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# Hydroacoustic assessment of pelagic stages of freshwater insects

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**Abstract** − Two independent surveys showed that aquatic insects can generate echoes comparable with the echoes of small fish. In the open water of two fishless mountain acidic waters of the Czech Republic, a very distinct population of well-defined single targets resembling fish (target strength –66 to –50 dB at 120 kHz) was discovered. These targets were found in the depth range of 5–7 m during the day (June–July 1997). At night, most targets were recorded by horizontal beaming (depth < 3 m). Towing of ichthyoplankton nets in these horizons revealed the presence of ‘water bugs’, Corixidae (Hemiptera), mostly genus *Glaenocorisa*. Target strengths of corixids was also verified by direct observations in an experimental tank, where it was possible to track side, dorsal and ventral aspects. In three Dutch reservoirs, Petrusplaat, Honderd-en-Dertig and De Gijster (area 100–300 ha, maximum depth 15–28 m, with fish presence) the targets of ascending dipteran pupae (Chironomidae, *Procladius signatus*) with target strength of –74 to –65 dB were observed by vertical beaming. The presence of pupae was verified by horizontally towed ichthyoplankton nets and by vertical plankton hauls inside the echosounder beam. The contribution of aquatic insects to the fish biomass was small but they can interfere in juvenile fish assessment. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

**echosounding / Corixidae / Chironomidae / sonar / target strength**

**Résumé − Évaluation acoustique de stades pélagiques d’insectes aquatiques.** Deux campagnes acoustiques distinctes ont montré que les insectes aquatiques peuvent générer des échos comparables à ceux de petits poissons. Dans deux lacs acides de montagne de la République Tchèque, où les poissons sont absents, une série d’indices de réflexion individuels, bien définis, a été observée, ressemblant à ceux des poissons (indices de réflexion à 120 kHz, de –66 à –50 dB). Ces ‘cibles’ ont été trouvées entre 5 et 7 m durant le jour (juin–juillet 1997). Durant la nuit, le nombre de cibles est plus élevé, enregistrées au moyen d’un échosondeur en émission horizontale (profondeur < 3 m). Des traits de filets à icthyoplancton effectués à cette profondeur ont révélé la présence d’Hémiptères Corixidés (punaises aquatiques), du genre *Glaenocorisa* pour la plupart. Les indices de réflexion des Corixidés ont aussi été vérifiés par observation directe en bassin expérimental, où il a été possible de mesurer les indices de réflexion des cibles en vues latérales, dorsales et ventrales. Dans trois réservoirs hollandais, Petrusplaat, Honderd-en-Dertig et De Gijster (100 à 300 ha, 15 à 28 m de profondeur, avec présence de poissons), les indices de réflexion des cibles telles les pupes de diptères chironomides (*Procladius signatus*) remontant en surface, de –74 et –65 dB, ont été observés par échosondeur émettant verticalement. La présence de pupes a été vérifiée par des traits de filets horizontaux à icthyoplancton et par des traits à plancton verticaux dans le faisceau acoustique. La part des insectes aquatiques par rapport à la biomasse des poissons était faible mais elle peut interférer lors d’évaluation de poissons juvéniles. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

**echosondeur / Corixidés / Chironomidés / sonar / indice de réflexion**

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**Table I.** Selected features of the localities studied.

| Locality | Area | Maximal depth (m) | Altitude (m) | pH | Pelagic insects | Geographical coordinates |
|---|---|---|---|---|---|---|
| Josefuv Dul Reservoir | 130 ha | 35 | 850 | 4.4 | *Glaenocorisa propinqua, Callicorixa praecusta* | 15°10'E; 50°40'N |
| Prášilské Lake | 4 ha | 15 | 1 080 | 4.9 | *Glaenocorisa propinqua* | 13°25'E; 49°8'N |
| Experimental tank | 5 $m^2$ | 2.3 | 400 | 7 | *Callicorixa praecusta, Paracorixa concinna* | 14°25'E; 48°55'N |
| Honderd-en-Dertig | 219 ha | 27 | 6 | > 7 | *Procladius signatus* | 4°46'E; 51°44'N |
| De Gijster Reservoir | 320 ha | 28 | 6 | > 7 | *Procladius signatus* | 4°49'E; 51°42'N |

## 1. INTRODUCTION

The application of fisheries sonar to shallow waters has revealed a number of interesting phenomena. One of them is the detection of invertebrates. Large marine zooplankton has been frequently studied by Greene et al. 1989, Holliday et al. 1989, Stanton et al., 1996 and others. Another group of freshwater animals notoriously known from echosounding records is dipteran *Chaoborus* larvae (Eckmann, 1998; Jones and Xie, 1994; Northcote, 1964 and Wagner-Dobler, 1988). These have two pairs of hydrostatic air sacks responsible for strong echoes. Freshwater amphipods can also generate well-defined acoustic targets as shown by Trevorrow and Tanaka (1997). Lyle and East, (1989) showed that it is possible to observe 'water bugs' (Corixidae) by a very simple echosounder (Lowrance chart recorder) down to the depth of 10 m. Our present paper summarises some experiments with recording aquatic insects in those cases when intercalibration with some direct capture gear was possible. Well-defined sub-fish targets were encountered during many other fisheries surveys of freshwater lakes and reservoirs and this is why the research on non-fisheries applications of fisheries echosounders can be considered as a promising source of information about aquatic systems.

## 2. MATERIAL AND METHODS

### 2.1. Localities

Two Czech localities searched for corixids are mountain waters with low nutrient content and a very high level of acidification (*table I*). These waters have been virtually fishless from the late 1970's until the present day. Laboratory observations were carried out in a 2.2 by 2 m tank located at the Hydrobiological Institute AS CR with maximum sonar range of 1.9–2 m. The Dutch reservoirs are highly eutrophic artificial bodies made by digging of original polders in the Meuse estuary. The reservoirs are artificially destratified by air jetting (Van Breemen and Ketelaars, 1995). The fish stock of these reservoirs is dominated by perciform fish (Kubecka et al., 1998).

### 2.2. Field surveys

All reservoirs and the lake were surveyed using standard fisheries methods consisting of a combination of horizontal and vertical beaming (Kubecka and Wittingerova, 1998). About 50 zigzag transects were equidistantly spaced around the whole area of the reservoirs. The sonar system used was Simrad EY500 splitbeam echosounder operating at 120 kHz. Pulse duration was 0.1 ms; the system was calibrated with a tungsten-carbide standard target (MacLennan and Simmonds, 1992). The transducer has an elliptical beam pattern with nominal beam angles $9.1 \times 4.3°$. The signal-to-noise ratio was 10 dB or better for corixids, and 6 dB or better for chironomid pupae. The data were recorded on the hard disk of a 486-DX PC and processed using the Simrad EP500 post-processing software. Target quantity was estimated in a classical way, using the average backscattering cross section from the target strength (*TS*) estimates for all targets above the threshold. The noise threshold was set firstly for echo sizing (time-varied gain, TVG of 40 log *R*) and than the threshold of the same restrictivity (Kubecka, 1996) was applied to echo-integration (TVG 20 log *R*). Average backscattering cross section from 40 log *R* data was used to scale echo-integrated volume scattering strength. Most animals were recorded as single non-overlapping echoes (scattering strength of single targets was usually 70% or more of the total echo-integrated value).

The abundance of detected insect larvae was estimated independently by using ichthyoplankton nets in two ways:

– A 2-m diameter conical tow net (Wanzenbock et al., 1997) was towed horizontally at controlled depths, 100 m behind the boat. The sampling volume was usually 2 000–3 000 $m^3$. The density of insects captured was compared with the density of targets in the same horizontal strata.

– A 0.6-m diameter plankton net (mesh size 0.78 mm) was used in a vertical mode in Honderd-en-Dertig. The net was lowered below the scatterers from a slowly drifting boat so that the net was within the vertically oriented sonar beam. It is interesting that the nylon rope of the net did not generate any noticeable echo. Then we waited for a patch of insect targets to appear and pulled the net towards the surface sweeping the whole acoustic range between the original net position and the transducer.

### 2.3. Experimental design

Several hundred corixids were released into an experimental tank. They were allowed to acclimatise for two days. Acoustic measurements were carried out by two transducers mounted in three ways: on the surface (conventional down looking observation recording the dorsal aspect), on the bottom (up-looking view) and on the side of the tank (side looking view). Two sonar systems were used:

– 1) Simrad EY500 splitbeam system with 7.1° circular transducer operating in the same way as in the mobile surveys.

– 2) Biosonics Model 101 dual-beam system, frequency 420 kHz, nominal beam widths of 6 and 15°, pulse duration 0.3 ms, pulse repetition rate 10 $s^{-1}$.

Both systems were calibrated using appropriate tungsten carbide standard targets (MacLennan and Simmonds, 1992). The nearfield of both transducers was about 0.9 m (no measurements were done in the nearfield). The records were analysed using Simrad EP 500 (Version 5.2) and Biosonics Echogram (Version 3.1) post-processing software. *TS* measurements were performed for the animal aspects with no range change during the beam passage (i.e. the true dorsal aspect during the down looking observations etc.). All insect tracks increasing or decreasing the range from the transducer in time were excluded from the analysis (such animals are likely to be tilted with respect to the transducer). For each animal with zero track slope, all hits inside the 2° band around the axis were used for the calculation of the average *TS*.

## 3. RESULTS

### 3.1. Detection of water bugs (Corixidae)

*Figure 1a* gives the target strength frequency distribution of targets recorded during two field surveys and under experimental conditions. All localities were without fish and other animals larger than 1 mm, so we have all reasons to believe that all echoes originate from corixids. Peaks of the *TS* frequency distribution were in the range of –57 to –54 dB. *TS* frequency distribution of the Josefuv Dul Reservoir was bimodal, the other two localities showing a unimodal distribution. This is in agreement with the direct measurements of the length of corixids (*figure 1b*). While the insonified populations in Prasilske Lake and experimental tank were mostly adult individuals or older (4–5th) nymph instars, large numbers of early nymphs were found in the net catch in Josefuv Dul Reservoir. The analogy with the known experimental population of corixids supports the notion that the larger *TS* peak corresponds to the adults and the smaller *TS* peak (with maximum of –63.5 dB) is probably caused by

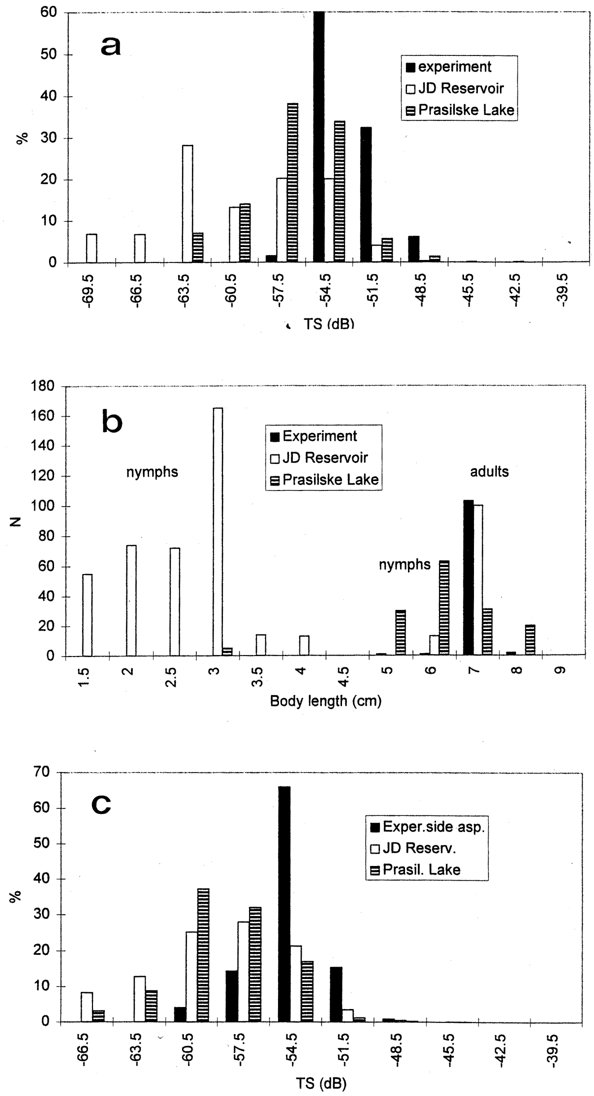


**Figure 1.** Size distribution of water bugs (corixids) in various localities: (a) target strength frequency distribution of water bugs recorded from their dorsal aspect, (b) body length frequency distribution, (c) target strength frequency distribution of water bugs recorded from their lateral aspects (in the experimental tank only side aspect).

nymphs, whose length is significantly lower. Unfortunately we were not able to obtain sufficient number of corixid nymphs to carry out experimental observations. Similarly to fish echoes, the side aspect appears to be the strongest aspect of the horizontal plane (*figure 1c*). While the observation of tracked side aspect from the experimental tank resembles the normal distribution with small variation, the *TS* frequency distribution from the field mobile surveys are much flatter due to weaker non-side aspect records.

*Figure 2* gives the *TS* frequency distribution of corixids recorded from various aspects in the experimental tank. For the frequency 120 kHz with the

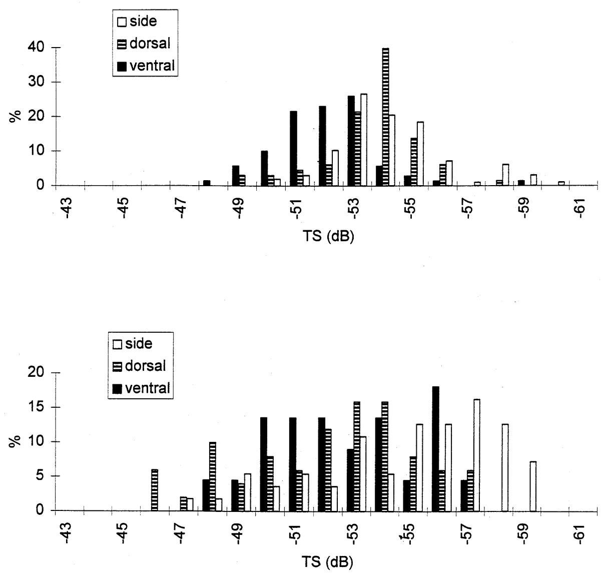


**Figure 2.** Target strength, *TS* frequency distribution of water bugs (corixids) recorded from various body aspects: (a) with frequency 120 kHz, (b) with 420 kHz.

**Table II.** Absolute corixid *TS* values from the experimental tank and significance of differences between aspects and frequencies (Student's *t*-test).

| Aspect | Mean *TS* (dB) | *SD* | Significance of differences | | |
|---|---|---|---|---|---|
| | | | Dorsal | Side | Ventral |
| 420 kHz | | | | | |
| Dorsal | –52.50 | 3.0 | NS | 0.001 | – |
| Side | –55.08 | 3.4 | 0.001 | NS | – |
| Ventral | –53.21 | 2.5 | NS | 0.001 | – |
| 120 kHz | | | | | |
| Dorsal | –54.06 | 1.7 | NS | NS | – |
| Side | –54.59 | 2.0 | NS | NS | – |
| Ventral | –52.41 | 1.7 | 0.001 | 0.001 | – |
| 420 vs. 120 kHz | | | | | |
| | | | 0.01 | NS | NS |

splitbeam system the *TS* frequency distributions resembles a normal distribution. The distribution of the 420 kHz data is more spread. This can be caused by generally worse estimate of *TS* by dual-beam system, by the frequency itself or by poorer performance of 15°-wide beam in a confined space. *TS* frequency interval was similar for the two frequencies. Coefficients of variation of *TS* of all individually tracked corixids were very reasonable (4–7%). At 420 kHz, the dorsal and ventral aspects were not significantly different when tested by the Student's *t*-test (*table II*), while the side aspect appears to be significantly weaker than vertical aspects. At 120 kHz, the ventral aspect appears the strongest which is in agreement with the fact that most of the entrained air is kept on the ventral side of the animal (Parsons, 1976). Dorsal and side aspects were significantly weaker. When the two frequencies are compared, only dorsal *TS* appears significantly stronger with 420 kHz (otherwise, corixids resemble geometrical scatterers with frequency independent TS).

## 3.2. Detection of water midges (Chironomidae)

Small targets with *TS* of –77 to –65 dB (*figure 3*) appeared frequently in the open water of the Biesbosch reservoirs (the Netherlands). The pattern of their occurrence was very characteristic. They were found in two independent surveys during August nights of 1995 and 1998 in the upper 10-m layer of the open water. The targets were distributed in apparent patches 10–20 m across, which occur randomly in the open water. Other parts of the open water were nearly empty and rather few fish were found in the depth range 3–10 m inhabited by small targets. There seems to be relatively small overlap between fish (most of fish are > –60 dB in highly productive reservoirs) and small targets. We were not able to carry out experimental observations of midge pupae, but the nature of small targets was revealed indirectly on the basis of comparison with the ichthyoplankton nets. They were identified as chironomid pupae (*Procladius signatus*). The length of the pupae was very uniform ranging from 4.9 to 6.0 mm (average 5.4 mm, SD 0.28 mm).

## 3.3. Quantity of pelagic insects

*Figure 4* compares the volume densities of pelagic insects estimated by acoustic and ichthyoplankton sampling in Czech acidic waters (corixids) and Dutch reservoirs (pupae, chironomids). Logarithmic scale is used because of high differences of pupae density in-

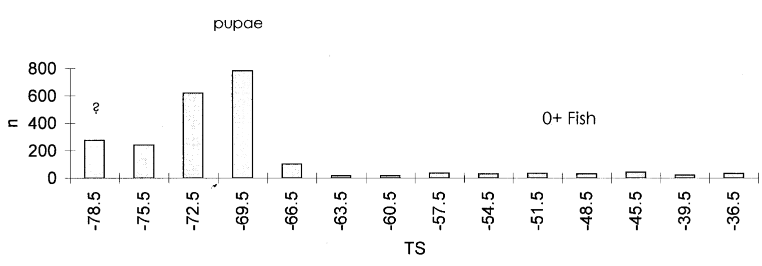


**Figure 3.** Target strength frequency distribution of chironomid pupae recorded from their dorsal aspect (Dutch reservoirs).

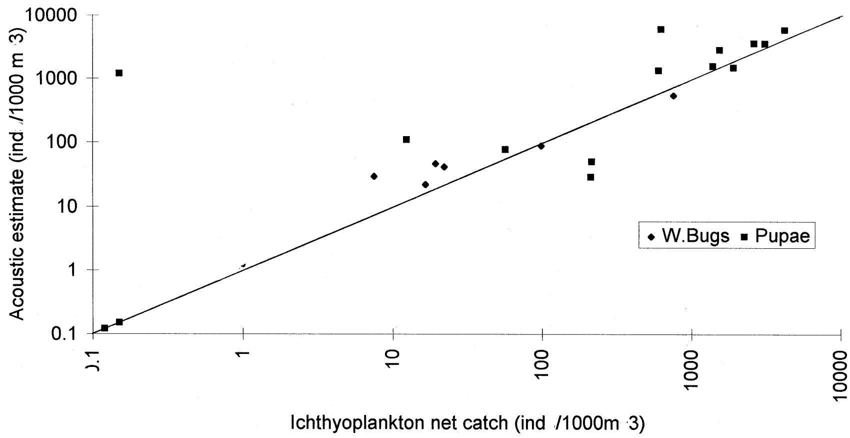


**Figure 4.** The relationship between the density of water bugs (corixids) and pupae (chironomids) estimated by the two methods: ichthyoplankton nets and acoustics. Straight line represents the 1:1 relationship.

and outside of the patches. The density of corixids was less variable ranging between 10–1 000 individuals·$10^{-3}$ $m^{-3}$. In most cases, the acoustic and ichthyoplankton densities were close to each other. Because of the relatively small sampling volume of vertical net tows for capturing pupae, we may have missed the patch while sampling on one occasion (acoustic estimate was much higher in this case). Despite this, both relationships on *figure 4* are highly significant ($r = 0.98$, $P < 0.001$ for corixids and $r = 0.73$, $P < 0.01$ for pupae). When acoustic estimates of corixids were processed in exactly the same way as fish records (insect targets were recorded, sized by using a fish regression and fish length-weight relationship was used to calculate average weight, Kubecka and Wittingerova, 1998), the false fish biomass of Josefuv Dul Reservoir and Prasilske Lake ranged between 0.08 and 9.6 kg·$ha^{-1}$ (average 1.36 kg·$ha^{-1}$). Average individual 'false fish' weight was 0.38 g in horizontal records and 0.64 g in vertical records. The contribution of pupae to the total fish biomass was about 0.09 kg·$ha^{-1}$ in De Gijster Reservoir and 0.084 kg·$ha^{-1}$ in Honderd-en-Dertig.

## 4. DISCUSSION

Two types of insects containing small amounts of air were found to be easily recognisable acoustically. Returning echoes can produce signals very similar to fish echoes and scientific fisheries sonar instruments appear to be able to record the size and quantity of these animals. These findings broaden the applicability of fisheries sonar in studying other groups of animals. On the other hand, the results show the possibility of interference with true fisheries surveys. In particular, the corixids have a *TS* equal to juvenile fish. Unlike *Chaoborus* larvae whose mass occurrence sometimes seriously increases volume reverberation Eckmann (1998), corixids and pupae tend to be less clumped and can be recognised as single targets. The *TS* and the way the insects behave can be used as the main discriminating criteria against fish. In our study it was also possible to carry out a fixed location observation of corixids swimming. Their swimming speed (several cm·$s^{-1}$) is lower than common fish swimming speed (about 10 cm·$s^{-1}$). However, even a brief study has shown quite extensive migrations of corixids. In Josefuv Dul Reservoir, in June 1997, the corixids stayed at depths 5–7 m during the day and migrated to the surface at night (here they could be only effectively detected by the horizontal approach). Such migrations of corixids seem to take place in other localities (Bailey, 1987; Lyle and East, 1989). In Prasilske Lake, many more corixids were recorded at night compared with the day. It is likely that most corixids stay inshore during the day and make extensive migrations over 100 m into the open water at dusk (the lake is small).

Chironomid pupae appear to be a less serious interference for the fisheries surveys. The body length of pupae is nearly as large as the length of corixids, but the pupae are much slimmer and lighter. The pupae have rather complex system of tiny gas hollows (thoracic horns) with hydrostatic and breathing function (Langton, 1995). Their bodies carry much less entrained air and their *TS* are much lower. According to our observations, the pupae do not behave in any complicated way. They stay in similar depths during both day and night. Their swimming speed is negligible, they resemble plankton rather than nekton. Similar observations were done in 1991 and 1992 when the layer of single targets was recorded in the open water of Loch Ness (Kubecka et al. 1993). The *TS* was very close to the one presented in *figure 3.* During the Loch Ness survey, a 1-m ichthyoplankton net was towed in the layer of targets and a large number of chironomid pupae were captured. During that survey we did not believe that the pupae would be responsible for the famous Loch Ness scattering layer, but in the light of recent findings this explanation appears rather convincing.

## 5. CONCLUSION

Water bugs (Corixidae) and midge pupae (Chironomidae) are well detected by ordinary scientific echosounders with the frequency of 120 and 420 kHz, they seem to be frequently the only nekton of highly acidic lakes and reservoirs. Corixids overlap in size with young-of-the-year fish, their *TS* range is in the interval –65 to –47 dB. The strongest is the ventral aspect (120 kHz). If the records of corixids were processed as fish (Love's and Kubecka's equations for *TS*/size), the biomass of false fish ranged between 0.5 and 10 $kg \cdot ha^{-1}$.

Chironomid pupae (*Procladius signatus*) occur in patches in upper open water of Dutch reservoirs. Their *TS* ranged between –75 and –65 dB. The effect of these records on the overall fish biomass is negligible, but they can interfere in larval fish surveys.

Ichthyoplankton nets are good complementary tools when you are in doubt about the nature of tiny targets recorded.

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