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Short communication

Tuna target-strength related to fish length and swimbladder volume

Arnaud Bertrand, and Erwan Josse

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This paper proposes target-strength (TS) to fork length (FL) and swimbladder volume relationships, respectively, for bigeye (*Thunnus obesus*) and yellowfin (*T. albacares*) tuna, based on previous TS measurements. TS *versus* FL relationships were determined using the equations TS=a logFL+b but the results should be regarded as preliminary because of the small number of observations. The TS of bigeye tuna was about 5 dB higher than yellowfin when comparing species at equal size. This result can be linked to the swimbladder volume difference between species. For both species a single trend is observed in the relationship between TS and swimbladder volume. This result confirms that this is the key factor in deciding the TS of physoclists fish. Since TS measurements were obtained from as deep as 500 m it would seem that a tuna's swimbladder is not fully compressed and maintains its cross-section even at great depths. Therefore tuna have the ability to control efficiently the volume of their swimbladders.

Key words: acoustics, tuna, target-strength, swimbladder.

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A. Bertrand and E. Josse: IRD, B.P. 70, 29280 Plouzané, France. Correspondence to A. Bertrand: tel: +33 2 98 22 45 01; fax: +33 2 98 22 45 14; e-mail: Arnaud.Bertrand@ird.fr

Introduction

Knowledge of target-strength (TS) is of prime importance for acoustic, stock assessment and behavioural studies. Recent investigations have proposed a first range of tuna TS at 38 kHz with two different protocols. The first consisted of measuring the tuna TS with simultaneous sonic tracking (Bertrand *et al.*, 1999a, b). This method was applied to tuna which were vertically distributed over a large range of depths. The second consisted of measuring tuna TS near a fish aggregating device (FAD, Josse and Bertrand, 2000). The results of both methods can be compiled to obtain a first range of TS for bigeye (*Thunnus obesus*) and yellowfin tuna (*T. albacares*) of juvenile and adult sizes (Table 1). The TS range obtained was successfully used to conduct acoustic estimation of tuna abundance around FADs (Josse *et al.*, 1999, 2000) and oceanic waters (Bertrand and Josse, 2000).

The swimbladder is responsible for 90–95% of the backscattering energy (Foote, 1980). Therefore the study of the relationships between TS and the swimbladder volume can improve our knowledge of tuna physiology and swimbladder volume compensation. Here, we propose preliminary relationships between TS and both fish length and swimbladder volume.

Target-strength measurements

Acoustic data were collected with a SIMRAD EK500 (version 4.01) echosounder connected to a 38 kHz split-beam hull-mounted transducer, SIMRAD ES38B (beam angle 6.9°) used with a pulse duration of 1.0 ms. The water column was up to 500 m in depth. The on-axis and off-axis calibration was done using the standard procedure described in the EK500 manual (SIMRAD, 1993). The EP500 trace tracking procedure (SIMRAD, 1994) was used to extract single targets selected by the

Table 1. Target-strength values for yellowfin (*Thunnus albacares*) and bigeye tuna (*T. obesus*) measured by (1) Bertrand *et al.* (1999b) and (2) Josse and Bertrand (2000). The number of acoustics observations is the number of single targets selected by EK500.

Species	Fork length (cm)	Estimated weight (kg)	Estimated swimbladder volume (cm^3)[1]	Number of acoustic observations	Average TS (dB)	References
T. albacares	60	4	59	18	−34.8	(1)
T. albacares	90	14	147	102	−33.0	(1)
T. albacares	108	25	254	189	−30.4	(1)
T. albacares	120	30	365	26	−26.1	(1)
T. obesus	50	3	107	642	−31.9	(2)
T. obesus	110	30	1085	141	−24.4	(1)
T. obesus	130	50	2349	70	−21.4	(1)

EK500. The precise settings used during TS measurements and trace tracking selection are described by Bertrand *et al.* (1999b) and Josse and Bertrand (2000). The TS used in the present paper are a logarithmic expression of the result of the backscattering cross-section measured *in situ*. Target-strength values were measured on single fish by Bertrand *et al.* (1999b), except for the bigeye 50 cm long. In this case, the TS corresponds to a mean value calculated on a tuna aggregation (Josse and Bertrand, 2000).

The fish fork length was measured for tuna small enough, fish less than 110 cm long, to be hauled aboard without causing injury, but was estimated as the fish was drawn alongside the ship in the case of larger tuna.

Swimbladder volume estimation

Tuna specimens used to determine swimbladder volume (SBV) *versus* fork length (FL) relationships were caught by longline in French Polynesia. Freshly caught fish fork length was measured to the nearest centimetre. The swimbladder volume was measured on 27 yellowfin and 40 bigeye tuna. The inflated swimbladder were carefully excised from the abdominal cavity and then frozen. A small incision was made on the anterior part of the frozen swimbladder, which was then filled with sea water several times until it burst. The volume of water was measured to the nearest 10 ml. Only the maximum swimbladder volumes were considered.

As already observed by Schaefer (1999), the relationships between swimbladder volume and fork length show an obvious difference between tuna species: the swimbladder volume is significantly greater for bigeye than for yellowfin (Fig. 1). The best fit regression function for swimbladder volume *versus* fork length (Table 2) was very similar to that proposed by Schaefer (1999), who used a geometrical reconstruction of the swimbladder for yellowfin, a power function in his case, but slightly different for bigeye tuna (Fig. 1).

Target-strength to length relationships

The proposed relationships are only preliminary because of the small number of observations (Table 1), the stochastic nature of target-strength and the possible error in estimating the length of the fish that were not hauled abroad. It is commonly assumed that TS depends on fish size according to the relationship: TS=a logFL+b, where a and b are constants for a species and a given frequency and FL is fork length (cm). The data were fitted and the following relationships were obtained (Fig. 2, Table 2):

- Yellowfin tuna: TS=25.26 logFL − 80.62;
- Bigeye tuna: TS=24.29 logFL − 73.31.

These relationships apply for 60–120 cm yellowfin and 50–130 cm bigeye tuna.

MacLennan and Simmonds (1992) indicate that, in the case of *in situ* target-strength measurements, a is generally close to a value of 20. Indeed, the acoustic cross-section ($\sigma=4\pi \cdot 10^{(TS/10)}$) is proportional to the

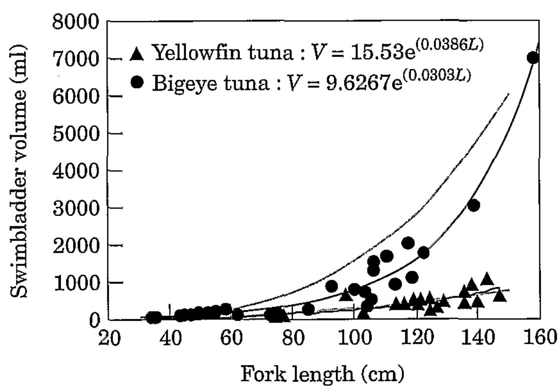

Figure 1. Relationships between swimbladder volume and fork length for yellowfin and bigeye tuna. The fitted lines are the regression function proposed from ECOTAP data (black lines) and by Schaefer (1999) (grey lines).

Table 2. Regression model parameters for swimbladder volume vs. fork length (SBV/FL), target-strength vs. fork length (TS/FL) and target-strength vs. swimbladder volume for yellowfin (YFT) and bigeye (BET) tuna. Models are exponential: $Y=a \times \exp^{(b \cdot X)}$ (1) and logarithmic: $Y=a \times \log X+b$ (2) relations. CV is the coefficient of variation, R^2 the measure of the sample coefficient of determination and n the number of samples.

Relation	Species	Model	a	CV (%)	b	CV (%)	R^2	n
SBV/FL	YFT	1	9.6267	24.5	0.0303	11.8	0.73	27
SBV/FL	BET	1	15.5385	14.2	0.0386	2.5	0.96	40
TS/FL	YFT	2	25.2596	36.9	−80.6154	22.7	0.79	4
TS/FL	BET	2	24.2919	11.7	−73.3112	7.6	0.99	3
TS/SBV	YFT+BET	2	8.5318	10.7	−49.9986	4.6	0.95	7

horizontal section of the organs contributing to the echo. This area should be proportional to the square of the length of the fish (FL^2). This assumes that σ is proportional to FL^2 and that the TS is defined by 20logFL+b. However, in the case of physoclists fish (e.g. tuna), TS increases more quickly with size, and Midttun (1984) proposes a relationship of 25logFL+b, which is consistent with our results.

According to our measurements, a bigeye tuna has a TS higher by approximately 5 dB than that of a yellowfin tuna of the same size. This difference is very significant given the similarity of the two species both in terms of their form and the density of their flesh.

Target-strength to swimbladder volume relationships

For a given length a bigeye tuna has a swimbladder that is longer than that of a yellowfin tuna (Bard *et al.*, 1998; Schaefer, 1999). The differing swimbladder length can explain the observed difference in the relationship of TS and fish length for the species. However, if we represent TS according to the volume of the swimbladder, we observe instead a single trajectory for both species (Fig. 3), since as TS increases logarithmically with the swimbladder volume (SBV, in ml). Thus the difference between species is not observed if the swimbladder volume is taken into account.

We estimated the following relationship based on our experimental observations (Table 2):

$$TS=8.53\log(SBV)-50.00.$$

This relationship applies for swimbladder volumes ranging between 80 and 2500 cm^3. Physoclistous fish such as yellowfin and bigeye tuna have a closed swimbladder with a gas gland and resorption area for gas secretion/resorption from the blood to and from the swimbladder (Blaxter and Batty, 1990; Misund, 1997). Bertrand *et al.* (1999b) showed that the swimbladder of the bigeye tuna was not fully compressed, even at great depths.

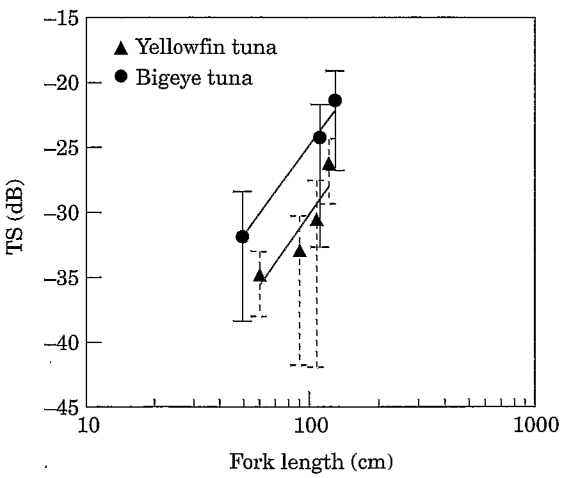

Figure 2. Variation of target-strength with tuna fork length (cm) for yellowfin and bigeye tuna. Solid line is the best-fit equation TS=a logFL+b of experimental data. The standard deviation of TS (computed using backscattering cross section) is also represented. Note: x-axis is a logarithmic scale.

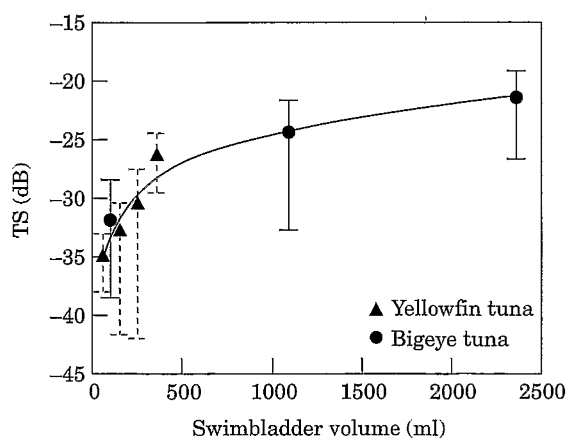

Figure 3. Variation of target-strength with tuna swimbladder volume (ml) for yellowfin and bigeye tuna together. Logarithmic curve fit to the data is represented as well as the standard deviation of TS (computed using backscattering cross-section).

Therefore, tuna (at least bigeye tuna) have the ability to adjust the volume of their swimbladders better than might be supposed from the literature for other physoclists (Harden Jones and Scholes, 1985; Arnold and Walker, 1992). It should be noted, however, that Fréon and Misund (1999) have already pointed out that the variations of TS with depth are weak, which suggests that there must be some compensation of gas volume with changing depth. More than the volume itself, though, it is the cross-section which contributes to TS (MacLennan and Simmonds, 1992). The swimbladder is not likely to compress uniformly in volume because the muscle and bone supporting the upper wall will maintain the shape of the upper surface area. Therefore, even if the swimbladder may be not fully inflated at depth, because the swimbladder may never be adapted precisely to depth at a given time (Blaxter pers. comm., in Bertrand *et al.*, 1999b), the volume of gas is likely to be sufficient to maintain the cross section. We suggest that future studies take more account of the surface area of the swimbladder normal to the insonification in particular.

Even given the relatively low numbers of fish involved and the "field" conditions in which some of the measurements were made, it has still proved possible empirically to validate the TS measurements by Bertrand *et al.* (1999b) and Josse and Bertrand (2000). These results also confirm, by *in situ* measurements, the dominating role played by the swimbladder in the energy backscattered by the fish. It was impossible to measure the rate of gas secretion into the swimbladder at the time of the measurements. However, TS was measured at different depths to a maximum of 480 m, and Bertrand *et al.* (1999b) observed depth-dependent TS variation, but they attributed this to non-biological factors such as a bias in the TVG calculation. Furthermore, they showed that ignoring TS at great depths, where the bias would be at its greatest, does not noticeably change the average TS for the fish used in the present study. These results (Fig. 3), therefore, confirm our assumption that tuna are very effective in controlling the volume of their swimbladders. Because the swimbladder always seems to contain enough gas to maintain the surface area presented to the insonification it would seem that it maintains its also reflectivity.

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