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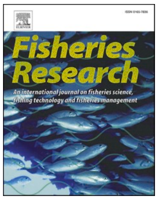

First target strength measurement of *Trachurus mediterraneus* and *Scomber colias* in the Mediterranean Sea

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ABSTRACT

Knowing the species-specific target strength (TS) allows converting volume backscattering strength to numerical abundance. Since the acoustic surveys conducted for biomass assessment in the Mediterranean Sea currently focus on the echoes of two or three target pelagic species, the TS of non-target species has seldom been investigated in this basin. This is the first study of the TS of two pelagic species – Mediterranean horse mackerel (*Trachurus mediterraneus*) and Atlantic chub mackerel (*Scomber colias*) – in the Mediterranean Sea. A pilot approach using tethered live fish but not involving hooks and anesthetic was tested in experiments using a split-beam scientific echosounder operating at 38, 120, and 200 kHz. The mean TS was estimated for 29 live fish. The relationship between TS and fish length was determined with a standard linear regression model; the b_{20} conversion parameter was obtained with the slope forced to 20. b_{20} was computed at all frequencies for both species. The key values at 38 kHz were −71.4 dB for *T. mediterraneus* and −71.6 dB for *S. colias*. Although these results differ from those obtained with *in situ* and *ex situ* experiments using Pacific chub mackerel and other species of the genus *Trachurus*, they have the potential to provide new reference values for *T. mediterraneus* and *S. colias* biomass assessment in the Mediterranean Sea. The proposed method removes some potential biases due to the unnatural behavior of anesthetized fish. Moreover, it provides an alternative to hooks, although the use of a piece of rope instead of the hook seems to increase the acoustic reflectivity of the tethering apparatus.

1. Introduction

Scomber colias and *Trachurus mediterraneus* are two pelagic species found throughout the Mediterranean Sea (Scoles et al., 1998; Zardoya et al., 2004). Their lower commercial value compared to other pelagic species involves that they are often considered as minor species in this basin (Santojanni et al., 2005; FAO, 2011; Carbonell et al., 2018). Yet, they are planktivorous and piscivorous species that play an important ecological role in pelagic niches (Šantić et al., 2003; Sever et al., 2006). Their early life stages are secondary consumers like *Sardina pilchardus* and *Engraulis encrasicolus,* linking plankton to top predators in the trophic chain (Bănaru et al., 2019), whereas the mature stages are major clupeid predators (Šantić et al., 2003; Sever et al., 2006; Yankova et al., 2008).

S. colias accounts for a substantial proportion of landings in the eastern Mediterranean fishing grounds (Bariche et al., 2006, 2007; Tsagarakis et al., 2012) whereas it is largely discarded in some Adriatic fisheries (Santojanni et al., 2005; STECF, 2016). In 2009 its total catch in the Mediterranean basin was about 12,000 tons (FAO, 2011). Since *S. colias* is often sold as *Scomber scombrus*, it is difficult to obtain reliable landings data (Zardoya et al., 2004). *T. mediterraneus* accounts for around 1.4 % of all landings in the Mediterranean, with total catches of about 50,000 tons in 2014–2016 (FAO, 2018), and for a substantial portion of landings in the south-western Mediterranean (Carbonell et al., 2018) and the Adriatic Sea (Šantić et al., 2003). However, since it is often pooled with *Trachurus trachurus*, data are not wholly reliable.

In the Atlantic Ocean the stocks of *T. mediterraneus* and *S. colias* are assessed yearly based on acoustic surveys carried out by the International Council for the Exploration of the Sea (ICES), whereas in the Mediterranean they have never been assessed, despite their ecological and commercial importance. The Scientific, Technical and Economic Committee for Fisheries (STECF) (2016) has highlighted the lack of species-specific landings and survey data for the genus *Trachurus* and *Scomber* and has stressed the importance of monitoring the status of

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Scomber in several geographical sub-areas (GSAs). The collection of species-specific, fishery-independent data can help address the problem and provide sufficient information to assess their stocks.

Acoustic surveys are highly effective approaches to assess the distribution and abundance of pelagic species (Simmonds and MacLennan, 2005). Acoustic surveys have been conducted in the Mediterranean Sea since 2009 to monitor the status of pelagic species (including Mediterranean horse mackerel and Atlantic chub mackerel) in the framework of the Mediterranean International Acoustic Surveys (MEDIAS) action, which involves several European countries joined by a standardized protocol (MEDIAS Handbook, 2019). However, the conversion of volume backscattering strength, provided by the surveys, to an absolute biomass estimate requires knowing the species-specific acoustic backscattering cross-section. This parameter is often expressed in terms of target strength (TS): $TS = 10 \log \sigma/4\pi$ (Foote, 1987; Ona, 1990; Simmonds and MacLennan, 2005), where sigma is the backscattering cross-section of the fish. TS is the amount of incident wave reflected from a single target and depends on the acoustic frequency used, fish body length, orientation (tilt angle) and swim-bladder features (Nakken and Olsen, 1977; Fässler et al., 2009a). Notably, the swim-bladder is responsible for around 90 % of the total energy reflected from a fish (Ona, 1990). Since TS is a stochastic variable (Simmonds and MacLennan, 2005), it can vary considerably within a species according to the behavior and physiological state of each individual (Horne, 2003). This should be kept in mind when computing the TS of a species or group of specimens.

TS measurement approaches can be grouped into three main categories:

- The *in situ* method consists of an acoustic survey of fish in their natural environment using a split-beam echosounder and of their synoptic capture with a trawl net. The TS histogram data are then matched against the size frequency distribution measured in the haul samples (MacLennan and Menz, 1996). This is currently considered as the best available method, because, unlike *ex situ* approaches, it detects echoes as the fish swim (Henderson and Horne, 2007). Its main problems are the availability of monospecific hauls and gear selectivity.
- Backscattering models are “analytical and numerical expressions implemented using computer algorithms to predict acoustic backscatter” (Jech et al., 2015) and its amplitude. The digital representations of target shape and properties, *e.g.* fish anatomy and morphometry (chiefly their swim-bladder), material properties, and boundary conditions are considered as model inputs (Jech et al., 2015).
- *Ex situ* approaches allow measuring the TS of live, anesthetized or dead fish of known total length (TL) held in a cage or tethered at a predetermined depth (Thomas et al., 2002; Hazen and Horne, 2004). These experiments also afford direct computation of TS to TL regression, which is used to convert acoustic size to target size. *Ex situ* methods are practical and easy to use and are commonly adopted as a first approach to measure the TS of new species (Azzali et al., 2010).

To the best of the authors’ knowledge, there are no published studies investigating the TS of *T. mediterraneus* and *S. colias* in the Mediterranean Sea, whereas several studies have been conducted on species of the genus *Trachurus* in the Atlantic Ocean (Barange and Hampton, 1994; Lillo et al., 1996; Axelsen, 1999; Svellingen and Ona, 1999; Axelsen et al., 2003; Robles et al., 2017) and on the species *Scomber japonicus* in the Pacific Ocean (Gutiérrez and Maclennan, 1998; Lee and Shin, 2005; Kang et al., 2018).

We describe a pilot *ex situ* approach, which involved tethering individual *T. mediterraneus* and *S. colias* specimens and placing them under the transducers to create a database encompassing a variety of body displacements and orientations. By this method, we calculated their conversion factor which allows converting volume backscattering strength to species-specific biomass estimates.

2. Materials and methods

A total number of 4 experiments were conducted in the Adriatic Sea during the 2013 MEDIAS cruise. The experiments were conducted at the Tremiti Islands (3 experiments) and off Porto Recanati (1 experiment) on board the R/V G. *Dallaporta*, which is equipped with a SIMRAD EK60 split-beam echosounder (Fig. 1). The operating frequencies were 38, 120, and 200 kHz. The sound speed parameter was set by measuring water temperature, density, and salinity using a CTD (SEABIRD 911 PLUS) before each experiment. Routine calibrations (Demer et al., 2015) were performed using a 38.1 mm diameter tungsten carbide (with 6% cobalt binder) calibration sphere prior to the TS measurements. The echosounder calibration and settings data are reported in Table 1.

2.1. Experimental design

The fish used in the experiments were caught at night in the area where the experiments would be conducted using hooks and lines as the fish were feeding near the surface (max depth, 60 m). After capture, they were allowed to acclimatize for 12–24 h in a tank (capacity, 200 L) placed on deck and with running seawater. No more than 10 fish were held in the tank at the same time, to avoid further stress due to excessive density. Their handling was minimized and never exceeded 1 min. The experimental setup envisaged using the standard rig (rods, reels, and monofilament lines) for sphere calibration (Simmonds and MacLennan, 2005). A slight but crucial modification was that we suspended a tethered live fish, rather than the target sphere, under the transducers. Moreover, whereas the sphere is commonly tied at the end of the monofilament lines issuing from three rods, we used an 8 m monofilament line (0.60 mm in diameter) one end of which was tied to the three lines (two on the starboard side and one on the port side), whereas the other end was tied to a 1 kg lead weight. Two knots were tied by turning the main line on itself, to mark the place where the fish tether would be tied and to prevent the fish from swimming too close to the weight (Fig. 2).

The experiments involved using one fish at a time. Each specimen was collected from the tank using a plastic fish basket that was immediately covered with a dark wet cloth, to reduce stress. To ensure that the fish remained still when it was placed on a table on deck, it was wrapped in and handled with the cloth. Then, a monofilament line (*ca.* 1 m in length and 0.40 mm in diameter) ending with a small fragment of synthetic rope (10 mm in length and 2 mm in diameter) was threaded through a thin needle which was passed through the fish palate and made to exit through the maxillary and lacrimal bones. The monofilament was then pulled until the rope fragment stopped against the palate. With the fish still wrapped in the wet cloth, the free end of the line was tied to the main line. The fish was lowered into the sea and allowed to swim near the surface for around 10 min. All fish were highly vital. As soon as the specimen began to swim naturally around the rig, the lines of the three reels were lengthened further and adjusted so as to place the fish into the acoustic beam at the desired depth, *i.e.* ≈21 m (*S. colias*) and ≈14 m (*T. mediterraneus*) at the Tremiti Islands and ≈18 m (*T. mediterraneus*) at Porto Recanati. Here the fish was again allowed to swim for 10 min before the TS measurements were performed. After the experiments the lines were gently reeled in. The fish were measured as soon as possible in the lab for biometric parameters, gender, and gonadal development in the shortest possible time. Thirty fish, 16 Atlantic chub mackerel (TL size range, 15.4–40.6 cm) and 14 Mediterranean horse mackerel (TL size range, 16.1–29.5 cm), were used in succession for the experiments. The study complies with the Italian animal research legislation (D. Lgs. n. 116 of 27/01/1992).

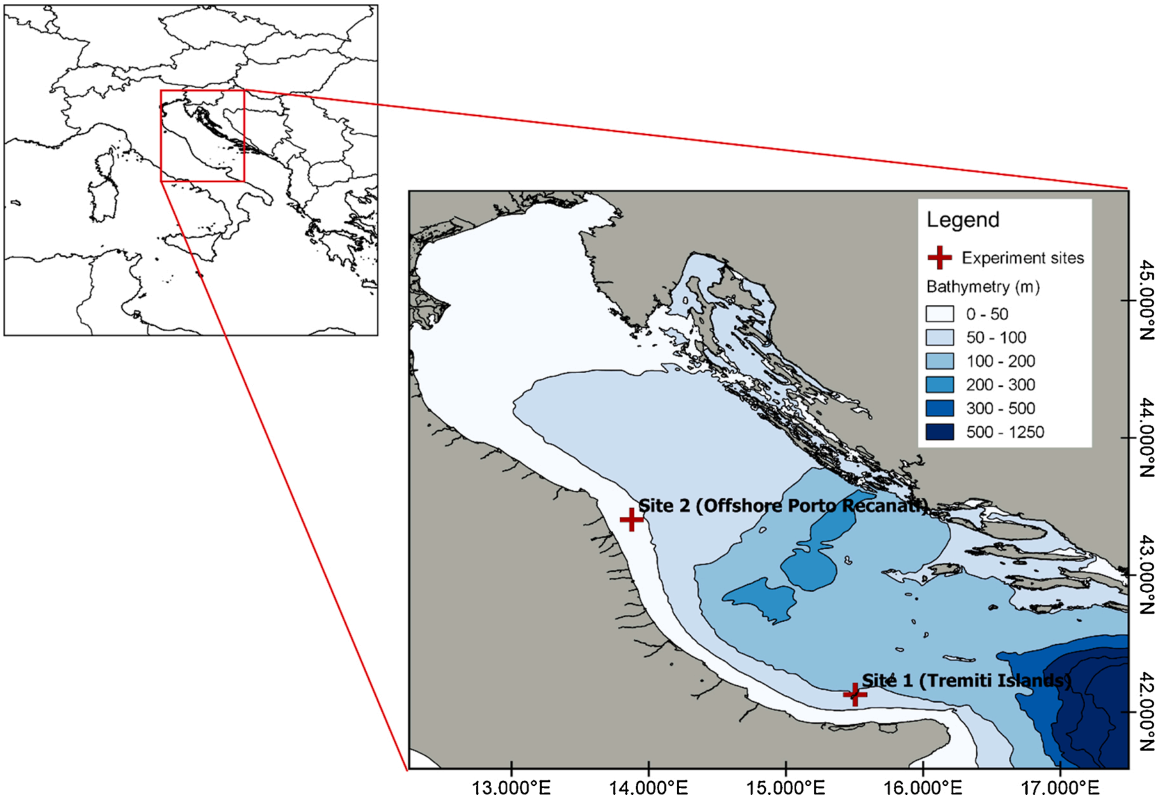

Fig. 1. Sites (+) where the experiments were carried out at the Tremiti Islands (3 experiments, 12th, 14th, and 24th September 2013) and offshore Porto Recanati (one experiment, 26th September 2013).

Table 1
Technical specifications and calibration parameters for the echosounder EK60 system used during the target strength measurements.

Specification	Tremiti Islands			Porto Recanati		
Frequency (kHz)	38	120	200	38	120	200
Absorption Coefficient (dB m^{-1})	0.0077	0.0501	0.0856	0.0083	0.05	0.0817
Sa Correction (dB)	−0.51	−0.34	−0.38	−0.61	−0.36	−0.31
Transducer Gain (dB)	25.54	25.32	25.41	25.77	26.14	25.15
Major Axis 3 dB Beam Angle (°)	7.03	6.35	6.41	7.07	6.26	6.36
Major Axis Angle Offset (°)	−0.07	−0.11	−0.05	−0.03	−0.01	−0.03
Major Axis Angle Sensitivity	21.9	23	23	21.9	23	23
Minor Axis3db Beam Angle (°)	6.97	6.54	6.32	7.07	6.27	6.3
Minor Axis Angle Offset (°)	−0.01	−0.04	−0.07	−0.09	0.02	−0.04
Minor Axis Angle Sensitivity	21.9	23	23	21.9	23	23
Sound Speed (m s^{-1})	1532.2	1532.2	1532.2	1525.3	1525.3	1525.3
Transmitted Power (W)	2000	250	150	2000	250	150
Transmitted Pulse Length (ms)	1.024	1.024	1.024	1.024	1.024	1.024
Two Way Beam Angle (dB re 1 sr)	−21	−20.4	−20.5	−21	−20.4	−20.5

2.2. Data analysis

The acoustic data were scrutinized using Echoview Software (v.10). The background noise removal and impulse noise removal functions were applied to the raw data according to the Echoview post-processing instructions (De Robertis and Higginbottom, 2007). Subsequently, the TS values were extracted through the single-target detection split-beam Method 2, whereby the application of an algorithm based on the standard phase deviation set on the split-beam angle data returns compensated TS values (Soule et al., 1997). The single-target detection parameters are listed in Table 2. To avoid including unwanted targets, only data from the depth layer where the fish was tethered were selected for single-target extraction. In all cases, the fish and the lead weight were clearly visible on the echogram, as shown in Fig. 3. Any echogram section depicting considerable movement of the lead were discarded, since the current had the potential to push the fish outside the acoustic beam. In particular, the sections lacking evident lead echoes were marked as bad regions and cut, or else excluded using the Region Edit function. Careful examination of a control acoustic test, where the entire rig minus the tethered fish was placed under the acoustic beam (using a threshold of -70 dB and the same single-target parameters), allowed calculating the TS thresholds. A threshold of -62 dB set at 38 kHz, -58 dB at 120 kHz and -57 dB at 200 kHz was felt to provide a good compromise between the loss of fish echoes and the gain of echoes from the rope fragment or the monofilament line.

The TS to TL regression was calculated using the standard model: $TS = m \log L + b$ and the model proposed by Foote (1987): $TS = 20 \log L + b_{20}$. The latter model is based on the proportionality of the mean backscattering cross-section (σ) and the square of fish length. The standard model equation was solved by applying a linear regression model, where m and b were respectively the slope and the intercept and L was the TL of the specimens. The parameter b_{20} was estimated according to Simmonds and MacLennan (2005), to compute the equation

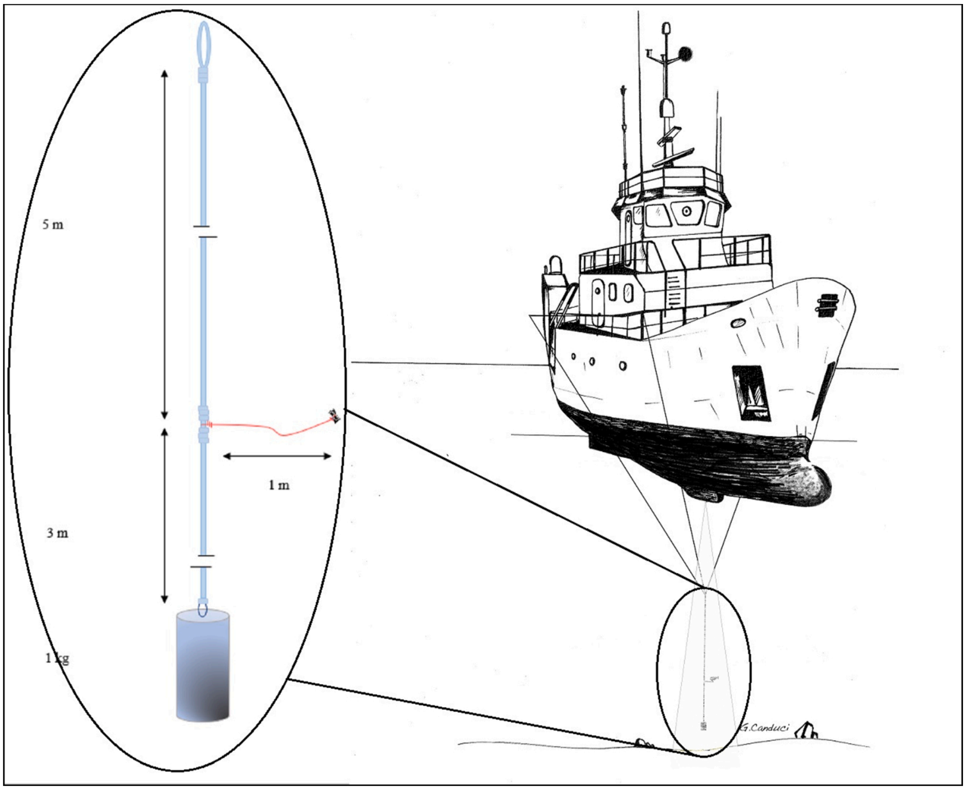

Fig. 2. Experimental design.

Table 2
List of the parameters used for the single-target detection split-beam Method 2 of Echoview software.

TS threshold	−62 dB
Pulse length determination level	6 dB
Minimum normalized pulse length	0.7 ms
Maximum normalized pulse length	1.5 ms
Two-way maximum beam compensation	4 dB
Maximum standard deviation minor-axis angle	0.6°
Maximum standard deviation major-axis angle	0.6°

proposed by Foote (1987) for each species and frequency.

3. Results

Data analyses were performed for all frequencies (38, 120, and 200 kHz), even though the frequency used most commonly for biomass estimations is 38 kHz. Only specimens presenting more than 50 single-target detections were included. A single individual did not meet this criterion and was excluded. Acoustic calibration with the standard sphere demonstrated little change between locations and no difference between days at the same site. The speed of sound was 1532 m/s at the

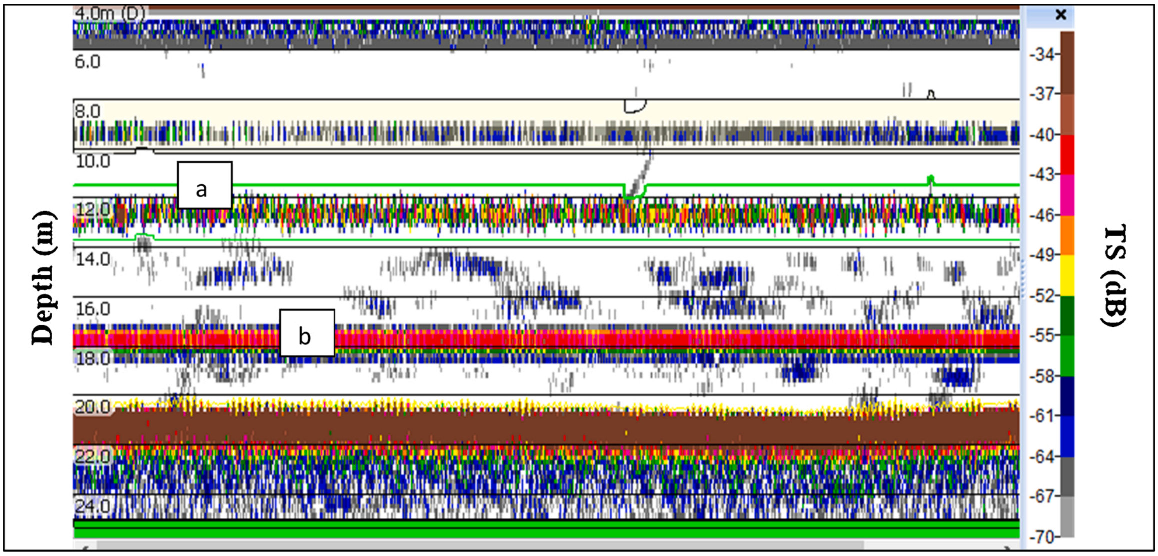

Fig. 3. Representative echogram showing raw TS data of *T. mediterraneus* (frequency, 38 kHz). The color scale of TS (dB) values is on the right. The two layers are (a) the fish and (b) the lead weight. Pings horizontal number = 789.

Tremiti Islands and 1525 m/s off Porto Recanati. Analysis of the control test data (monofilament minus the fish) yielded a TS range of −69.4 to −61.4 dB (mean, −65.6 dB) at 38 kHz, which lent support to the threshold of −62 dB; a TS range from −67.3 dB to −57.7 dB at 120 kHz which lent support to the threshold of−58 dB, and a TS range from −63 dB to −56.6 dB at 200 kHz, which lent support to the threshold of −57 dB. As demonstrated by the TS distribution histograms shown in Figs. 4 and 5, very few single targets reflected at −62 dB at 38 kHz. The histograms display a wide range of values ($\geq$ 25 dB), from −62 dB to −35 dB for *T. mediterraneus* and from −61 dB to −30 dB for *S. colias*.

The TS distribution can often be characterized by more than one mode and mostly exhibits a Gaussian distribution. The TS distribution of Atlantic chub mackerel specimens N8 (38.6 cm), N9 (39.7 cm), and N10 (15.4 cm) was characterized by a single mode to the right of the histogram, with a predominance of higher TS values (note the sign -).

The mean TS was computed on 16 Atlantic chub mackerel (TL size range, 15.4; 31.6–40.6 cm) and 13 Mediterranean horse mackerel (TL size range, 16.1–29.5 cm) specimens based on the mean backscattering cross-section as $\overline{TS} = 10\log(\overline{\sigma}_{bs})$. Further details on the biometric features of the fish specimens are reported in Table S1 supplementary material. For *T. mediterraneus*, the mean TS ranged from −48.4 dB to −41.4 dB at 38 kHz, from −50.2 dB to −43. dB at 120 kHz, and from −49.14 dB to −41.9 dB at 200 kHz; the mean TS for *S. colias* ranged from −45.6 dB to −37.4 dB, from −47.6 dB to −41.1 dB, and from −46.8 dB to −40.5 dB, respectively. In Figs. 6 and 7, the mean TS values are plotted against TL and the two regression lines are fitted in the same Cartesian plane, demonstrating that the mean TS values measured at 120 kHz and 200 kHz were lower and spread more widely around the slopes than those measured at 38 kHz. The mean TS increased significantly with TL for both species at 38 kHz (13 *T. mediterraneus* specimens: $r^2 = 0.37$; $p = <0.05$; 16 *S. colias* specimens: $r^2 = 0.48$; $p = <0.01$) and for Atlantic chub mackerel at 200 kHz (16 individuals; $r^2 = 0.29$; $p = <0.05$), whereas it showed a non-significant relationship with TL at 120 kHz, despite the fact that the trend was positive. The results of the fitted linear model are reported in Table 3.

4. Discussion

This is the first *ex situ* experiment performed on the genus *Trachurus* and on species *S. colias* (Lee and Shin, 2005; Robles et al., 2017). Use of the correct echosounder and echo detection settings and scrutinization of the raw data enabled accurate single-target detection and direct

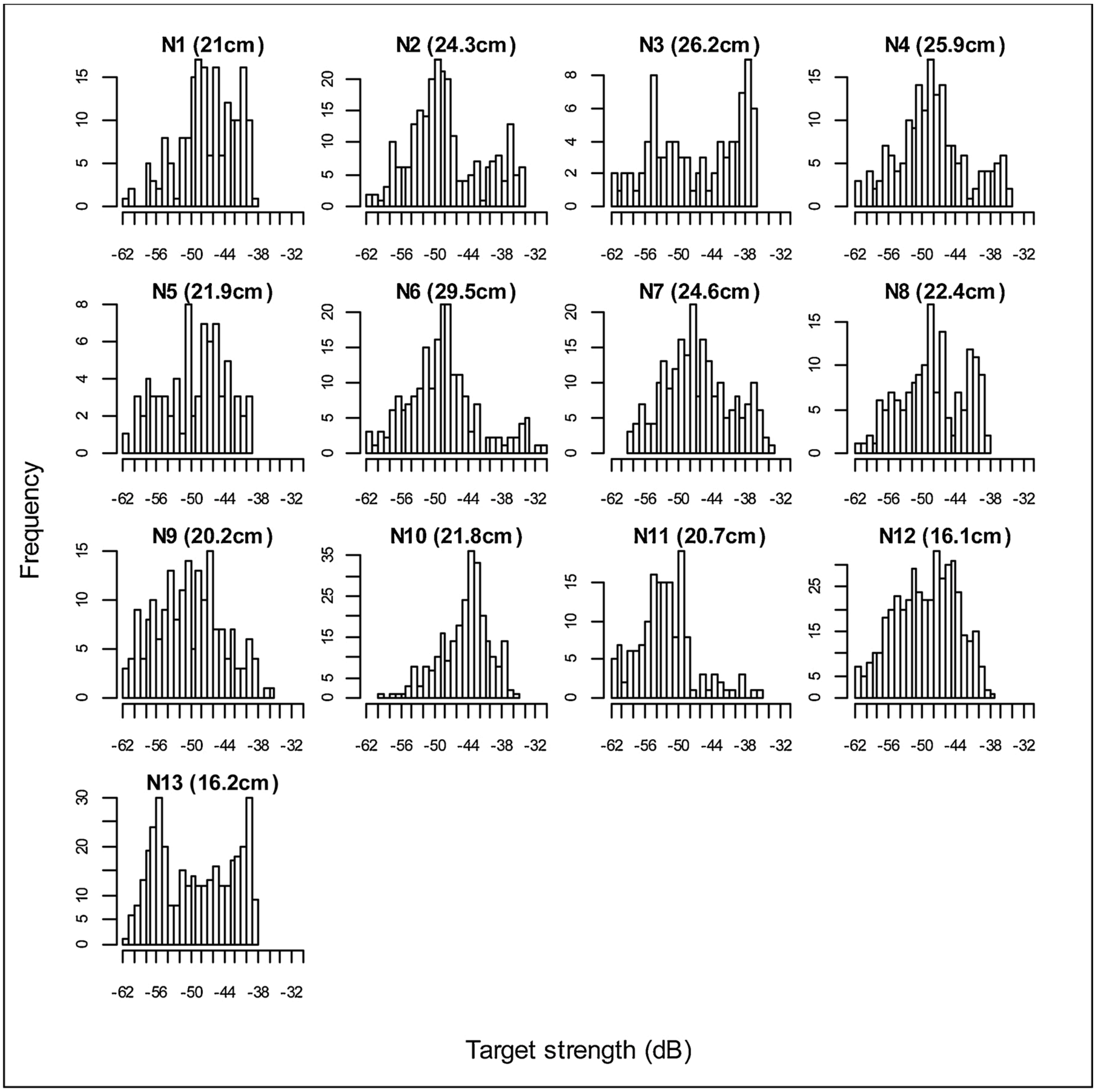

Fig. 4. TS distribution of *T. mediterraneus* at 38 kHz. The ID and total length of each specimen are in parentheses.

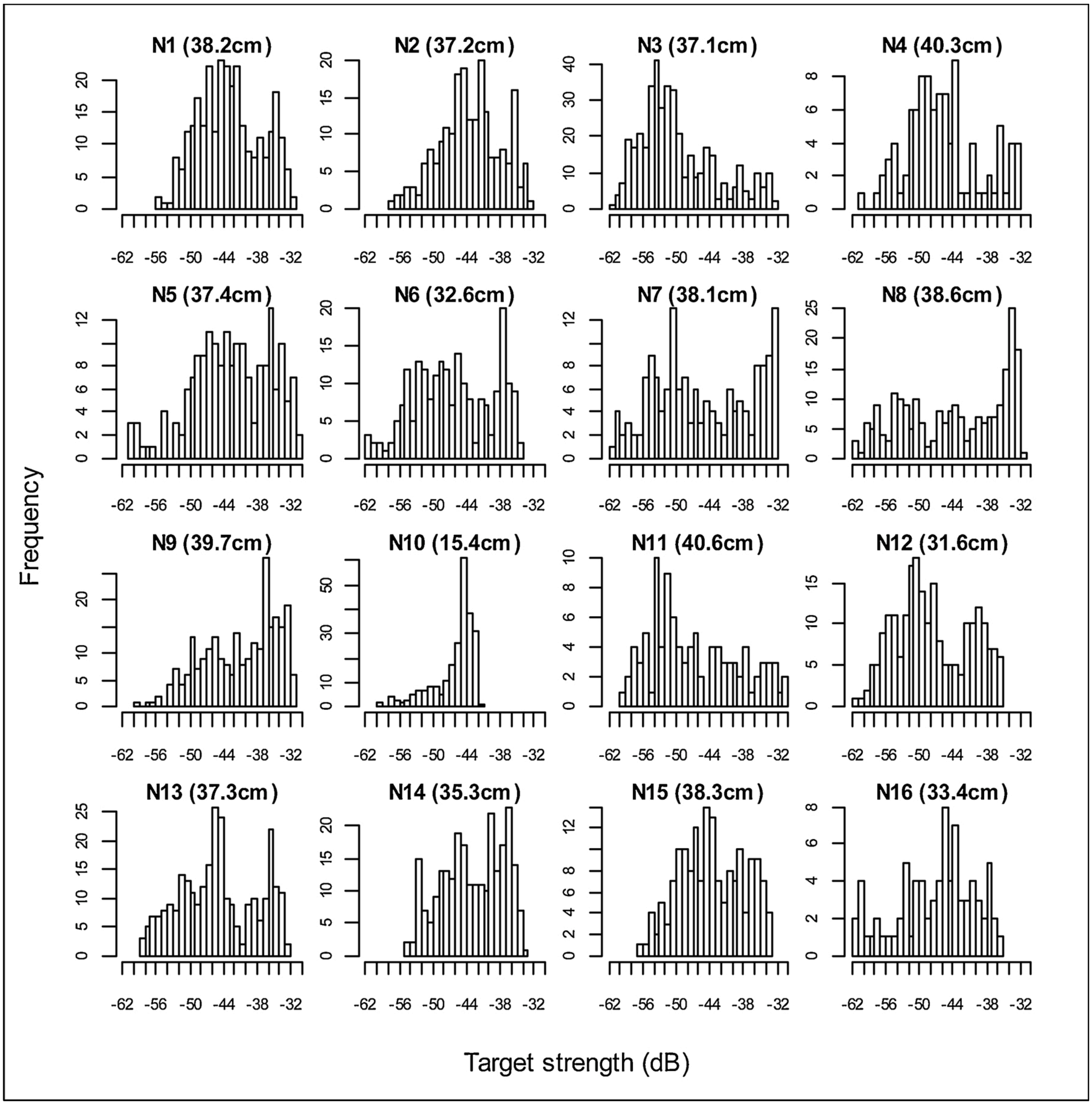

Fig. 5. TS histograms of *S. colias* at 38 kHz. The total length and ID of each specimen are in parentheses.

comparison of the TS and TL of each specimen. Notably, the tethered individuals used in *ex situ* experiments are often hooked and anesthetized, despite the fact that the anesthetic and the hook affect both fish behavior and echo reflection (O’Driscoll et al., 2018). According to Simmonds and MacLennan (2005), experiments carried out on immobile or not healthy fish are insufficiently accurate. The present experiments were devised to overcome these problems, obviating the use of the hook, hence of the anesthetic, and allowing the fish free to move around the tethering apparatus.

Scrutinization of the control test data (where no fish was tied to the line) demonstrated high values of maximum TS, especially at the higher frequencies. Therefore, the small piece of rope yielded worse results of acustic gain of echoes coming from the tethered apparatus compared to ex situ experiments involving hooks (Thomas et al., 2002; Henderson and Horne, 2007; Boswell and Wilson, 2008). On the other hand, all fish displayed a good vitality and the data reported in Figs. 4 and 5 clearly show their stochastic displacements, since TS variability largely depends on fish tilt angle and roll (McClatchie et al., 1996; Horne et al., 2000). Generally, data indicated that we acquired a wide range of tilt angles and fish movements, which however could not be measured. The results of the Atlantic chub mackerel specimens N8, N9 and N10 are likely due to the predominance of a narrow range of negative tilt angles during TS measurements. Notably, fish orientation influences the number of modes and echo intensity. Moreover, while swimming, the mean tilt angle of most fish with a swim-bladder is close to 0° (Henderson and Horne, 2007; Kubilius and Ona, 2012). Peña and Foote (2008) have described a mean angle between $+1^\circ$ and -6° with a standard deviation of 8° to 18° for the genus Trachurus. Our data showed multiple modes and a Gaussian distribution in a 30 dB range as well as low values of the slopes (Table 3). Interestingly, Figs. 4 and 5 suggest that the tethered specimens displayed a satisfactory range of tilt angles during the experiments. Indeed, several ex situ experiments involving medium-large fish have described a slope exceeding 20, probably because the fish were forced in a near-horizontal position, thus exposing the swim-bladder to a tiny positive or negative tilt angle due to the general offset of this organ to the body axis (Simmonds and MacLennan, 2005). All our values are lower than 15.1. Furthermore, in all cases r^2 is greater in the standard equation (Figs. 6 and 7), indicating a more limited adaptation of the TS to TL regression with the slope forced to 20. The great variability in the mean TS, shown in Figs. 6 and 7 at all frequencies, how for these species, fish characterized by 10 cm different size can bring to around the same mean TS. This may be due to an

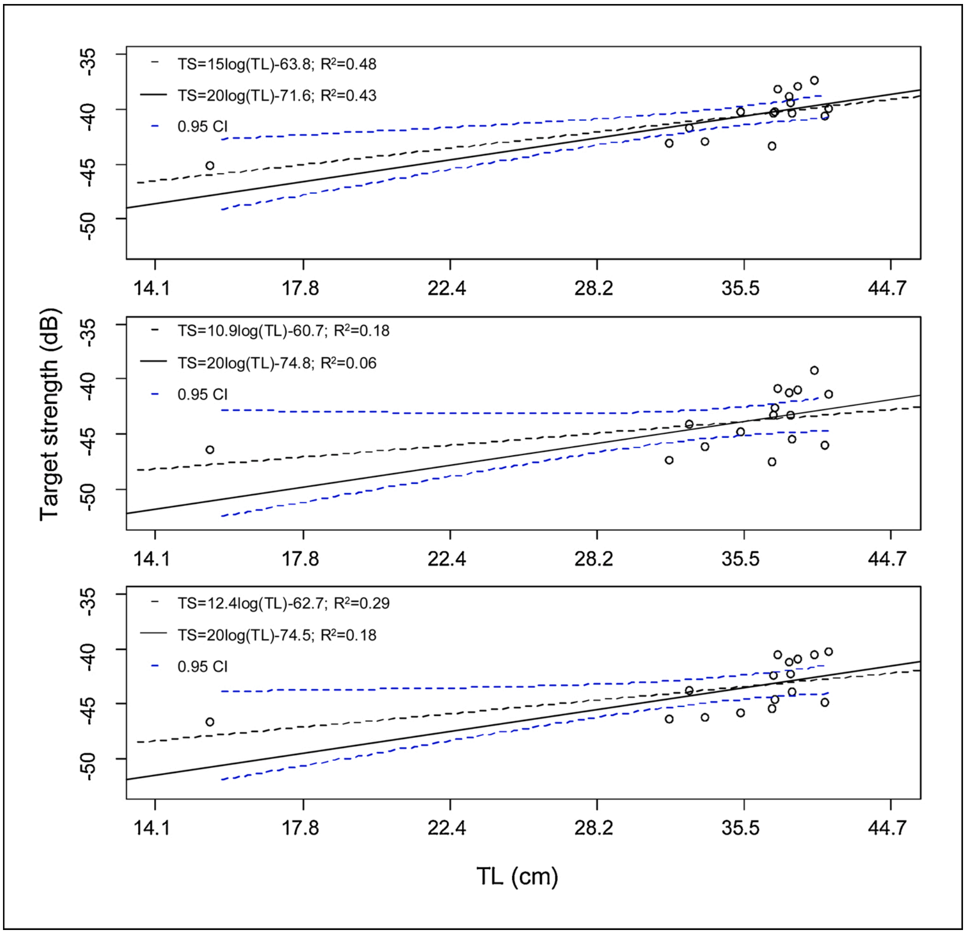

Fig. 6. Target strength length (in logarithmic scale) relationship for *S. colias* calculated at 38 kHz (upper panel), 120 kHz (middle panel), and 200 kHz (lower panel). The results of the standard linear regression model (continuous line) and those obtained with the slope forced to 20 (dashed line) are also shown. Dots represent the mean TS of individual specimens, whereas the dashed blue lines represent the 95 % Confidence Interval.

incongruent growth of the swim-bladder compared to the square of fish TL, to abnormal fish behavior, to a highly variable tilt angle, or to the narrow size range considered (T. mediterraneus, 15.4; 31.6–40.6 cm, S. colias, 16.1–29.5 cm). Therefore, the conversion parameter of the standard model may be more accurate for S. colias and T. mediterraneus. Nevertheless, the limited size range and number of specimens used in our experiments involve that we must accept the 20 log L dependence (Simmonds and MacLennan, 2005; McClatchie et al., 1996) as the best function. The use of target strength–length regressions forced through a slope of 20 appears to be useful for comparisons within the same species and between species of the same group, as suggested by McClatchie et al. (1996). Since there are no published acoustic data on *T. mediterraneus* and *S. colias* (Table 4), the most rational approach seems to be using a model fit to 20 to compare our data to those of the three most widely studied species, *Trachurus capensis* (Cape horse mackerel), *Trachurus symmetricus murphy*, and *Scomber japonicus* (Table 4). These species share similar physiological and morphological features with *T. mediterraneus* and *S. colias*, including same swim-bladder anatomy (Fischer et al., 1981).

Axelsen and co-workers (Axelsen, 1999; Axelsen et al., 2003) have obtained very low b_{20} values for *T. capensis* in an experiment involving a submersible transducer that was suspended just above the fish school. Barange and Hampton (1994) documented that the escape behavior of Cape horse mackerel can influence the backscattering cross-section results. Notably, the TS distribution shifted downward during trawling operations, due to an increased tilt angle. This suggests that the results reported by Axelsen and co-workers may have been influenced by fish escape behavior. In our study this bias was removed by performing all TS measurements with the vessel stationary. If the results of Axelsen and co-workers are excluded, the published b_{20} values of *Trachurus* range from −65.2 dB to −72.1 dB. In particular, at −71.4 dB our b_{20} is similar to the one obtained by Peña and Foote (2008) applying the Kirchoff Ray Mode model to a 3D swim-bladder shape, but it is lower than those reported by other researchers. This can be explained by the smaller size of the *T. mediterraneus* specimens used in our experiments (mean TL, 22.4 cm; range, 16.2–29.5 cm) and by the test conditions, which may influence fish behavior. Comparison of our data to the reference values used by the MEDIAS research groups for biomass assessment, which come from Lillo et al. (1996), yields a 2.5 dB lower value.

TS experiments have seldom been performed at 120 kHz and 200 kHz, due to the sporadic use of the latter frequencies in fish biomass estimations. Indeed, frequency selection should minimize the $L(\mathit{length})/\lambda(\mathit{wavelength})$ ratio (Demer et al., 1999; Hazen and Horne, 2003; McKelvey and Wilson, 2006). The TS to TL relationships found in the present study demonstrate that measurements at 38 kHz provide the best-fit linear models (*T. mediterraneus*, $r^2 = 0.37$; *S. colias*, $r^2 = 0.48$). However, the other two frequencies were also used to gather data to improve the multifrequency approach (Korneliussen, 2018). The difference between $b_{20} = -72.7$ dB at 120 kHz, reported in Table 3, and $b_{20} = -69.6$ dB reported by Robles et al. (2017) for *T. symmetricus murphyi* is probably to be attributed to the application by the authors of a −55 dB threshold besides the different fish size range.

Since Mediterranean horse mackerel is a physoclist species whereas Atlantic chub mackerel is a physostome species (Park et al., 2015), we expected a greater difference between them, as reported in the literature

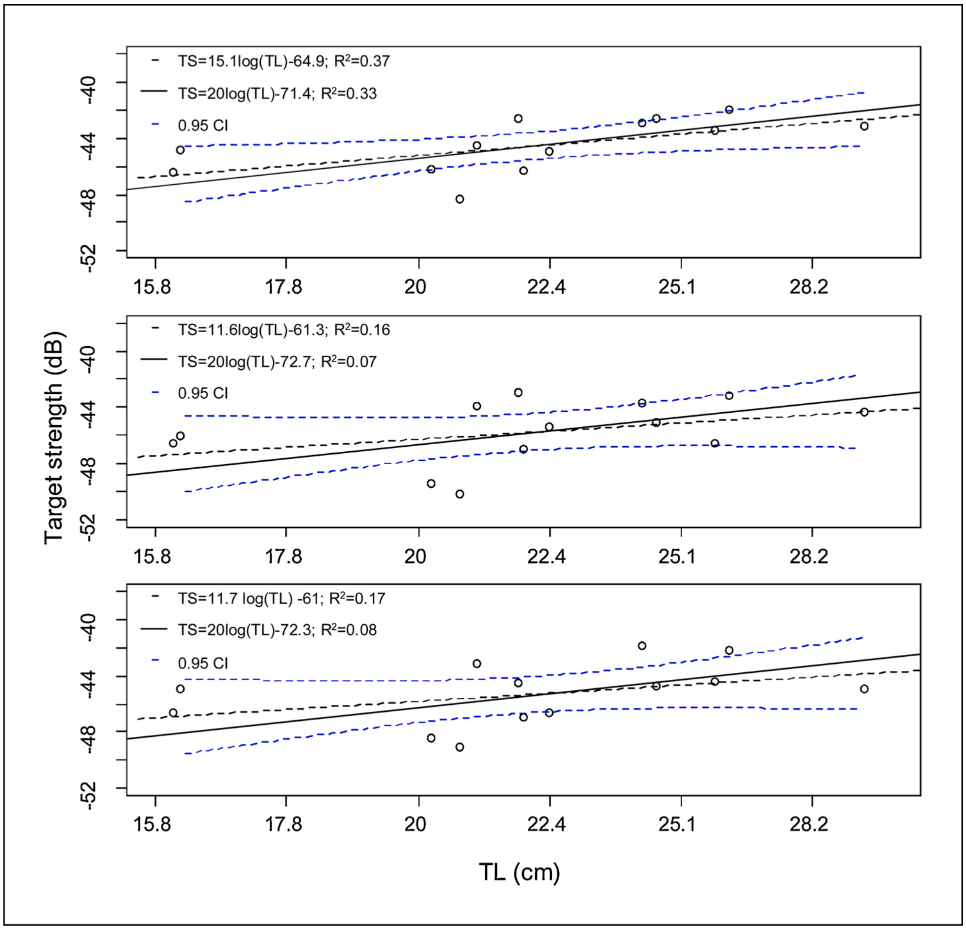

Fig. 7. Target strength-TL relationship for *T. mediterraneus* at 38 kHz (upper panel), 120 kHz (middle panel), and 200 kHz (lower panel). The results of the standard linear regression model (continuous line) and those obtained with the slope forced to 20 (dashed line) are also reported. Dots represent the mean TS of individual specimens, whereas the dashed blue lines represent the 95 % Confidence Interval.

Table 3
Results of the linear model regressions. The slope represents the parameter m in the standard equation. To compute the b_{20} values displayed below the slope was forced to 20.

Frequencies	*T. mediterraneus*		*S. colias*	
38 kHz	Slope = 15.1 Intercept b= −64.9	b_{20}= −71.4	Slope = 15 Intercept b= −63.8	b_{20}= −71.6
120 kHz	Slope = 11.6 Intercept b= −61.4	b_{20}= −72.7	Slope = 10.9 Intercept b= −60.7	b_{20}= −74.8
200 kHz	Slope = 11.8 Intercept b= −61	b_{20}= −72.2	Slope = 12.4 Intercept b= −62.7	b_{20}= −74.5

for other fish families (Foote et al., 1986; Foote, 1987). The difference in their acoustic reflectivity is usually due to depth, since Atlantic chub mackerel is unable to compensate for the volume compression caused by pressure (Thomas et al., 2002; Gorska and Ona, 2003; Fässler et al., 2009b; Ganias et al., 2015). However, all the specimens used in the experiments were first acclimatized in a tank and insonified at about the same depth, thus removing the variability related to this parameter. Moreover, the comparison between physoclist and physostome species is often performed against clupeids, which are physostomes but show significant morphological differences to Scombridae (Somarakis et al., 2000; Fischer et al., 1981). Therefore, the comparison between Carangidae and Scombridae does not necessarily reflect the classic distinction. The similarity may be attributed to a similar shape of the swim-bladder rather than to similar meristic and morphological features. Further modeling experiments based on fish anatomy and swim-bladder dimension and shape will likely clarify this issue.

As shown in Figs. 4 and 5 and in Table 3, TS (and consequently b_{20}) is highly variable within the same species and genus. This variability can be associated with a number of environmental factors, resulting in a different morphological adaptation and reflection (Horne, 2003; Hannachi et al., 2004; Fässler and Gorska, 2009). Since the physical environment influences fish physiology and morphology (Scoles et al., 1998), as demonstrated for *S. japonicus* and *T. mediterraneus* in the Black and Mediterranean Seas (Turan, 2004; Erguden et al., 2009), TS may vary among areas as reported for herring (Ona, 1990), among other species. Therefore, the $b_{20} = -68.7$ dB used by some MEDIAS researchers to estimate *T. mediterraneus* and *S. colias* biomass (Lillo et al., 1996) and the $b_{20} = -70.9$ dB obtained in the Pacific Ocean and used by IFREMER for *S. colias* (Gutiérrez and Maclennan, 1998), may be insufficiently accurate.

5. Conclusion

In the framework of the MEDIAS program, the data of *T. mediterraneus* and *S. colias*, collected for biomass assessment purposes, are pooled under the category “other species”. The b_{20} values obtained in the present study, -71.4 dB for *T. mediterraneus* and -71.6 dB for *S. colias,* can be used for single-species assessment and can be considered as a starting point to overcome the regional knowledge gap in the acoustic backscattering coefficients of non-target species. The main limitation of our approach is related to its possible influence on fish

Table 4
Overview of published b_{20} values for the genus *Trachurus* and the species *S. japonicus*. The mean TS ($\overline{TS}$) or the TS range (/) are reported where available.

REFERENCE	SPECIES	METHOD	FREQ (kHz)	TL (cm)	TS (dB)	b_{20} (dB)
Svellingen and Ona, 1999	*T. capensis*	*In-situ*	38	$\overline{17.2}$	$\overline{-42.1}$	**−66.8**
				$\overline{15.8}$	$\overline{-41.4}$	**−65.2**
Axelsen, 1999	*T. capensis*	*In-situ*	38	$\overline{17.5}$	−55/−28	**−75**
					−55/−36	**−76.2**
Axelsen et al., 2003	*T. capensis*	*In-situ*	38	$\overline{17.2}$	$\overline{-45.9}$	**−70.9**
				$\overline{18}$	$\overline{-49.5}$	**−74.9**
				$\overline{26.7}$	$\overline{-48.8}$	**−77.5**
				$\overline{25.1}$	$\overline{-46.9}$	**−75.1**
				$\overline{25.1}$	$\overline{-48.4}$	**−76.6**
Barange and Hampton, 1994	*T. capensis*	*In-situ*	38	$\overline{40.2}$	$\overline{-38.5}$	**−66.8**
Lillo et al., 1996	*T. symmetricus murphyi*	*In-situ*	38	22−40		**−68.91**
Peña and Foote, 2008	*T. symmetricus murphyi*	*Model*	38	20−47	−28/−47	**−72.1**
Robles et al., 2017	*T. symmetricus murphyi*	*In-situ*	38	27−38	$\overline{-38.11}$	**−68.9**
			120		$\overline{-38.79}$	**−69.6**
Gutiérrez and Maclennan, 1998	*T. capensis*	*In-situ*	38	33−48		**−68.15**
Gutiérrez and Maclennan, 1998	*S. japonicus*	*In-situ*	38	26−30		**−70.95**
			120			**−70.8**
Lee and Shin, 2005	*S. japonicus*	*Ex-situ*	120	26.2−38.3		**−66.9**
			200			**−71.1**
Svellingen and Charouki, 2008	*S. japonicus*	*In-situ*	38	$\overline{21.8}$	$\overline{-50.9}$	**−77.6**
			120		$\overline{-53.1}$	**−79.8**

swimming behavior, although it can be less invasive than the other methods used in *ex situ* experiments. The specimen size range considered in the study may also be too narrow. Further work is clearly needed to validate our approach. A backscatter model would be able to support our conclusions by enabling processing factors, such as the tilt angle, which are not measured in this study. In contrast, *in situ* experiments to assess these species are difficult to perform, since they require monospecific hauls but have to be conducted at night, when several other species come to the surface to feed, thus forming multispecies schools. Altogether, our findings have the potential to be used for future biomass estimations of Atlantic chub mackerel and Mediterranean horse mackerel, provided that they are validated by further investigations of their backscattering cross-section.

CRediT authorship contribution statement

Antonio Palermino: Formal analysis, Data curation, Writing - original draft, Visualization. **Andrea De Felice:** Conceptualization, Methodology, Validation, Investigation, Writing - review & editing, Supervision. **Giovanni Canduci:** Conceptualization, Methodology, Investigation, Writing - review & editing. **Ilaria Biagiotti:** Writing - review & editing. **Ilaria Costantini:** Investigation, Writing - review & editing. **Sara Malavolti:** Writing - review & editing. **Iole Leonori:** Supervision, Conceptualization, Project administration, Writing - review & editing, Resources.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fishres.2021.105973.

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