ICES Journal of Marine Science, 61: 267–273. 2004
doi:10.1016/j.icesjms.2003.11.007

Simultaneous Sv and TS measurements on Young-of-the-Year (YOY) freshwater fish using three frequencies

J. Guillard, A. Lebourges-Dhaussy, and P. Brehmer

Guillard, J., Lebourges-Dhaussy, A., and Brehmer, P. 2004. Simultaneous Sv and TS measurements on Young-of-the-Year (YOY) freshwater fish using three frequencies. – ICES Journal of Marine Science, 61: 267–273.

In autumn, the fish population above the thermocline in Lake Annecy mainly comprises young perch (*Perca fluviatilis*) of the year. The fish are distributed in schools during the day and as scattered individual fish targets at night. Measurements of volume-backscattering strength and target strengths (TS) were carried out in a synchronous way using three echosounders operating at three frequencies (70, 120, and 129 kHz), with different characteristics (split beam, dual beam, beam shape, pulse length, etc.). Target-strength values show variability from one elementary sampling unit to another and from one device to another, but the mean global TS values are similar, independently of the frequency. The volume-backscattering strengths measured on precise schools by the three acoustic devices give significantly similar results. Acoustic measurements on YOY perch are completely independent of the frequency and the characteristics of the echosounders.

Keywords: dual beam, freshwater, lake, multi-frequency, *Perca fluviatilis*, split beam, target strength.

Received 21 July 2003; accepted 19 November 2003.

J. Guillard and P. Brehmer: Institut de Recherches pour le Développement, US004 - UR061, BP 171, 34203 Sète, France. A. Lebourges-Dhaussy: Institut de Recherches pour le Développement, US004, BP 70, 29280 Plouzané, France. Correspondence to J. Guillard: Institut National de Recherche Agronomique, CARRTEL, BP 511, 74203 Thonon les Bains, France; tel: +33 4 50 26 78 51; fax: +33 4 50 26 07 60; e-mail: guillard@thonon.inra.fr

Introduction

The fisheries scientific community is currently very impressed by the improvements of stock estimates that can result from the use of multi-frequency acoustic information. Several exercises were carried out in relatively recent years with wideband prototypes (Lebourges, 1990; Simmonds *et al.*, 1996) on fish species identification. The observations made in this case with multi-frequency echosounders show clearly that different organisms are not detected in the same way by all the frequencies. The classical frequencies, 38 and 120 kHz, have often been used jointly with a general aim of separating fish and euphausiids (Madureira *et al.*, 1993; Mitson *et al.*, 1996). Advantage is taken here of the fact that the miniaturization of equipment allows several frequencies to be used at the same time on small boats. The multi-frequency approach is therefore available for surveys performed on lakes. Additionally, new tools are available within the processing software that allows the combination of frequencies in order to highlight the different types of acoustic detection.

The present work focuses on measurements made at three frequencies (70, 120, and 129 kHz) on a rather simple population, viz. fish above the thermocline in Lake Annecy. The surveys were carried out during the autumn, in order to compare the results produced by the three portable, scientific echosounders at their respective frequencies. We used two split-beam echosounders (SIMRAD EY 500) simultaneously, one at 70 kHz and the other at 120 kHz (SIMRAD, 1995), and a dual-beam transducer (BioSonics DT 5000) at 129 kHz (BioSonics, 1998). In October 2000, during the experiment, the main part of the fish biomass comprised "Young-of-the-Year" (YOY) perch (*Perca fluviatilis*) (Guillard, 1991) distributed in schools during the day and in scattered individual fish targets at night (Fréon *et al.*, 1993). This behaviour gave us the opportunity to acquire data from two acoustically energetic data descriptors of an aggregative fish population, the volume-scattering strength "Sv" (dB re 1 m^{-1}) and the target strengths (TS) (dB) (MacLennan *et al.*, 2002), and thus to compare the measurements from the three frequencies. Finally, the average TS of single targets were calculated according to

1054-3139/$30

four different equations taken from the literature: the general equations of Love (1971) and Foote (1987) and two specific ones for perch (Chorier *et al.*, 1995; Imbrock *et al.*, 1996).

The purpose of this paper is to compare the results of Sv and TS measurements obtained at the three frequencies and not to evaluate the performances for discriminating individual targets between dual-beam and split-beam systems. This has already been carried out and showed good convergence of the methods (Ona, 1999; Gauthier and Rose, 2002). In this instance, a specific *in situ* application in freshwater was studied in conditions of low perturbation generated by the swell (pitch and roll) not usually found in the open sea in order to obtain highly accurate acoustic measurements.

Materials and methods

Acoustic methods

The measurements were made from the boat "Antares" of 6.4-m length, with each of the three transducers fixed on a pole on the side of the boat and thus positioned at the same depth and less than 0.50 m from each other (Figure 1). The characteristics of the three echosounders are summarized in the figure. The bandwidths of the two sounders, 120 and 129 kHz, overlapped and will not be compared directly. The 70-kHz echosounder was used as a reference and the two other sounders were alternately started at 10-min intervals. Because of the small "alongship" distance between the transducers, the low speed of the boat, and the pulse rate of 5 pings per second, it can be assumed that there is good reception of the beams from ping to ping. Therefore, it is possible to assume that the same targets are being simultaneously detected via a GPS by the two different echosounders. Available pulse lengths were used, which were not identical for all the echosounders.

Before the field stage, the three echosounders had been calibrated in a large seawater tank (100 m long, 25-m depth, Ifremer, Brest) according to the standard protocol recommended by Foote *et al.* (1987) and the recommendations of the user's handbooks (SIMRAD, 1995; BioSonics, 1998). Then, an *in situ* calibration was performed on the boat, confirming the results obtained previously. Processing thresholds were set at −60 dB for individual target-strength (TS) recognition, and at −55 dB for volume-scattering strength calculation.

The criteria used to extract the individual targets with the split-beam transducers were: (1) minimum and maximum returned pulsewidths of 0.6 and 1.8, respectively (relative to the transmitted pulsewidth), (2) maximum gain compensation of 6 dB, one way, and (3) maximum phase deviation

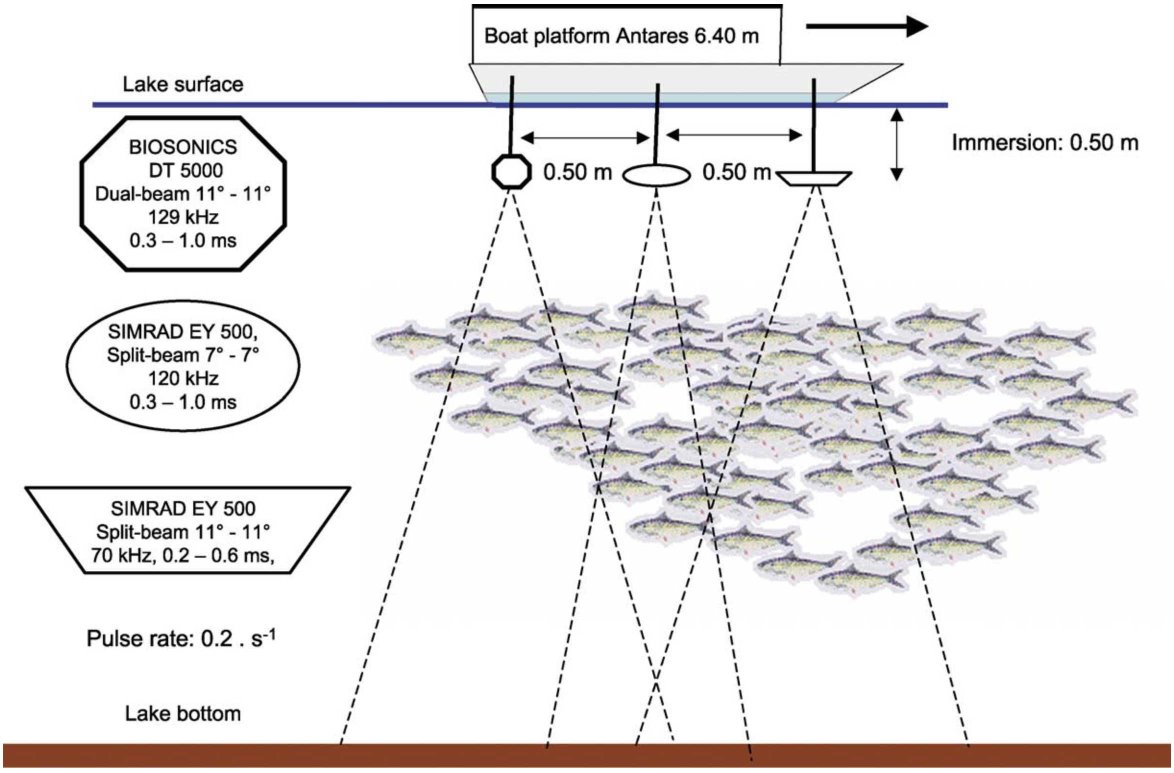


Figure 1. A diagram of the three transducers in place along the boat and their characteristics.

of three phase steps, as recommended by the manufacturer for a low-noise environment (SIMRAD, 1995).

For the dual-beam transducer, the isolated target criteria were set to the following values: (1) minimum and maximum returned pulsewidth factors: 0.75 and 3, respectively, and (2) correlation factor i.e. the result of the correlation between the incident pulse and the echo pulse as a criterion to eliminate multiple targets: 0.9.

The software used for the echosounder data analysis was the DT analyser version 2.1 for BioSonics (BioSonics, 1998) and EP 500 version 5.5 for SIMRAD (SIMRAD, 1995).

To complete the comparison between the frequencies, we defined for each school the same integration cell, i.e. the same depth range and the same ping range, and the precise boundaries of the processed school, as shown in Figure 2. The last of these was necessary as there were no tools available to determine the outlines of the schools and to perform an echo-integration by school for both types of data. For TS measurements, we analysed the same sections and the same depth layers (Figure 2). "Results' files" with a minimum of 100 single targets have been considered. For the echo-integration purpose, the speed of the boat was varied between nil (drift) and 4 knots, and fixed for trawling at 1.5 knots. For practical reasons, it was not possible during trawling to acquire data with the EY 500 at 120 kHz.

There are two ways to calculate a mean TS on a sample of individual targets: first, through the individual echoes and the calculation of $TS_m = 10 \log \sigma_m/(4\pi)$ (MacLennan and Simmonds, 1992), where σ_m is the mean value of all the recognized targets; or second, the use of a "tracking" tool available in some of the processing softwares in order to calculate initially an average TS for each tracked fish, and then to find the average of these mean TSs. It is thought that there is less bias in this approach. In the present case, however, only the EP 500 software includes the "tracking" tool and there is no possibility of tracking with a dual-beam transducer because the location of the fish under the transducer is not precisely known. Consequently, the first option was used.

Field experiment and biological samples

From the hydrological point of view, the lake was structured with a marked thermocline around 20 m (Figure 3a). Biological samples were caught at night with a pelagic trawl as described in Guillard and Gerdeaux (1993), in the same areas where schools were detected during daytime. The thermocline caused a strong vertical distribution of fish according to species. Above the thermocline, two main species, *Rutilus rutilus* (20%) and *Perca fluviatilis* (80%), and a few big salmonids were present. Most specimens were "Young-of-the-Year" (YOY) and of similar size (perch: mean total length 9.7 cm (s.d.: 0.97); roach: mean total length 12.3 cm (s.d.: 1.92)) (Figure 3b). Below the thermocline, the fish were mainly salmonids.

YOY fish were found in schools spatially distributed near the shore (Guillard *et al.*, 1990) with a bottom depth around 20 m during the daytime (Figure 2). Performing comparative echo-integration on well-identified structures is therefore possible. At dusk, the schools disintegrated and became layers of scattered fish during the night (Figure 2). This meant that TS measurements could be made. The fish were scattered over the whole zone above the thermocline and not only close to the shore.

Results

Volume-backscattering strength of schools: comparison between frequencies

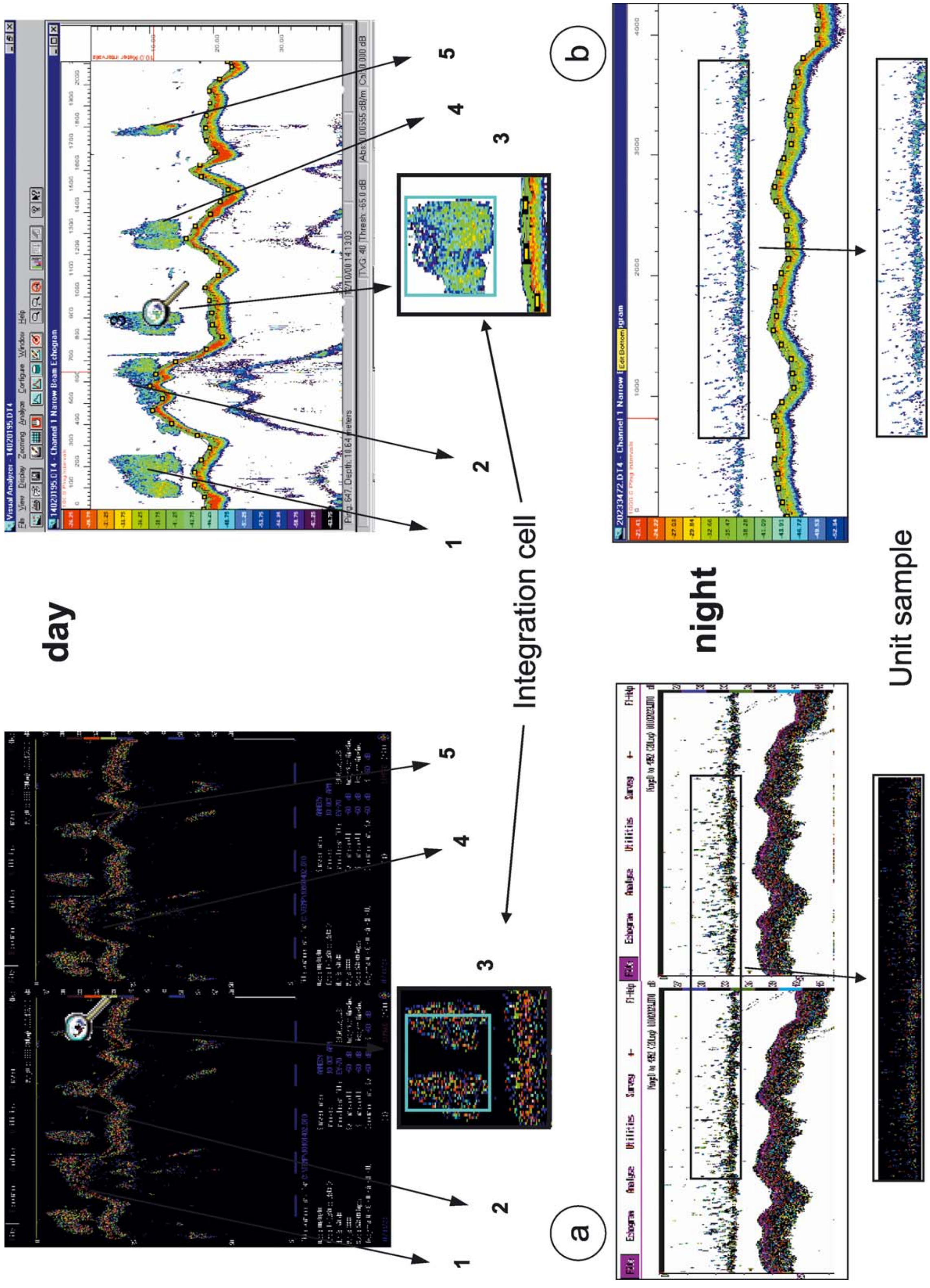
We have made Sv calculations on 54 different acoustic schools, detected at 70 and 129 kHz, using different combinations of pulse lengths. There is a significant linear correlation between the two results (Table 1), independent of the pulse length used (Figure 4a). There is no difference between the Sv measured by BioSonics DT 5000 at 129 kHz and by EY 500 at 70 kHz (Student's test, $p < 0.05$).

In the same way, Sv calculations were performed on 44 different schools, detected at 70 and 120 kHz, using several combinations of pulse lengths. There is a significant linear correlation between the two sounders (Table 1), independent of the pulse length used (Figure 4b). There is no significant difference between the Sv measured by the EY 500, at 120 and 70 kHz (Student's test, $p < 0.05$).

Mean TS

Mean TS values were calculated by averaging the single-target TSs obtained during the night when fish are scattered in the layer above the thermocline over every selected distance section. Eight sections of transects, each of about 0.4-nmi length, have been processed. To compare our results with equations from the literature, we used the mean length (total fish length) of the fish caught and Love's (1971) equation, a general reference for physoclist fish from Foote (1987), and two equations specific for perch, according to Chorier *et al.* (1995) and Imbrock *et al.* (1996).

The mean TS values obtained from the two frequencies 70 and 129 kHz are different in most cases, but not always in the same way (Figure 5). In fact, there is a high variability within the TS measurements at each frequency. The values are even more variable at 70 kHz (−42.8; −45.9) than at 129 kHz (−43.9; −45.6). The "global mean TSs", the average of single values over the whole data set, are −44.2 dB for 70 kHz and −44.6 dB for 129 kHz. The classical equation of Love (1971) and the equation from Imbrock *et al.* (1996) are in good agreement with our data


day
night
Integration cell
Unit sample
a
b
1
2
3
4
5
Visual Analyzer - 14020195.DT4
File View Display Zooming Analyze Configure Window Help
14020195.DT4 - Channel 1 Narrow Beam Echogram
Ping: 647, Depth: 10.64 meters
TVG: 40 Thresh: -65.0 dB
Abs: 0.00555 dB/m Cal: 0.000 dB
20233472.DT4 - Channel 1 Narrow Edit Bottom gram
Echogram Analyse Utilities Survey F1-Help

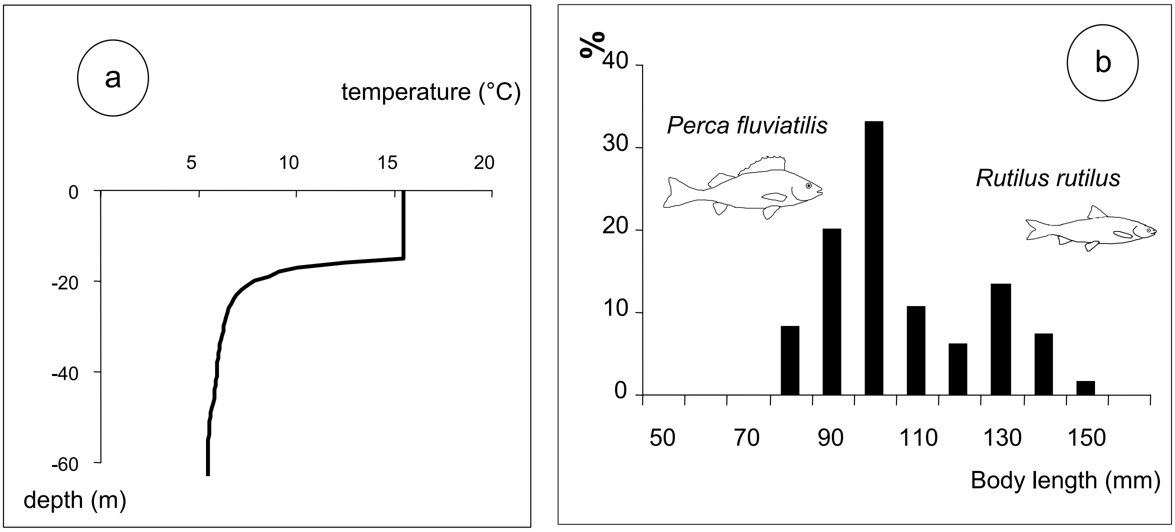


Figure 3. (a) The position of the thermocline in Lake Annecy, 16 October 2000. (b) The fish-size distributions caught by a pelagic trawl.

but the Chorier *et al.* (1995) equation gives greater values whilst that of Foote (1987) gives smaller values.

Discussion

This work has shown that in the case of YOY freshwater-fish schools (perch 80% and roach 20%), significantly similar results are obtained for values of the average volume-backscattering strength when measured by three acoustic devices at 70, 120, and 129 kHz, respectively. From the theoretical point of view, this result was expected (MacLennan and Simmonds, 1992) and we reach the same conclusion as Wanzenböck *et al.* (2003), namely, that the use of equipment from different manufacturers with different characteristics (beam width, pulse length, frequency, software, etc.) produces comparable biomass estimates. Furthermore, our results corroborate the view that direct *in situ* TS measurements by dual-beam and split-beam methods also give similar results (Foote, 1991; Ona, 1999). The variability of the values obtained originates in physiological and behavioural factors (Ona, 1999).

We explored the possibility that spectral variability could exceed the other intrinsic TS variability and become pertinent information about a species. Our measurements at each frequency show a high variability. Intra-frequency variability can be due to differences in the species composition from one elementary sample to the other, the densities (Rudstam *et al.*, 2003), the range of sizes of the YOY-sample communities induced by behavioural change (Freon and Misund, 1999) according to spatio-temporal factors (hour, localization, direction of the boat, windspeed,...), the boat's engine noise (Mitson, 1995), and, as pointed by MacLennan and Simmonds (1992), the stochastic aspect of the TS.

Size estimates from acoustic target-strength measurements must be made carefully, and it is probably safer to refer to an "acoustic relative size". Depending on the theoretical equation used, in our case of freshwater studies, there is bad (Foote, 1987; Chorier *et al.*, 1995) or good (Love, 1971; Imbrock *et al.*, 1996) fitting to the observed data. Therefore, the conversion of acoustic densities into fish weights via the mean TS should not be made. Nevertheless, the Sv at both frequencies were identical, which means that the two TSs should be equal also. According to the "intra-frequency" variability, the weak difference between the two "global mean TSs" has no significance and, as we see it, more data are needed to obtain a mean value.

Table 1. Correlations between Sv from EY 500, 70 kHz, and BioSonics DT 5000, 129 kHz, and between EY 500, 70 kHz, and EY 500, 120 kHz.

	Level of significance	r	Number of schools	Equations
70 vs. 129	$p < 0.0001$	0.99	54	$Sv(70) = 0.994 \times Sv(129)$
70 vs. 120	$p < 0.0001$	0.99	44	$Sv(70) = 1.029 \times Sv(120)$

Figure 2. Echograms from SIMRAD EY 500, 70 kHz (a), and BioSonics DT 5000, 129 kHz (b): fish are in schools during the day and scattered at night. An example of the echo-integration cells, the sample unit for TS estimation, is shown.

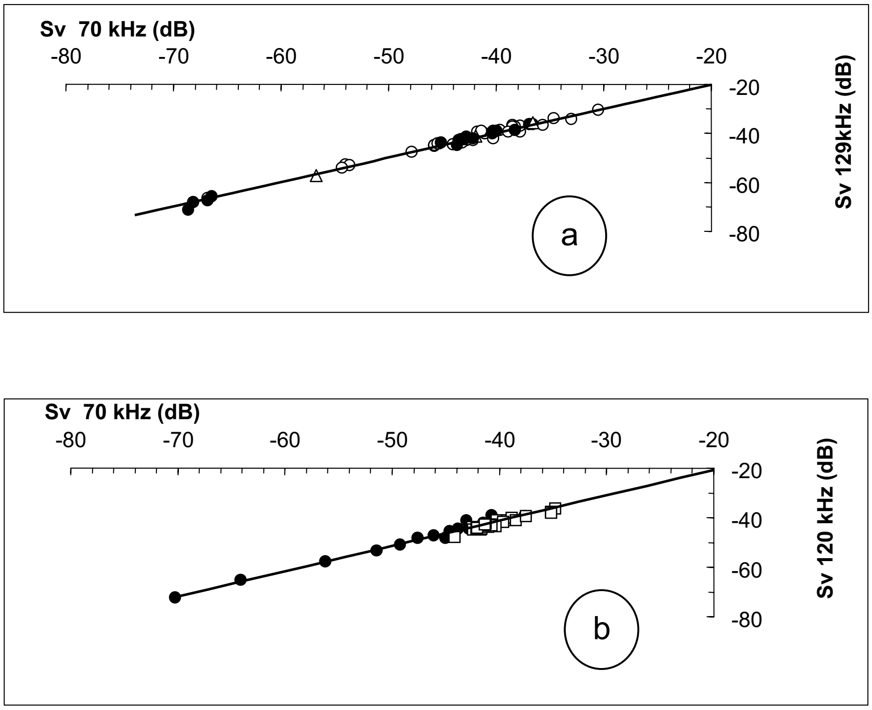


Figure 4. (a) The correlation between the Sv from the EY 500, 70 kHz, and the DT 5000, 129 kHz, on the same sampling units, was significant. Pulse length used for EY 500 and BioSonics DT 5000, respectively: ○ 0.2–0.3 ms, ● 0.6–1.0 ms, and △ 0.6–0.3 ms. (b) Data from the EY 500, 70 and 120 kHz, over the same sampling units, significantly correlated. Pulse length used for EY 500, 70 and 120 kHz, respectively: ● 0.3–0.2 and □ 0.6–1 ms.

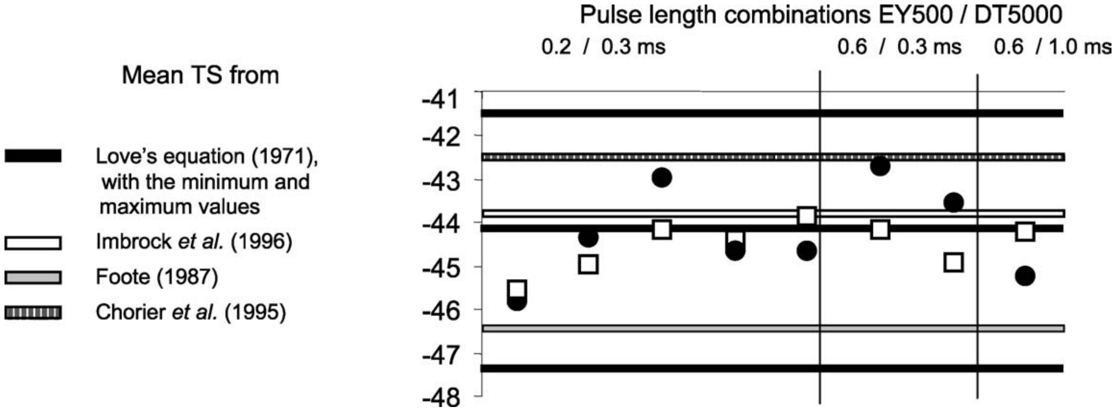


Figure 5. The mean TS obtained with the EY 500, 70 kHz (black circle), and the DT 5000, 129 kHz (white square), and indications of mean TS from a historical review of different methodologies applied on TS mean estimation, based on the mean total length of fish caught by trawl. For Love's (1971) equation we have added the minimum value and maximum value from the minimum and maximum length sampled.

Acknowledgements

We thank Michel Colon for his great help.

References

BioSonics. 1998. BioSonics DT series Hardware and Software, version 2.1.

Chorier, C., Dziedzic, A., and Dubois, J. P. 1995. Broadband dorsal target-strength functions of a free-swimming, individual fish: size and position dependence. *In* 15th International Congress on Acoustics, Throndheim, Norway. pp. 389–392.

Foote, K. G. 1987. Fish target strengths for use in echo-integrator surveys. Journal of the Acoustical Society of America, 82: 981–987.

Foote, K. G. 1991. Summary of methods for determining fish target strength at ultrasonic frequencies. ICES Journal of Marine Science, 48: 211–217.

Foote, K. G., Knudsen, H. P., Vestnes, G., MacLennan, D. N., and Simmonds, E. J. 1987. Calibration of acoustic instruments for fish-density estimation: a practical guide. ICES Cooperative Research Report. 144 pp.

Fréon, P., and Misund, O. A. 1999. Dynamics of Pelagic Fish Distribution and Behaviour: Effects on Fisheries and Stock Assessment. Fishing News Books, Oxford. 348 pp.

Fréon, P., Soria, M., Mullon, C., and Gerlotto, F. 1993. Diurnal variation in fish-density estimate during acoustic surveys in relation to spatial distribution and avoidance reaction. Aquatic Living Resources, 3: 169–296.

Gauthier, S., and Rose, G. A. 2002. *In situ* target-strength studies on Atlantic redfish (*Sebastes* spp.). ICES Journal of Marine Science, 59: 805–815.

Guillard, J. 1991. Etude des stocks pisciaires lacustres par échointégration: problèmes méthodologiques. Th. Doct. Sci.: Un. Cl. Bernard, Lyon I. 156 pp.

Guillard, J., and Gerdeaux, D. 1993. *In situ* determinations of the target strength of roach (*Rutilus rutilus* L.) in Lake Bourget with a single-beam sounder. Aquatic Living Resources, 6: 285–289.

Imbrock, F., Appenzeller, A., and Eckmann, R. 1996. Diel and seasonal distribution of perch in Lake Constance: a hydroacoustic study and *in situ* observations. Journal of Fish Biology, 49: 1–13.

Lebourges, A. 1990. Utilisation de la spectroscopie ultrasonore en vue d'identifier les espèces de poisson. Th. Doct.de l'Université Paris VI. 231 pp.

Love, R. 1971. Dorsal-aspect target strength of an individual fish. Journal of the Acoustical Society of America, 49: 816–823.

MacLennan, D., Fernandes, P. G., and Dalen, J. 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES Journal of Marine Science, 59: 365–369.

MacLennan, D. N., and Simmonds, E. J. 1992. Fisheries Acoustics. Chapman and Hill, New York. 325 pp.

Madureira, L. S. P., Everson, I., and Murphy, E. J. 1993. Interpretation of acoustic data at two frequencies to discriminate between Antarctic krill (*Euphausia superba* Dana) and other scatterers. Journal of Plankton Research, 15(7): 787–802.

Mitson, R. B. 1995. Underwater noise of research vessels: review and recommendations. ICES Cooperative Research Report. 209 pp.

Mitson, R. B., Simard, Y., and Goss, C. 1996. Use of a two-frequency algorithm to determine the size and abundance of plankton in three widely spaced locations. ICES Journal of Marine Science, 53: 209–215.

Ona, E. 1999. Methodolgy for TS measurements. ICES Co-operative Research Report. 235 pp.

Rudstam, L. G., Parkera, S. L., Einhouse, D. W., Witzelc, L. D., Warnera, D. M., Stritzeld, J. L., Parrish, D. L., and Sullivana, P. J. 2003. Application of *in situ* target-strength estimations in lakes: examples from rainbow-smelt surveys in Lakes Erie and Champlain. ICES Journal of Marine Science, 60: 500–507.

Simmonds, J. E., Armstrong, F., and Copland, P. J. 1996. Species identification using wideband backscatter with neural network and discriminant analysis. ICES Journal of Marine Science, 53: 189–195.

SIMRAD 1995. SIMRAD EP500 echo-processing system, P2593E/857-130201/INM/AA009.

Wanzenböck, J., Mehner, T., Schulz, M., Gassner, H., and Winfield, I. J. 2003. Quality assurance of hydroacoustic surveys: the repeatability of fish-abundance and biomass estimates in lakes within and between hydroacoustic systems. ICES Journal of Marine Science, 60: 486–492.