NASC
Day	0–6	22	11.1	8	12.1	30	
	6–12	7	10.3	19	12.0	26	842 ± 99
Night	0–6	68	8.8	44	10.9	112	
	6–12	40	8.9	77	10.6	67	132 ± 38

the highest S_v of *Chaoborus* recorded in our study suggesting that the contribution of echo energy from *Chaoborus* at 38 kHz is insignificant or can be removed by thresholding. The corresponding value at 200 kHz was –44 dB re m^{-1}.

A NASC for fish was established at 38 kHz from the mobile recordings, day and night, in the depth interval 6–12 m, corresponding to the lower gill net. The daytime NASC was more than six-fold compared with the night-time NASC (Table 1). The higher daytime NASC should therefore reflect a higher fish biomass in the 6–12 m depth layer than at night. The corresponding gill net catches reflected a different situation, with more fish caught at night than during the day.

Vertical distributions of *Chaoborus* from acoustic recordings and counts showed the same trend (Table 2). During the day, high values were found close to the bottom and low values in the open water column. At night, low values were found near the bottom, and high values were found in the open water column. The relationship between combined day and night acoustic data and actual counts was also good (r^2 = 0.89). There was a small increase in *Chaoborus* length with depth at night (Table 2).

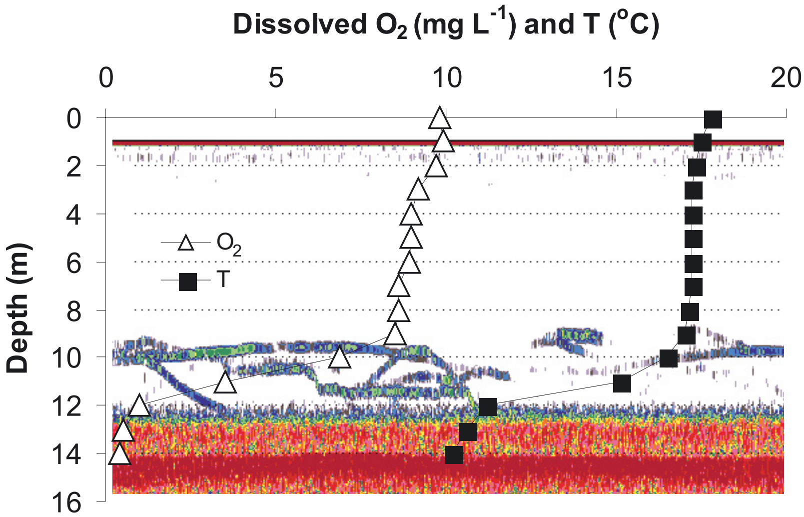

Fig. 2. Dissolved oxygen and temperature profiles in Lake Borrevann superimposed on the 200 kHz echogram from the recording site. Echogram color bar and S_v threshold are as in Fig. 1.

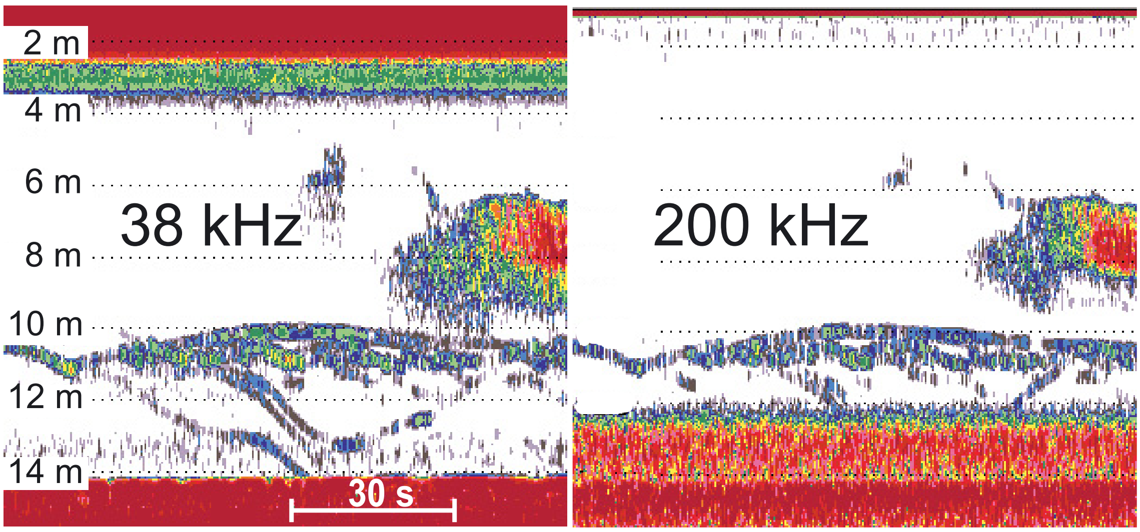

Fig. 3. Echograms from stationary recordings displaying fish tracks at 38 kHz diving into the *Chaoborus* layer displayed at 200 kHz. Color bar and S_v threshold are as in Fig. 1.

The mean *Chaoborus* night-time NASC (± SD) from the seven mobile transects based on the masking method for was 974 ± 99 m^2nmi^{-2}. The corresponding daytime NASC, based on direct measurements and not masking since *Chaoborus* was not mixed with fish, was 754 ± 110 m^2nmi^{-2}. Since the S_v of fish is different at 38 and 200 kHz, simply subtracting the fish S_v at 38 kHz from the 200 kHz recordings to obtain the *Chaoborus* S_v would be wrong.

The wide and the narrow beam echo sounders produced similar NASC values (Fig. 4), thus confirming that the new echo sounder performs similarly to standard systems used for acoustic assessment. The NASC was similar for different target densities and the total NASC for the whole water column deviated by less than 6% between the two echo sounder systems (1114 and 1051 m^2nmi^{-2}). Since similar NASC values were obtained for such a large difference in sampling volume (21 ×), the distribution of targets in the water column must have been reasonably even. No benefit could therefore be attributed to the wide beam under our conditions, but at lower target densities, increasing the sampling volume ought to improve the precision of an acoustic survey, particularly in shallow water.

4 Discussion

Analysis of fish in the presence of *Chaoborus* has been a long unsolved problem making it difficult to perform fish stock assessment (Eckmann 1998; Malinen et al. 2001; 2005). We have demonstrated that using a 38 kHz frequency removes echoes from *Chaoborus* to such an extent that an unbiased fish assessment can be obtained. In addition, removing fish echoes from the high frequency recordings by masking provides a method for assessment of *Chaoborus*. The daytime 200 kHz NASC from the mobile recordings obtained without

Table 2. Numbers (± SD) and mean length of *Chaoborus* at different sampling depths and the corresponding mean S_v (dB re m^{-1}). Total mean *Chaoborus* length was 8.3 mm.

	Depth (m)	Numbers ± SD	Mean length (mm)	S_v
Day	1	0		–80
	4	0		–81
	7	53 ± 17	9.2	–63
	13	427 ± 35	7.7	–48
Night	1	107 ± 24	7.5	–52
	4	413 ± 13	8.2	–53
	7	187 ± 17	7.7	–54
	13	93 ± 37	9.4	–75

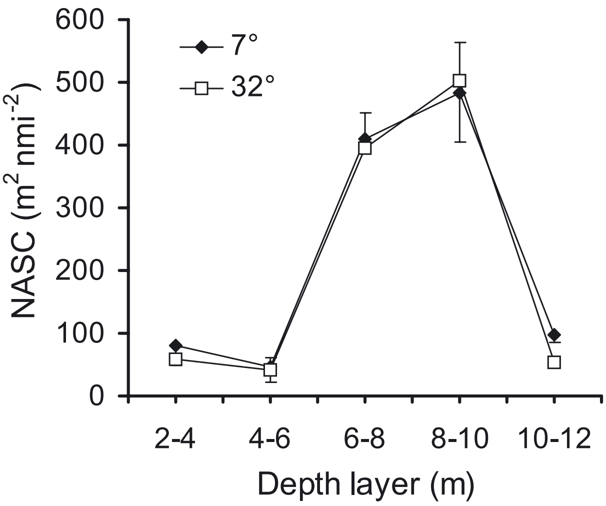

Fig. 4. Corresponding NASC (± SD) for the 32° single-beam and 7° split-beam echo sounder in 2 m high layers from the surface to the bottom (2–12 m) over the 300 m transect.

masking was only a little lower than the night-time NASC where masking was applied. This agreement supports the validity the masking method. A lower daytime value is reasonable since some of the *Chaoborus* is likely in the echosounder blind-zone (Ona and Mitson 1996) or buried into the sediments (Malueg and Hasler 1966; Voss and Mumm 1999). The masking method is capable of estimating *Chaoborus* abundance in the presence of fish without having to know ΔS_v for fish, and it allows mixture of fish and *Chaoborus* in the integration cell as opposed to established methods based primarily on ΔS_v (Kang 2002; Kloser et al. 2002; Korneliussen and Ona 2002; McKelvey and Wilson 2006). However, this approach is not valid if fish are schooling or occur in high densities while mixed with *Chaoborus*.

The echo sounder frequencies (38 and 200 kHz) were chosen on the basis of earlier results of Knudsen et al. (2006). The opposite frequency response of *Chaoborus* and fish established at these two frequencies is a rapid means of species separation and classification. This is in agreement with previous results on both zooplankton and swimbladder fish (Kang 2002; Pedersen et al. 2004; Kaartvedt et al. 2005; McKelvey and Wilson 2006; Jurvelius 2008; Rudstam et al. 2008b).

The night-time NASC of the 6–12 m layer was lower than during the day, most likely due to diel vertical migration of the fish (Fig. 1). This is in agreement with previous horizontal echo sounding results from the same lake, which detected large numbers of fish near surface at night, but not during the day (Knudsen and Sægrov 2002; Sonny et al. 2006). The gill-net CPUE was higher at night probably due to higher activity of fish. Activity as a factor in increasing gill net catches has already been well described (Hamley 1975; Rudstam et al. 1984; Linløkken and Haugen 2006). In addition, the gill-net is less visible in the dark, thus reducing fish avoidance and increasing catches. We collected data only along one transect and nothing is known about differences in the horizontal movements of the fish between day and night. Nor if there was a contribution of other fish species in the acoustic data than those caught in the nets. In any case, the higher fish catches at night, contrary to the acoustic recordings, should be related to higher fish activity and reduced net avoidance.

The observation of fish diving into the low-oxygen *Chaoborus* refuge was unexpected. Avoidance of hypoxic conditions by fish and the use of low-oxygen regions as refugees for invertebrates, including *Chaoborus*, are well established (La Row 1970; Threlkeld 1979; Dini and Carpenter 1991; Voss and Mumm 1999). However, Rahel and Nutzman (1994) found that mud minnows (*Umbra limi*) foraged on *Chaoborus* in oxygen depleted bottom waters. Little is known about such behavior in roach and bleak, but our observations indicate that at least one of these species, probably roach, forage in hypoxic environments. This will be followed up in a separate experiment.

A good relationship was found between actual counts of *Chaoborus* and echosounder recordings. Whether the increase in the length of *Chaoborus* with depth has any influence on these results is difficult to say, since the variation in length as a function of depth was small. Voss and Mumm (1999) reported that an increase in the size of *Chaoborus* with depth was accompanied by an increase in backscattering, but this involved much larger size differences than in our study. Knudsen et al. (2006) reported a good agreement between distribution maxima of *Chaoborus* in acoustic recordings and actual sampling and acoustics correlated well with counts down to 6 m water depth, but this broke down in deeper water without any obvious explanation. Others have concluded that backscattering from layers of zooplankton correlates well with actual samplings (Melnik et al. 1993; Trevorrow and Tanaka 1997), in agreement with our finding. It is reasonable to expect a good correlation between backscattering and actual counts of *Chaoborus*. First, the air-sac volume is compensated for buoyancy regulation (Teraguchi 1975), meaning that the TS of each animal is constant with depth. Secondly, since the pairs of air-sacs are localized at the ends of the animal, it will float horizontally and the TS measured with a vertically pointing transducer will not be influenced by animal tilt, as would be the case for *Mysis* (Gal et al. 1999; Rudstam et al. 2008a). Compared to fish, where both swimbladder volume and tilt-angle may vary widely, the S_v of *Chaoborus* should be a relatively precise index of density, provided that other scatterers can be removed from the estimate. Although both samplings were made at almost the same location, *Chaoborus* patchiness might introduce some variation between acoustic and actual samples (Pinel-Alloul 1995; Mehner et al. 2005). Patchiness is also confirmed in the echograms from mobile recordings and the sampling error in acoustic data likely increases towards the surface because decreasing sampling volume. Moreover, selectivity of the plankton sampler might produce a bias, and increasing the volume of the sampler could reduce this. However, routine assessments are likely to involve mobile surveys and possibly zooplankton trawling, which would solve problems of patchiness and sampling volume. Jurvelius et al. (2008) found a good correlation between NASC and *Chaoborus* densities in a combined mobile acoustic and zooplankton trawl survey.

The wide-beam transducer employed has not previously been used for scientific purposes and was therefore validated by comparison with a standard scientific split-beam echosounder. Both systems gave similar results confirming that the wide-beam echosounder can be used for scientific purposes. The advantages of the new echosounder are the small and portable transducer that has overlapping and similar beams, thus satisfying requirements for multifrequency acoustic setups (Korneliussen and Ona 2002; Korneliussen et al. 2004). It has 32° beam angle at both frequencies, which ensures a large sampling volume being an advantage in shallow water environments. The disadvantage is that the transducer is single-beam, so it is only valid for establishing abundance indexes (S_v or NASC) and not fish size distribution (target strength, TS) unless a statistical approach is employed in order to compensate for beam effects (Craig and Forbes 1969).

5 Conclusion

A low echosounder frequency (e.g. 38 kHz) is recommended for estimating fish abundance in the presence of *Chaobourus*. *Chaoborus* can be assessed from the 200 kHz recording by first removing fish echoes using a masking technique based on the 38 kHz recording. The vertical distribution of *Chaoborus* agreed well between acoustic recordings and sampling with a Schindler-Patalas trap. The acoustic index of fish density decreased at night. The gill-net CPUE, however, was higher at night, probably due to the higher activity of fish and higher gill-net catchability. A combination of 38 and 200 kHz echo sounder frequencies can be used as a rapid method for selective monitoring and real-time studies of species interactions. Oxygen depleted water has been regarded as safe refuge for *Chaoborus*, but our results indicate that predation may take place also in the low-oxygen layer by diving fish.

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