

Allocation of echo integrator output to small larval insect (*Chaoborus* sp.) and medium-sized (juvenile fish) targets

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Abstract

In acoustic sampling for fish, thresholding is normally applied to eliminate the unwanted contribution of noise to the integrator output. Since thresholding discriminates against small targets, this technique cannot be used for the quantitative study of these small targets in the presence of larger ones. When the integrator output (area backscattering coefficient, s_a) due to one size class of targets is plotted vs. decreasing s_v -threshold (volume backscattering strength) in 1 dB steps, the resulting curve can be described by an asymptotic Bertalanffy growth function. If the slope of the resulting curve decreases at some intermediate threshold level and then increases again before the final plateau is reached, the total integrator output can be allocated to two groups of targets according to the linearity principle in acoustics. The maximum s_a value for the larger targets (s_a -large) is estimated by fitting a Bertalanffy function to the lower part of the curve. The echo integral that corresponds to the smaller targets is then found by subtracting s_a -large from the s_a value that is reached at the lower threshold level. In a shallow (max. depth 8.5 m) mesotrophic lake of 24 ha surface area in northeastern Germany, this new technique was tested to estimate the abundance of insect (*Chaoborus*) larvae in spring. Hydroacoustic data were sampled during night, when juvenile roach occurred together with midge larvae in the pelagic zone. *Chaoborus* abundance was estimated by replicate vertical tows of a 1 m² plankton net of 0.5 mm mesh size. The s_a values that were allocated to *Chaoborus* larvae were significantly correlated to mean *Chaoborus* abundance. This relationship was then used to map the lakewide distribution of *Chaoborus* larvae on two dates in spring. © 1998 Elsevier Science B.V.

Keywords: Acoustic size discrimination; *Chaoborus* larvae; Juvenile roach; Integrator output; Use of Bertalanffy function

1. Introduction

The precision of abundance estimates of differently sized acoustic targets depends to a great extent on the reliable allocation of integrator output to the various size classes of targets. If an equal proportion of single targets is resolved for each size class,

integrator values are usually allocated according to the frequency distribution of target strengths. In many cases, however, single target resolution decreases with decreasing target strength, and a different method must be adopted.

The simplest and widely used alternative is to consider the echoes from small targets as noise and to eliminate their contribution to the total echo integral by thresholding (MacLennan and Simmonds, 1992). There seems to be no generally accepted, objective way to choose the appropriate threshold

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level, so this is usually done rather subjectively according to the operator's experience.

Since thresholding discriminates against small targets, this technique cannot be used to estimate the abundance of these small targets. To do this, their contribution to the overall echo integral must be quantified. This can be achieved under different scenarios.

First, the small targets that are of interest can only be insonified in the presence of larger targets, while these larger targets can also be insonified in the absence of the smaller ones. The echo integral due to the larger targets may be determined during a certain time of the day, and then subtracted from the integral due to the large plus small targets that is measured during a different time of the day. Second, both small and large targets cannot be insonified alone, because they always occur together in the only habitat that is accessible to hydroacoustics.

The second scenario is often found in shallow, meso- to eutrophic lakes of the northeastern lowlands in Germany. In these lakes, *Chaoborus* larvae are abundant. They escape from fish predation by living in the anoxic hypolimnion, mostly even hidden in the sediment, during the day. At dusk, they ascend into the epilimnion where they feed on zooplankton, and they descend again at dawn. In parallel, juvenile fish display a diel horizontal migration, invading the pelagic zone at dusk and returning to the littoral at dawn. In this situation, acoustic abundance estimates of either juvenile fish or *Chaoborus* larvae require that integrator values are allocated according to clearly defined, objective criteria.

This paper proposes a method for distributing integrator values between two clearly distinct size classes of targets. To illustrate potential applications of this method, the horizontal distribution of *Chaoborus* larvae in a shallow mesotrophic lake was analysed and is presented as contour maps.

2. Materials and methods

Kleiner Doellnsee is a small (24 ha surface area), shallow (max. depth 8.5 m) lake of glacial origin situated in the northeastern lowlands in Germany about 50 km north of Berlin. The lake is mesotrophic with average summer concentrations of 20 $\mu\text{g}/\text{l}$

total P and 10 $\mu\text{g}/\text{l}$ chlorophyll-a (Eckmann, 1995). During winter and summer stagnation, the hypolimnion may become completely anoxic, and hydrogen sulphide is always present in the extremely soft bottom sediment. The lake's fish fauna of 10 species (Eckmann, 1995) is largely dominated by roach (*Rutilus rutilus*) and perch (*Perca fluviatilis*). During the growing season, the pelagic zone is almost completely clear of fish during the day, while at dusk it is invaded by young age classes of roach and perch. In parallel, *Chaoborus* sp. larvae ascend from the sediment into the oxygen-rich pelagic zone. At dawn, both fish and *Chaoborus* larvae are clear of the epilimnion (Eisenbeiss, 1995).

Phantom midge larvae were sampled with a four-walled pyramidal plankton net of 1 m² opening area and 500 μm mesh size. Sampling took place during the night, when the echogram showed that the larvae had completed their upward migration. Only the upper 6 m of water were sampled, because during summer stagnation, the larvae always ascended to less than 6 m depth. Three replicate tows were made at each of three sampling sites. Additionally, three replicate tows from 2 m depth to the surface were made at each site. This procedure was adopted to estimate by subtraction the average abundance of *Chaoborus* larvae between 2 and 6 m depth, because hydroacoustic data could not be sampled in the uppermost 2 m of water. The three sites (west, centre, east) that were marked with buoys were sampled on six occasions during summer 1995. At each sampling site, the six vertical tows were made while the boat was drifting within an area of 10–20 m diameter. If the boat did not drift passively, it was rowed to different spots between successive samplings. This avoided sampling the same body of water between successive hauls. If the boat drifted out of the sampling area, it was rowed back. After each vertical tow, the net was thoroughly washed using a battery-powered bilge pump, and the larvae were preserved in 5% formalin solution. Samples were sorted into large (4th instars, the last larval stage prior to pupation) and small specimens if necessary, and the whole sample was counted in each case.

Acoustic data were sampled with a SIMRAD EY500 scientific sounder with 70 kHz split-beam transducer. The system was calibrated with a stan-

standard copper sphere using software that is supplied by the manufacturer. Pulse duration was set to 0.2 ms, bandwidth to 7 kHz and ping rate to 10/s.

The transducer was mounted in a fin that was suspended from the side of the boat at about 0.5 m depth. Boat speed was around 1 m/s. To observe fish and *Chaoborus* migrations at dusk, acoustic data were sampled along a standard transect of about 400 m length that runs across the deepest part of the lake. After dusk migrations of fish and *Chaoborus* larvae were completed, acoustic data were sampled. The boat was steered at about 0.5 m/s in a circle of about 10 m radius around each of the three buoys until at least 3000 pings had been collected. Immediately afterwards, *Chaoborus* samples were taken. To map the horizontal distribution of *Chaoborus* larvae, acoustic data were sampled on two parallel transects across the lake and on one transect along the longest axis of the lake.

During postprocessing with EP500 software, time-varied gain was set to $20 \log R$. The integration threshold was decreased in 1-dB steps from -30 down to -60 dB and then in 2- or 5-dB steps down to -75 dB. Sample units were subdivided so that each subunit contained approximately 1000 pings. For each subunit, the area backscattering coefficient s_a [m^2/ha] was plotted versus integrator threshold.

3. Results

Chaoborus abundance varied both between sampling dates and between sites during summer 1995 (Table 1). On four out of six occasions, the highest abundance was observed at the central site, and on five occasions the lowest abundance occurred at the western site. Average abundance per unit surface area (from 2 to 6 m depth) ranged from 45 to 1056

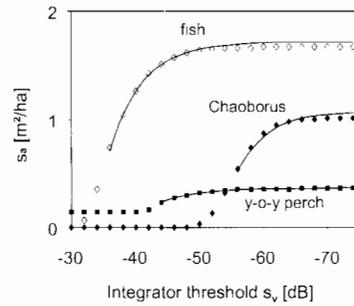


Fig. 1. Integrator output (area backscattering coefficient in m^2/ha) as a function of integrator threshold (volume backscattering strength in dB) for three size classes of targets. Data were sampled when each of the three classes of targets could be insonified separately.

ind./ m^2 . Standard errors ranged from 4 to 60% of the mean and were negatively correlated with average abundance ($p < 0.01$). During the first two samplings in May, only large (10.6 ± 0.9 mm length) *Chaoborus* larvae were present, while a new generation of larvae appeared in June. These specimens contributed between 2 and 17% to the total number of larvae in June. In the September samples, large and small larvae could still be differentiated easily, while in the October sample, all larvae were of similar size but significantly smaller (8.7 ± 1.3 mm) than in May ($p < 0.01$).

The evening ascent of *Chaoborus* larvae from the lake bottom occurred approximately at the same time as when fish started to move from the littoral into the pelagic zone. These fish were mainly roach of age classes 1 to 3 and perch of age class 1 (Eisenbeiss, 1995). Fish and *Chaoborus* migrations lasted for about 30 to 60 min, and this was the only time when both groups of targets could be separately analysed acoustically. During darkness, both *Chaoborus* and fish always inhabited the same body of water until they returned to their daytime habitats at dawn.

Table 1

Mean abundance (individuals/ m^2) \pm 1 SD of *Chaoborus* spp. larvae between 2 and 6 m depth at three sampling sites in Kleiner Doellnsee during summer 1995

	10 May	17 May	15 June	19 June	4 Sept.	9 Oct.
West	171 \pm 27	149 \pm 34	45 \pm 27	149 \pm 62	934 \pm 71	244 \pm 59
Centre	224 \pm 48	665 \pm 191	525 \pm 40	814 \pm 43	1056 \pm 59	488 \pm 55
East	465 \pm 18	153 \pm 21	167 \pm 24	448 \pm 81	170 \pm 39	739 \pm 56

Values are based on the difference between three replicate tows from 6 m depth to the surface and from 2 m depth to the surface.

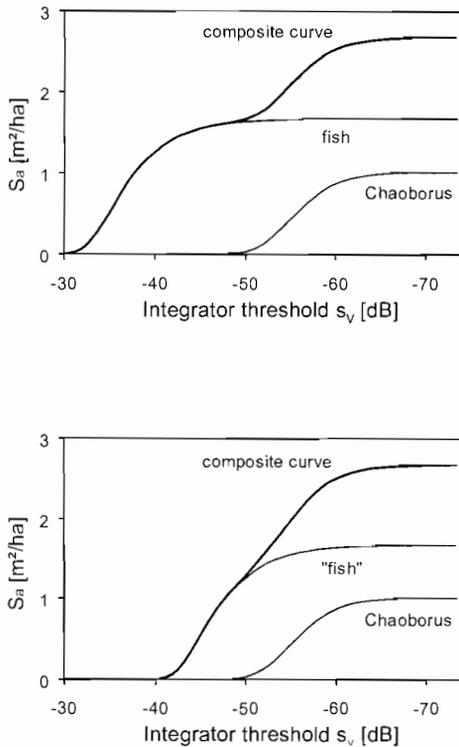


Fig. 2. Integrator–threshold curves for large *Chaoborus* larvae (original s_a values multiplied by 5) and fish. The composite curve is the linear addition of the s_a values. In the lower panel, the integrator–threshold curve for fish is shifted to a lower threshold by 10 dB.

Typical integrator–threshold values for large *Chaoborus* larvae, young-of-the-year perch and for juvenile fish are shown in Fig. 1. These curves can be described by Bertalanffy functions, which are otherwise normally used to describe the asymptotic growth of fish. For the asymptotic upper part of the curves, the deviation between measured and calculated values is of the order 1 to 5%.

When *Chaoborus* larvae and juvenile fish were insonified simultaneously, the integrator–threshold curves were characterised by decreasing slopes at intermediate threshold levels, until the final plateau was reached. These curves are interpreted as the result of a simple addition of the integrator outputs due to juvenile fish and due to *Chaoborus* larvae. This situation is shown in Fig. 2 (upper panel). In this particular case, the integrator output due to fish has almost reached its maximum value when the

integrator output due to *Chaoborus* larvae just starts to build up at about -48 dB threshold level. When a Bertalanffy function is fitted to the composite curve for x -values from -36 to -48 dB, the asymptotic s_a value due to fish is estimated at 1.71, which is 102% of the true maximum s_a value due to fish.

If the integrator–threshold curve due to fish is shifted to lower threshold levels, the intermediate plateau of the composite curve becomes less pronounced (Fig. 2, lower panel). In this situation, only a smaller number of data points may be used to fit a Bertalanffy function to the lower, left-handed part of the composite curve. The range of data points to be included in the calculation was defined by that part of the composite curve for which the slope is continuously decreasing. In this way, the lower part of the curve that may have increasing or constant slope is discarded, as well as the central part of the curve, where the slope starts to increase again. In the example given in Fig. 2 (lower panel), this means that only 3 data points are available for fitting a Bertalanffy function. Hence, the s_a value due to fish could not be estimated reliably. This situation was observed during summer and autumn, when the integrator–threshold curves did not show an intermedi-

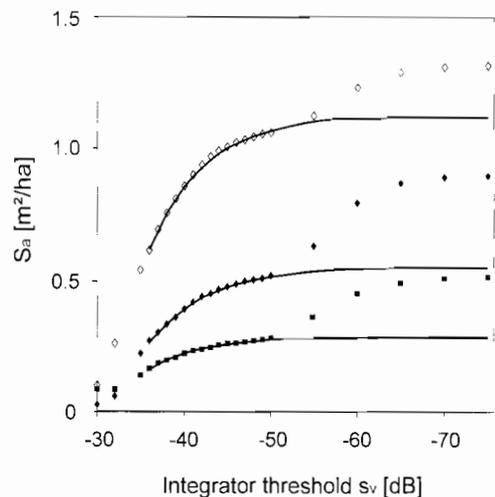


Fig. 3. Integrator–threshold curves for three subtransects on 11 May 1995 in Kleiner Doellensee. Bertalanffy functions were fitted to the left-hand parts of the curves where slopes are continuously decreasing. The asymptotic function value is an estimate of the integrator output due to the larger targets.

ate depression, but increased steadily to the final plateau. During this time, in addition to juvenile fish and *Chaoborus* larvae, the open water was inhabited by young-of-the-year perch and possibly by young-of-the-year roach (Radke, pers. commun.). Adding integrator–threshold curves that are characteristic for juvenile fish, young-of-the-year fish and *Chaoborus* larvae will eventually suppress the intermediate plateau.

During May, however, when the pelagic zone was mainly inhabited by large *Chaoborus* larvae and juvenile fish, it was possible to estimate s_a values due to fish (Fig. 3). Since each of the six circular acoustic transects sampled at the buoy stations was analysed in 3 to 7 subunits of approximately 1000 pings, the standard deviation of the fish s_a values could be calculated for each transect. These ranged from 16 to 63% of the mean. For each subtransect, the difference between a fish s_a value and the final maximal s_a value was allocated to the *Chaoborus* s_a value. The standard deviations of the *Chaoborus* s_a values for each transect ranged from 4 to 13% of the mean. Finally, a relationship between mean

Chaoborus s_a values per transect and the mean *Chaoborus* abundance from net samples was established as $y = -255 + 188629x$ ($n = 6$, $r^2 = 0.91$), where y is *Chaoborus* abundance in individuals/m² and x is *Chaoborus* s_a values in m²/ha.

Based upon this relationship, the lakewide horizontal distribution of *Chaoborus* larvae was mapped on May 11 and May 18, 1995. The near-shore region down to 3 m deep was excluded from this analysis because of the presence of macrophytes and of large groups of fish in the shallow areas. For each subtransect that comprised about 1000 pings, a *Chaoborus* s_a value was estimated, and the corresponding abundance level was calculated. Finally, isopleths of different abundance levels were drawn by hand (Fig. 4).

The abundance of *Chaoborus* was not homogeneously distributed throughout the lake on these two occasions. The horizontal distribution patterns were also dissimilar. The average *Chaoborus* densities, calculated from unweighted subtransect means, decreased from 300 to 140 ind./m² within one week. During this time, dense clouds of emerging adults could be seen above the lake surface at night.

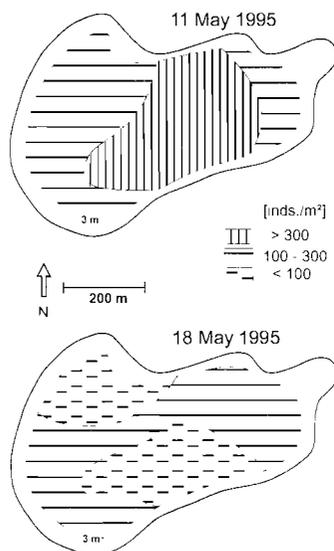


Fig. 4. Isopleths of *Chaoborus* abundance from 2 to 6 m depth in the pelagic zone (where the depth is > 3 m deep) of Kleiner Doellinsee on two dates in May 1995. Data were sampled on two transects across the lake and one transect along its longest axis, and they were analysed in subtransects of about 1000 pings each (equivalent to about 100 m length). Isolines were drawn by hand.

4. Discussion

Based upon the linearity principle in acoustics (MacLennan and Simmonds, 1992), the integrator output of a scientific echosounder can be conceived as the linear addition of the echo energy from all targets that are insonified simultaneously. Therefore, it is theoretically possible to redistribute the integrator output to the different size classes of targets such as the frequency distribution of target strengths. The advantage of this is that it allows the allocation of integrator outputs to small and to distinctly large targets, even if single-target resolution is nil.

Chaoborus larvae could only be insonified separately during a short time interval when they emerged from the sediment at dusk. Even in this situation, single-target resolution was low and only a few targets were observed in the size range of -72 to -75 dB. This may be caused by the high density of larvae (several hundred larvae per one or two m³), and by their backscattering characteristics. *Chaoborus* larvae possess two pairs of kidney-shaped tracheal bladders that are 6–8 mm apart. Phase

stability in the backscattered sound wave may, therefore, be weak, and the echo eventually rejected according to the single-target criteria implemented in the EY500 sounder.

Irrespective of single target resolution, the proposed method permits the estimation of abundance of small targets instead of considering them as noise. Their identity must, of course, be verified by traditional sampling techniques. Then a relationship between integrator output due to small targets and their abundance can be established. The main disadvantage of this method is that it is only applicable to targets that are both simultaneously insonified and of clearly distinct sizes. If the integrator–threshold curves overlap too much, the s_a value due to the larger targets cannot be estimated. This was the case in Kleiner Doellensee from early June until October. Nevertheless, the use of the integrator output as a function of integration threshold is a valuable tool that will focus the operator's attention on the problem of selecting an appropriate threshold level. In the situation illustrated in Fig. 2 (lower panel), small changes in threshold level can result in considerable changes of integrator output.

This method of data analysis may be equally useful for abundance estimates of large targets in the presence of small targets. Normally, an integrator threshold level is selected subjectively by progressively increasing the threshold until almost all noise disappears from the echogram. The error that is now associated with the corresponding abundance estimate is largely unknown. It is less subjective to choose a threshold level by inspecting integrator–threshold curves, and the best alternative is to estimate s_a values from those curves by fitting Bertalanffy functions. The estimated s_a value for the larger targets is distributed among these targets according to the frequency distribution of target strengths.

Phantom midge larvae may play an important role in the pelagic food web of eutrophic lakes, where their impact on the zooplankton community via top-down control by an invertebrate zooplanktivore is of special interest within the framework of biomanipulation (Benndorf et al., 1988; Benndorf, 1990; Elser et al., 1987; Yan et al., 1991). Therefore, precise knowledge of *Chaoborus* abundance and distribution patterns is often required. Without mapping the

lakewide distribution of the larvae, their overall decrease by about 50% between May 11–18 might have been undetected. The analysis of distribution patterns also helps to assess how representative is one particular sampling station for the whole system.

Even when *Chaoborus* abundance cannot be mapped throughout the growing season by the method proposed here, it might still be useful to apply it on certain dates. The horizontal heterogeneity of *Chaoborus* distribution will become evident and, assuming it to be representative for the whole period, the sampling protocol adjusted accordingly.

The *Chaoborus* s_a values were very similar between the subtransects sampled at the buoy stations, with coefficients of variation of only 4–13% when using an averaging interval of about 50 m. In contrast, the fish s_a values had much wider coefficients of variation of 16–63% for the same subtransects. This suggests that the fish distribution at the same spatial scale is much more patchy than that of *Chaoborus*. However, on a finer spatial scale, the *Chaoborus* can be seen to be patchily distributed. This is clearly seen in the results from the net samples (Table 1) where coefficients of variation ranged from 4 to 60%. On a broader scale of ~100 m along the transects across the lake, *Chaoborus* s_a values were also less variable than those for fish. In seven subtransects sampled along the longest axis of the lake, fish s_a values differed by a factor of 4.6, while those for *Chaoborus* differed by only a factor of 2.1. These data suggest that there is a very fine-scaled patchiness in the *Chaoborus* distribution that makes it difficult to sample the larvae representatively by standard techniques in a reasonable amount of time. Averaging acoustic data along short, circular transects is proposed as a tool to overcome this difficulty.

5. Conclusions

Plots of the integrator output (area backscattering coefficient in m^2/ha) from a scientific echosounder vs. integrator threshold (volume backscattering strength in dB) can be described by Bertalanffy functions (Fig. 1).

If the integrator output is based on the echoes from two clearly distinct size classes of targets, these

plots are characterised by decreasing slopes at intermediate threshold levels (Fig. 2). The asymptote integrator output due to the larger targets may then be found by fitting a Bertalanffy function, and the contribution of the smaller size class can be determined by subtraction (Fig. 3).

By calibration of the area backscattering coefficients against conventional abundance measurements, the areal density of the smaller targets can be evaluated acoustically, even when in the presence of larger targets. It is then possible to map the horizontal distribution of small targets like *Chaoborus* larvae (Fig. 4).

Fitting Bertalanffy functions to integrator-threshold curves can also improve abundance estimates for the larger targets as compared to conventional thresholding.

This method cannot be used when the two target groups are insufficiently different in size, or if more than two size classes are insonified simultaneously.

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