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Measurement of acoustic impedance of skipjack tuna (*Katsuwonus pelamis*) tissues

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Isabel Pérez-Arjona[1], Víctor Espinosa[1], Lucía García[1], Anderson Ladino[1], Gala Moreno[2] and Guillermo Boyra[3].
[1]Instituto para la Gestión Integrada de Zonas Costeras (IGIC) Universitat Politècnica de València, Grau de Gandia, Spain
[2] International Seafood Sustainability Foundation (ISSF), 601 New Jersey Ave NW Suite 220 Washington DC 20001
[3]Azti Foundation. Herrera kaia, portualdea z/g, 20110, Pasaia, Spain.:
Phone: 96 284 93 00 Ext. 43145E-Mail: iparjona@upv.es

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ABSTRACT.

The aim of this work is to obtain reference values for the acoustic properties (c,ρ) of skipjack tuna spine and flesh. These parameters rule the backscattering of acoustic energy when an ultrasonic beam insonifies the target, and the target strength of the fish target is dependent on them. Therefore, to characterize the acoustic response (target strength, TS) of a target is necessary to know the value of c and ρ. The acoustic parameters depend on the fish species –and, for the same species, depend on the fat content, the age…- and also depend on the working ultrasonic frequency.

RESUMEN.

En este trabajo se pretende obtener valores de referencia para las propiedades acústicas (c,ρ) de la espina y la carne del atú listado. Estos parámetros gobiernan la energía acústica retrodispersada cuando un haz ultrasónico el blanco, y el factor de blanco depende de ellos. Por tanto, para caracterizar la respuesta acústica de un blanco es necesario conocer el valor de la velocidad del sonido y la densidad. Los parámetros acústicos pedenden de la especies y, dentro de la misma especie, del contenido en grasa, la edad…así como de la frecuencia de trabajo.

INTRODUCTION

The backscattered acoustic intensity (Ibs) is dependent on the acoustic impedance of the target material. In the case of swimmbladdered fish, most of the backscattered acoustic field is due to the gas of the swimbladder, due to the high impedance contrast between gas and surrounding medium. Neverthless, in the case of non swimbladdered fish, the acoustic impedance (z) of the flesh and backbone became more relevant. The acoustic impedance is given by z= ρ c, being ρ the density (kg/m3) and c (m/s) the sound velocity. Both quantities are dependent on the species and, in the case of c, can be dependent also on the working frequency. For each species, they are dependent on individual parameters, such as fat content or age. While other species have been acoustically characterized, as it is the case of Atlantic mackerel, to the best of our knowledge, there are not previous works providing the acoustic properties of skipjack tuna (Katsuwonus pelamis). The aim of this work is to provide typical values of rho and c corresponding to skipjack tuna flesh and backbone. The measurements have been performed

on tuna with 40-45 cm of total length. To ensure the reliability of the method, the applied technique has been tested on Atlantic mackerel flesh and bone and compared with previous experimental results (Sigfusson 2001).

MATERIAL AND METHODS

Sound speed measurement

The available data of sound speed measurements in fish flesh (Sigfusson 2000) have been obtained using high frequency ultrasound (of the order of 1 MHz and higher). In order to take into account possible dependences on the acoustic frequency, we have developed a method to measure the sound speed in the frequency range used by scientific echosounders (100 kHz).

An ultrasonic pulse is generated with the function generator and an ultrasonic transducer, which is in contact to the target tissue. Target tissue is located between two transducers, being the first one used as source and the second as receiver. Both the emitted signal from the first transducer (Emit) and the transmitted across the target tissue signal (Rec) are displayed on a digital oscilloscope Tektronix TDS2022C, which is controlled with a personal computer via the Tektronix software (VISA).

In the case of fish bone, to increase the amplitude of the Rec signal, an amplifier providing a 100x amplification of the emitted signal was introduced.

The Emit and Rec signals are registered to be further analyzed with own code developed on MATLAB®. The ultrasonic velocity of the material was calculated as c= Δx / Δt being Δx the distance path between the transducers and Δt the flying time between Emit and Rec signals.

Two different emitted signals were considered along the measurements:

-5-cycles burst at 120 kHz central frequency.

-1 cycle signal at 120 kHz central frequency.

- Flying time in 5-cycle burst signal

The acquired signals Emit and Rec are processed as follows: the eigencorrelation of Emit and the crosscorrelations between Rec and Emit are calculated. The flying time is calculated as the difference between the maxima of eigen and crosscorrelation. Δt is calculated dividing Δn is the sample interval dividing by the sampling frequency f_s .

The 5-cycle burst signal was used for measuring c in fresh water (system calibration) and in skipjack flesh.

- Flying time in 1-cycle signal

The acquired signals Emit and Rec are processed to look for the first zero-cross point after the minimum of the signal both in the Emit and the Rec signals. The difference between these zeros gives the flying time Δt the eigencorrelation of Emit and the crosscorrelations between Rec and Emit are calculated. The 1 cycle signal was used for measuring c along fish backbones: due to the small width of the bone, if the 5-cycle burst signal was used, direct Emit signal overlaps (in time) with the beginning of the Rec signal. The same happens in the case of thin slices of mackerel flesh, and the 1-cycle signal was used in this study, too.

The system was calibrated to compensate the system time response.

Volumetric density measurement

In order to characterize the acoustic properties of SKJ tissues, it is necessary to obtain the volumetric mass density (ρ) of SKJ flesh and spine. We measured at first step the density of mackerel in order to compare with well-stablished data from previous studies (Gorka2005) and later we characterize the density of SKJ tissues. We describe in this section the experimental setup for measuring the densities and the obtained results.

Volumetric mass density, or as usual, density, is defined as

$$\rho = \frac{m}{V}$$

being *m* (kg) the mass and V (m^3) the volume of the sample. Mass was directly measured using a *KERN EW600-2M* balance,with a precision of 0.01 g, was used.

To measure the sample volume a method based in Archimedes' principle was used. The sample was immersed in water and the weight of the water that the object displaces is measured using the same *KERN EW600-2M* balance that was used for measuring the mass of displaced water. Taking into account the density of the water used in the experiment, ρ_w, once the water weight (V_w) is known, the water volume (V_w) is also known, $V_w = \rho_w m_w$,and it is the same as sample volume $V = V_w$ (Archimedes' principle). This is a common method used in jewelry and medicine. The method is illustrated in Fig. 1

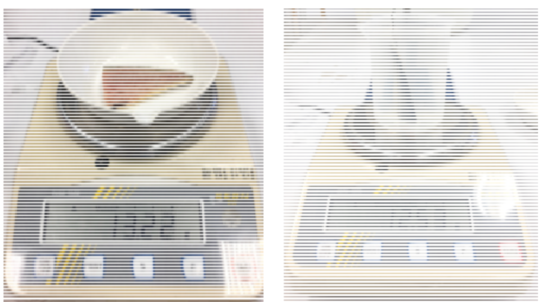

Fig. 1. Left: mass measurement. Right: volume measurement. Case study: mackerel flesh.

RESULTS

Sound speed measurement

1. Mackerel bone

The mackerel bone was place between the transducers (Fig.2).

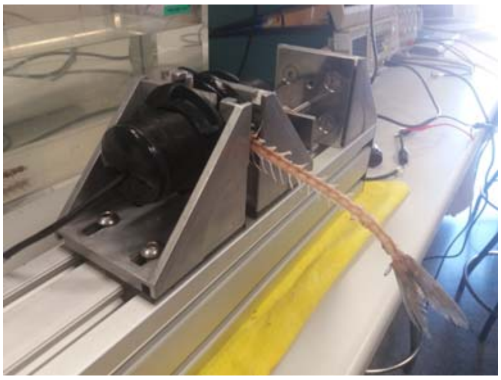

Figure 2. Sound speed measurement in mackerel bone.

To obtain an average value of c in mackerel bone, a total of 12 measurements were performed, changing the bone orientation and position.
Taking into account the dispersion error of the measurement, the obtained value of **$c_{bone,mack}$=2200±200 m/s**. Taking into account the dispersion of the measurements (28%), to obtaine more accurately results a statistical treatment, increasing the number of samples, should be addressed. Neverthless, the data is in good agreement with previous data considered by (Gorska 2005). It should be noted that Gorska et al. did not report any sound speed measurement on mackerel bone. In fact, they noted that measurements on bone were not performed and they remarked explicitly the lack of information on this parameter.

2. Mackerel flesh

The path between the transducers was increased adding pieces of mackerel flesh, and the linear fitting between distance and flying time provides the sound speed in mackerel bone, guaranteeing the same pressure on the flesh. Results are shown in Figure 3.

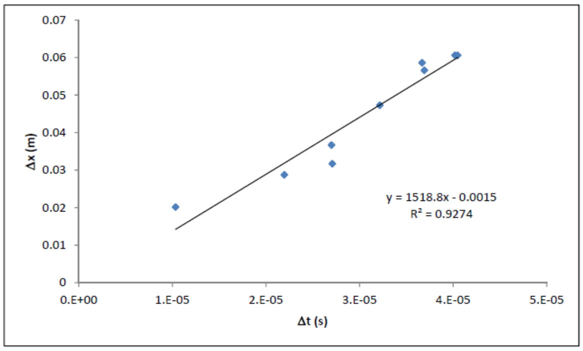

Fig.3. Linear adjustment between flying time and distance in mackerel flesh.

Taking into account the dispersion error of the measurement, the obtained value of **$c_{fl,mack}$=1520±160 m/s**, which is in good agreement with the previous results in (Gorska2005)

3. Skipjack bone

To obtain an average value of c in skipjack bone, a total of 18 measurements were performed, on two different samples, as following: sample n.1, 6 measurements, and sample n.2, 12 measurements.

As has been reported for other species, as is the case of Atlantic mackerel, the results show a large variability of sound speed in skipjack bone, depending on the sample. The measurements on Sample 1 exhibit large dispersion and in order to provide a statistical analysis it would be necessary to increase the number of measurements. The velocity on Sample 2 reveals that sound speed in skipjack bone is higher than in mackerel one, with a good dispersion value. The measured speed of sound in this case was **$c_{bone,SKJ}$=3530±160 m/s**.

4. Skipjack flesh

The flying time between Emit and Rec signals was measured, and the linear adjustment between path and flying time is shown in Fig. 4

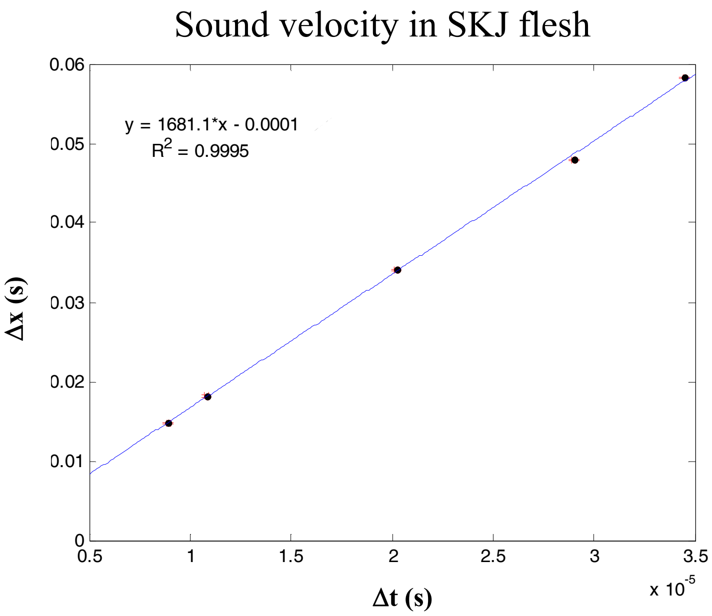

Fig. 4. Linear adjustment of flying time and distance in skipjack flesh.

The measured sound speed in skipjack flesh at 120 kHz is $\mathbf{c_{fl,SKJ}}$ **= 1681 ± 11 m/s.**

Volumetric density measurement

1. Mackerel bone

The Table 1 shows the obtained results:

	m (g)	m_w(g)
M 1	1.05	0.96
M 2	1.05	0.96
M 3	1.05	0.96

$\rho_{bone.mack}$ (g/cm^3)	1.09±0.02

Table 1. Measurements corresponding to mackerel spine density.

The result is in good agreement with the values reported by (Gorska2005a)

2. Mackerel flesh

The same the proceeding was employed to measure the density of mackerel flesh, illustrated in Fig. 4. Results are shown in Table 2.

	m (g)	m_w(g)
M 1	13.46	12.34
M 2	13.22	12.53
M 3	13.02	12.29
M 4	12.81	12.16
M 5	12.77	12.11
M 6	12.76	12.12
Dispersion (%)	5.4	3.43

$\rho_{flesh.\ mack}$ (g/cm^3)	1.06±0.04

Table 2. Measurements corresponding to mackerel flesh density.

This result is in good agreement with previous values given by (Gorska2005), who reported measured mackerel bone density contrast of 1.10±0.05.

3. Skipjack bone

The density of skipjack spine was measured for two samples.Results are shown in Table 3.

SAMPLE 1	m (g)	m_w(g)
M 1	3.06	2.5
M 2	3.08	2.51
M 3	3.1	2.55
Dispersión (%)	1.30	1.98

$\rho_{bone.\ SKJ}$ (g/cm^3)	1.22±0.02

SAMPLE 2	m (g)	m_w(g)
M 1	3.08	2.52
M 2	3.1	2.53
M 3	3.11	2.55
Dispersión (%)	0.97	1.18

$\rho_{bone.\ SKJ}$ (g/cm^3)	1.23±0.02

Table 3. Measurements corresponding to skipjack spine density.

4. Skipjack flesh

We measured the density of the skipjack flesh of two defrost individuals.

The results are shown in Table 4. Sample 1 corresponds to the specimen 1 and Samples 2 and 3. to the specimen 2.

SAMPLE 1	m (g)	m_w(g)
M 1	51.96	47.72
M 2	51.82	47.77
M 3	51.8	47.76
Dispersión (%)	0.31	0.10

$\rho_{flesh.\ SKJ}$ (g/cm^3)	1.086±0.003

SAMPLE 2	m (g)	m_w(g)
M 1	42.23	38.7
M 2	42.01	38.26
M 3	42.04	38.56
Dispersión (%)	0.52	1.14

$\rho_{flesh.\ SKJ}$ (g/cm^3)	1.093± 0.009

SAMPLE 3	m (g)	m_w(g)
M 1	41.49	38.05
M 2	41.53	38.12
M 3	41.49	38.1
Dispersión (%)	0.10	0.18

$\rho_{flesh.\ SKJ}$ (g/cm^3)	1.090± 0.002

Table 4. Measurements corresponding to skipjack flesh density.

The result is in very good agreement with vales from literature (Alexander2013): $\rho_{flesh.\ SKJ}$=1.090 g/cm^3.

CONCLUSIONS

The lack of information of the values of material properties for most of the species has been pointed in previous works, even for well-known species as Atlantic mackerel (Gorska2005). In order to be able to interpret and to numerically simulate the acoustic response of skipjack tuna we characterize the acoustic impedance z= ρ c of SKJ tissues and it is compared with z value for MACK.

It should be noted that, in any case, sound-speed in higher for SKJ tissues. It should be also remarked that c value of SKJ flesh is even slightly higher than previous c values reported for Albacore tuna (*Thunnus alalunga*) in (Sigfusson2001b). There is only one a referenced value for sound speed in skipjack flesh (Shibata1970) giving a value of c=1580 m/s. Nevertheless, this value has to be considered with caution since other measurements for different species in the same work exhibited a big dispersion and the value for skipjack was given with only one measurement. We note also the higher values of SKJ densities both in the case of one and flesh.

The higher value of z in the case of SKJ is relevant to interpret data from this species. Even more when it is compared with other swimbladderedless species as MACK. When higher z values, higher backscattered acoustic intensity, and then higher TS values can be expected. (Nevertheless, to predict and analyze properly the TS the rest of factors such as orientation or anatomy should be considered).

BIBLIOGRAFIA

(Sigfusson2001) Sigfusson, Halldor, Eric A. Decker, and David J. McClements. "Ultrasonic characterization of Atlantic mackerel (Scomber scombrus)." Food Research International 34.1 (2001): 15-23.
(Gorska2005) Gorska, Natalia, Egil Ona, and Rolf Korneliussen. "Acoustic backscattering by Atlantic mackerel as being representative of fish that lack a swimbladder. Backscattering by individual fish." ICES Journal of Marine Science 62.5 (2005): 984-995.
(Sigfusson2001b) Sigfusson, Halldor, et al. "Ultrasonic characterization of north Pacific Albacore (Thunnus alalunga)." Journal of Aquatic Food Product Technology 10.3 (2001): 5-20.
Alexander, Robert, ed. Locomotion of animals. Springer Science & Business Media, 2013
S Shibata, Keishi. "Study on details of ultrasonic reflection from individual fish." (1970): 1-82.