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In situ acoustic target strength measurements of tuna associated with a fish aggregating device

Erwan Josse, and Arnaud Bertrand

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In situ measurements of target strength (TS) at 38 kHz have been taken from tuna gathering around a fish aggregating device (FAD) during two cruises carried out at an interval of a year. Mean TS of −31.9 dB and −32.8 dB were measured on tuna aggregations composed mainly of 50 cm mean fork length *Thunnus obesus*. Mean TS were very similar between the different surveys of the same cruise. Between cruises a small difference in average TS was observed. It may be explained by the variation of the species composition of the aggregation. A greater proportion of *Thunnus albacares* and *Katsuwonus pelamis* was observed in the second year. *In situ* TS measurements on tuna associated with a FAD provide references of value in estimating aggregation's biomass. Furthermore TS data obtained on aggregated tuna may be useful for behavioural studies of the aggregation such as school behaviour and cohesiveness, fish length distribution, and vessel avoidance.

Key words: acoustics, target strength, tuna, *Thunnus obesus*, aggregation, FAD.

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

Introduction

Knowledge about individual target strength (TS) is essential for the acoustic assessment of fish biomass and behavioural studies. Since the development of split-beam and dual-beam technology, *in situ* TS measurements have been applied on most important small pelagic fish but rarely on tuna and other large pelagic species.

Two approaches to *in situ* tuna target strength measurements have been developed within the ECOTAP[1] programme carried out in French Polynesia:

(1) TS measurements on acoustically tracked fish; and
(2) TS measurements on fish aggregated close to a fish aggregating device (FAD).

The first method described by Bertrand *et al.* (1999a, b) allows TS measurements of easily identified fish only. It is applicable especially to large fish scattered in depth and allows observations of TS variations in relation to free-swimming fish behaviour. In the second method, as described here, a mean TS is obtained for a whole aggregation. TS measurements are carried out on a large number of targets and a fish sample has to be caught in order to determine the length and species composition of the detected targets. This method is technically easier to carry out than the other but only has a statistical meaning, as there is no direct relationship between one target and one echo.

[1]ECOTAP (Etude du COmportement des Thonidés par l'Acoustique et la Pêche/Studies of tuna behaviour using acoustic and fishing experiments) is a joint programme between two French research institutes (IFREMER: Institut français de recherche pour l'exploitation de la mer and ORSTOM: L'institut français de recherches scientifiques pour le développement en coopération, now IRD: Institut de recherche pour le développement) and a Polynesian institute (EVAAM: Etablissement pour la Valorisation des Activités Aquacoles et Maritimes, now SRM: Service des Ressources Marines). The aim of this programme was to study the distribution and the behaviour of subsurface tuna: bigeye tuna (*Thunnus obesus*, Lowe 1839), yellowfin tuna (*Thunnus albacares*, Bonnaterre, 1788) and albacore tuna (*Thunnus alalunga*, Bonnaterre 1788), exploited by local longline in open ocean and drop-stone technique near FADs (Moarii & Leproux, 1996).

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Table 1. *Main settings of the SIMRAD EK500 echosounder used during ECOTAP05 and ECOTAP12 cruises.*

Operation menu	Ping interval	0.0	
	Transmit power	Normal	
	Noise margin	10 dB	
Tranceiver menu	Absorption coef.	10 dB/km	
	Pulse length	Medium	
	Bandwidth	Auto	
	Maximum power	2000 W	
	2-way beam angle	− 20.9 dB	
		ECOTAP05	ECOTAP12
	Sv transducer gain	27.7 dB	27.2 dB
	TS transducer gain	27.8 dB	26.6 dB
	Angle sensitiv.	21.9	21.9
	3 dB beam angle	6.9 deg	6.8 deg
	Alongship offset	− 0.07 deg	− 0.00 deg
	Athw. ship offset	0.21 deg	0.02 deg
TS Detection menu	Minimum value	− 50 dB	
	Minimum echo length	0.8	
	Maximum echo length	1.8	
	Maximum gain comp.	6.0 dB	
	Maximum phase dev.	2.0	

Methods

Experiments took place near an oceanographic buoy anchored within the TOGA (Tropical Ocean Global Atmosphere) sampling grid. This buoy, which is comparable to an anchored FAD, is located at 5° South and 140° West, approximately 200 nautical miles from the nearest island.

The field work was carried out from the 28 m IRD Research Vessel "Alis" during ECOTAP05 and ECOTAP12 cruises carried out in January 1996 and February 1997, respectively. The R/V "Alis" was equipped with a SIMRAD EK500 echosounder (version 4.01) connected to a 38 kHz SIMRAD ES38B (full beam angle: 6.9°) hull-mounted split-beam transducer and a pulse duration of 1 ms was used. Acoustic and navigation data were stored via ETHERNET on a personal computer (PC) through SIMRAD EP500 software (SIMRAD, 1994). The on-axis and off-axis calibrations of acoustic equipment were carried out before each cruise with a 60 mm copper sphere using the standard procedure described in the EK500 operator manual (SIMRAD Subsea, 1993). Table 1 gives the main settings used during the two cruises.

Echo-surveys (Table 2) were conducted at a mean speed of 6 to 7 knots around the FAD following an eight-branch star pattern. These two hour-long surveys, were limited to a radius of 0.6 to 0.8 nautical mile around the FAD and repeated several times over a 24-hour period. Additional target strength data were recorded during fishing operations at the same speed ("Trolling" surveys). In January 1996 all acoustic measurements were carried out between the surface and a depth of 500 m. In February 1997 additional observations were carried out between the surface and a depth of 150 m both during a fishing operation ("Trolling 2" survey) at a speed of 6 to 7 knots, and during an acoustic survey ("Target" survey) at a speed of 1 to 2 knots.

Target strength data selected by the EK500 (see Soule *et al.* (1995) for a review of the SIMRAD algorithms) were extracted from data files using the "trace tracking" procedure of the SIMRAD EP500 software (SIMRAD, 1994). A minimum TS threshold of − 46 dB was applied and only individual targets tracked on at least two pings and with a maximum of one missing ping per track were considered. A visual comparison between selected targets by EP500 software and echograms was done to validate each individual TS data. Selected TS data were transformed to acoustic cross section (arithmetic values) to calculate mean TS values.

In order to determine the species composition and length structure of the tuna aggregation fishing operations using surface trolling lines were conducted during daytime from the R/V "Alis". Species, fork length, swimbladder condition (intact or damaged, gas-filled or not) and time were recorded for each fish caught.

Results

Table 3 presents the main characteristics of trolling catches surveyed in the proximity of the TOGA oceanographic buoy. The proportion of *T. obesus* in catches was smaller in 1997 than in 1996 but always made up most of each catch. During the two cruises the mean fork length for *T. obesus* was quite similar (Fig. 1).

During all the experiments around the TOGA oceanographic buoy, a total of 5717 tracked fish target

Table 2. Mean TS measurements during surveys around the TOGA oceanographic buoy.

Cruise	Survey	Date	Time	Vessel speed (knots)	Range (m)	Number of obs.	CV (%)	TS (dB)
ECOTAP05 (January 1996)	1	19/01/96	06 h 30–08 h 20	6–7	500	16	80	− 33.3
	2	19/01/96	09 h 10–11 h 40	6–7	500	60	104	− 32.6
	3	19/01/96	13 h 20–15 h 10	6–7	500	76	89	− 30.6
	4	19/01/96	17 h 05–18 h 52	6–7	500	0	—	—
	5	19/01/96	21 h 18–21 h 41	6–7	500	0	—	—
	6	20/01/96	05 h 00–06 h 30	6–7	500	2	673	− 40.7
	7	20/01/96	08 h 30–10 h 10	6–7	500	37	105	− 31.4
	Total 1 to 7			6–7	500	191	89	− 31.6
	Trolling 1	20/01/96	12 h 50–14 h 50	6–7	500	74	92	− 31.3
	Trolling 2	21/01/96	07 h 30–13 h 10	6–7	500	377	76	− 32.2
	Total trolling	—	—	6–7	500	451	79	− 32.0
	Total	—	—	6–7	500	642	82	− 31.9
ECOTAP12 (February 1997)	1	10/02/97	06 h 00–08 h 20	6–7	500	60	122	− 33.5
	2	10/02/97	09 h 30–11 h 45	6–7	500	61	92	− 31.5
	3	10/02/97	13 h 00–15 h 00	6–7	500	8	132	− 30.8
	4	10/02/97	16 h 30–18 h 45	6–7	500	4	205	− 37.5
	5	10/02/97	21 h 00–23 h 20	6–7	500	1	—	− 26.6
	6	11/02/97	01 h 30–03 h 40	6–7	500	14	179	− 28.3
	Total 1 to 4	—	—	6–7	500	133	94	− 32.3
	Total 1 to 6	—	—	6–7	500	148	97	− 31.7
	Target	11/02/97	08 h 10–10 h 15	1–2	150	1751	73	− 33.2
	Trolling 1	11/02/97	10 h 15–11 h 30	6–7	500	106	100	− 32.8
	Trolling 2	12/02/97	05 h 45–11 h 30	6–7	150	3070	60	− 32.7
	Total trolling	—	—	6–7	—	3176	61	− 32.7
	Total	—	—	—	—	5075	64	− 32.8

Time is local time: UT − 09 h 30. CV, coefficient of variation calculated on the mean acoustic cross section data.

Table 3. Species composition of tuna catches around the TOGA oceanographic buoy (fork length measurements were made to the lower centimetre).

Cruise	Species	*Katsuwonus pelamis*	*Thunnus albacares*	*Thunnus obesus*
ECOTAP05 (January 1996)	Number (%) of fish	1 (1%)	7 (7%)	97 (92%)
	Minimum length	44	41	34
	Maximum length	44	79	85
	Mean length	44	67.1	50.1
ECOTAP12 (February 1997)	Number (%) of fish	5 (5%)	14 (15%)	72 (79%)
	Minimum length	40	44	37
	Maximum length	80	72	65
	Mean length	54.6	56.1	49.9

strength were measured (Fig. 2, Table 2). Mean target strength measurements were compared among surveys for each cruise using Student t-tests. Survey 6 from January 1996, and surveys 3, 4 and 5 from February 1997, were not included because of a small number of observations.

Student t-tests did not show significant differences ($p>0.05$) among the mean target strengths measured during the different surveys carried out in January 1996. The only exception was survey 3 where mean TS was significantly higher ($p<0.05$) than those of surveys 1, 2 and "Trolling 2". In February 1997 night-time and daytime TS were significantly or highly significantly ($p<0.01$) different: night-time TS values were higher than daytime TS values. Significant differences were also observed between "Target" and "Trolling 2" surveys.

Target strength values were classified by depth for each cruise. Six 25 m depth strata from the surface to 150 m, and four 50 m depth strata between 150 and 350 m were defined (Table 4). Student t-tests were used to study the influence of depth on TS values.

Significant and highly significant differences between the mean target strengths by depth stratum were frequently observed (Table 5). Strata can be combined in

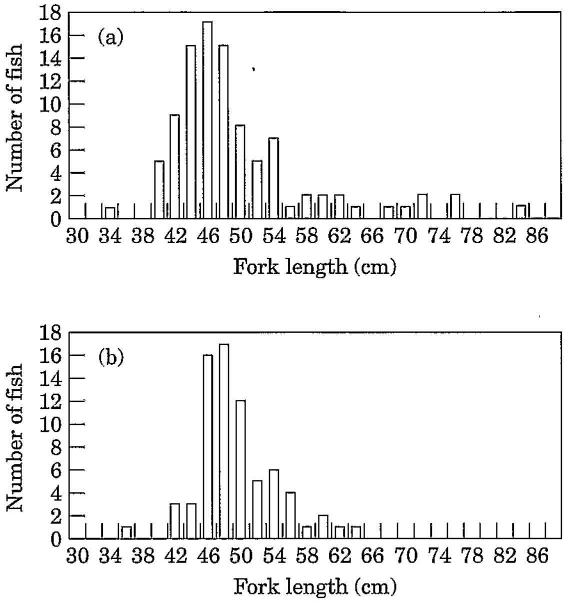

Figure 1. Size composition of *T. obesus* observed from trolling operations around the TOGA oceanographic buoy in (a) January 1996 (n=97) and (b) February 1997 (n=72).

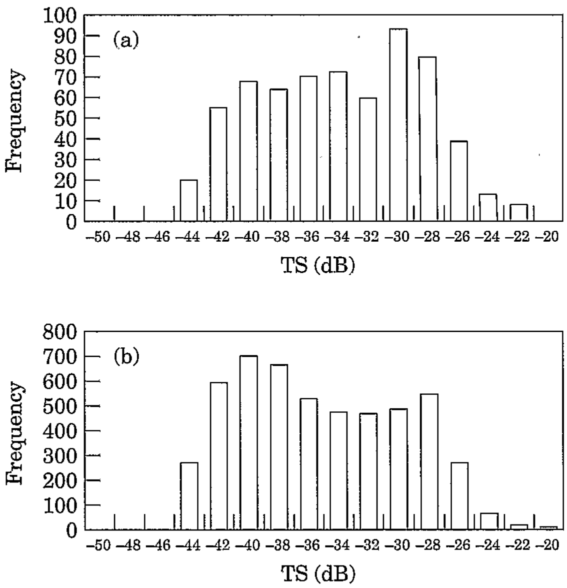

Figure 2. Histograms of *in situ* TS data from tuna measured around the TOGA oceanographic buoy in (a) January 1996 (n=642) and (b) February 1997 (n=5075).

four homogeneous groups that are quite similar from cruise to cruise:

ECOTAP05 cruise:

– stratum 0–25 m with a high mean TS (> −30 dB),

– strata 25–50 m and 50–75 m where low mean TS (< −36 dB) were observed,

– strata 75–100 m, 100–125 m, 125–150 m and 150–200 m with intermediate mean TS values (−32 to −33 dB).

– strata deeper than 200 m with high values of mean TS (−29 to −27 dB).

ECOTAP12 cruise:

– stratum 0–25 m with a high mean TS (−31 dB),

– stratum 25–50 m with a low mean TS (−34 dB),

– stratum 50–75 m and 75–100 m with mean TS a bit higher than in the previous stratum (−33 dB).

– strata 100–125 m and 125–150 m where mean TS is close to that observed in the surface stratum (−31 dB).

As highly significant target strength differences were observed between "Target" and "Trolling 2" surveys in February 1997, TS distribution versus depth was also studied for the two experiments (Table 6). During the "Target" survey the vessel speed was between 1 and 2 knots while it was between 6 and 7 knots during the "Trolling 2" survey (Table 2). Therefore as the ping rate was constant the number of hits on a same fish was different. The vertical TS variability was lower during the "Target" survey than during the "Trolling 2" survey as a high mean TS, usually observed close to the surface, was not observed during the "Target" survey. In the deepest strata the increase of mean TS is also lower during the "Target" survey than during the "Trolling 2" survey. Furthermore a different vertical distribution of targets in the water column was observed. Detected fish were on average deeper during the "Target" survey (Table 6).

Discussion

Fishing technique

One of the main difficulties in interpreting target strength data rests in the biological sampling necessary to identify the species and the size composition of the insonified targets. In this study tuna aggregations have been sampled with surface trolling lines. With this fishing technique bias is possible in catch composition and fish length distribution of the studied aggregation. However other techniques like the purse seine are not easy to bring into operation without the help of a commercial fishing boat and in any case are difficult around anchored FADs because of the mooring line.

Inter-cruise variation

The situations encountered around the TOGA oceanographic buoy both in January 1996 and in February 1997 were close to the optimal conditions described by MacLennan & Simmonds (1992): fish distribution was homogenous. Fishing samples between years were similar (Table 3 and Fig. 1). Catches were primarily composed of juvenile *T. obesus*. Mean target strength measured in each of the two cruises was similar: −31.9

Table 4. Mean TS measurements in relation to depth strata around the TOGA oceanographic buoy.

Cruise	Depth stratum	Number of observations	Mean depth (m)	CV (%)	TS (dB)
ECOTAP05 (January 1996)	0–25 m	19	19.0	131	− 29.6
	25–50 m	24	37.4	82	− 36.4
	50–75 m	44	64.4	57	− 36.7
	75–100 m	123	90.0	77	− 33.3
	100–125 m	205	111.7	83	− 31.9
	125–150 m	122	135.0	108	− 32.6
	150–200 m	39	166.4	74	− 33.5
	200–250 m	21	222.5	111	− 29.3
	250–300 m	30	281.5	165	− 27.4
	300–350 m	15	322.8	148	− 28.0
ECOTAP12 (February 1997)	0–25 m	414	21.8	107	− 31.2
	25–50 m	1781	36.6	59	− 34.0
	50–75 m	1132	61.6	44	− 33.2
	75–100 m	832	86.8	71	− 33.0
	100–125 m	655	112.2	107	− 31.4
	125–150 m	252	133.3	89	− 31.0
	>150 m	9	213.8	98	− 30.2

Table 5. Results of Student t-tests on mean TS comparison between depth strata around the TOGA oceanographic buoy.

Cruise	Depth stratum (m)	25–50	50–75	75–100	100–125	125–150	150–200	200–250	250–300	300–350
ECOTAP05 (January 1996)	0–25	**	**	**	*	*	**	NS	*	NS
	25–50		NS	**	**	**	NS	**	**	**
	50–75			**	**	**	*	**	**	**
	75–100				*	NS	NS	**	**	**
	100–125					NS	NS	*	**	**
	125–150						NS	*	**	**
	150–200							**	**	**
	200–250								NS	NS
	250–300									NS
ECOTAP12 (January 1997)	0–25	**	**	**	NS	NS				
	25–50		*	**	**	**				
	50–75			NS	**	**				
	75–100				**	**				
	100–125					NS				

NS, not significant; *significant (p=0.05); **highly significant (p=0.01).

and − 32.8 dB. In this paper TS values will be expressed with one decimal. However, the decimals are here only for illustration and should not be interpreted physically. Average fork lengths of *T. obesus* caught during both cruises were almost equal (50 cm). The small difference (close to 1 dB) observed between the two cruises can be explained by the species composition of the aggregation and variations in swimbladder volume between species. Indeed the swimbladder is assumed to be responsible for 90–95% of the backscattering energy (Foote, 1980). In February 1997 catch data indicate a larger proportion of *T. albacares* and *Katsuwonus pelamis* than in January 1996. *K. pelamis* does not have a swimbladder while *T. albacares* develops a gas-filled swimbladder when the fish weight exceeds 2 kg (Magnusson, 1973). However the swimbladder volume of *T. albacares* is, for the same fish length, lower than *T. obesus* one (Bard *et al.*, 1998). Bertrand *et al.* (1999a, b) determined TS values of − 34.8 and − 33.0 dB for a 60 and a 90 cm fork length *T. albacares*, respectively. *T. albacares* caught by trolling lines were respectively 67 and 56 cm fork length in January 1996 and February 1997. It can be assumed that the average TS of these fish is lower than those of a 50 cm fork length *T. obesus*. The greater proportion of *T. albacares* in February 1997 could then explain a part of the 1 dB difference observed between the two cruises. The same reasoning is possible for *K. pelamis* which has no swimbladder.

Table 6. Comparison between mean TS vs. depth during "Target" and "Trolling 2" surveys around the TOGA oceanographic buoy in February 1997.

Depth stratum	Target survey: Number of observations	Target survey: Mean depth (m)	Target survey: TS (dB)	Trolling 2 survey: Number of observations	Trolling 2 survey: Mean depth (m)	Trolling 2 survey: TS (dB)
0–25 m	85 (5%)	22.0	−33.6	326 (11%)	21.7	−30.7
25–50 m	562 (32%)	36.6	−33.1	1199 (39%)	36.6	−34.6
50–75 m	358 (20%)	61.6	−34.4	726 (24%)	61.4	−32.9
75–100 m	252 (14%)	86.9	−33.6	501 (16%)	86.5	−32.8
100–125 m	316 (18%)	114.5	−32.4	270 (9%)	109.5	−30.2
125–150 m	178 (10%)	132.1	−32.1	48 (2%)	136.3	−28.1
Total	1751 (100%)	72.0	−33.2	3070 (100%)	57.0	−32.7

Histograms of this distribution of target strength values observed during the two cruises are very similar (Fig. 2). Two modes are noticeable but they cannot be related to species or size composition of the aggregation (Table 3 and Fig. 1). TS values vary from −46 to −20 dB. For the same fish, 15 dB variations or more in *in situ* TS measurements are common (Rose & Porter, 1996; Bertrand *et al.*, 1999a, b), particularly when fish have a swimbladder. In the case of *in situ* TS measurements on a great number of targets, MacLennan & Simmonds (1992) concluded that the observed target strengths cover a large range, spanning 20 dB or more, even when the fish are nearly the same size.

Intra-cruise variability

For each cruise the target strengths measured during the different surveys were similar. In January 1996 no significant difference in mean TS was observed during the 3 days of survey work. It was the same in February 1997 with one exception that is discussed later. This stability is attributed to the behaviour of the fish. Indeed all the different echo-surveys showed that the aggregation abundance around the FAD was at a maximum in the early morning after sunrise and that the fish scattered or disappeared in the afternoon. This pattern is consistent with the acoustic track of a 77 cm fork length *T. obesus* in January 1996 (Josse *et al.*, 1998). The tracked fish, caught within the aggregation, left the vicinity of the TOGA oceanographic buoy in the afternoon as the aggregation dissipated. During the night the fish was swimming a few miles off the FAD outside any detected aggregation. The fish came back close to the FAD the next morning at sunrise when the aggregation re-formed. Thus the stability of the TS values observed may be interpreted as being the daily repetition of the structure pattern and the specific composition of the aggregation.

Comparison with other studies

The only other target strength data available on *T. obesus* were obtained in the framework of the ECOTAP programme (Bertrand *et al.*, 1999a, b). Mean TS of −24.4 dB and −21.4 dB were measured for fish of 110 and 130 cm fork length. The lower mean TS obtained in this study (−31.9 and −32.8 dB for fish of 50 cm fork length) must be related to the fish length, and consequently to the swimbladder volume differences. The swimbladder volume has been estimated to be 1000 and 2500 cm^3 for the two *T. obesus* (110 and 130 cm fork length) studied by Bertrand *et al.* (1999a, b). It has been estimated at 120 cm^3 for a 50 cm fork length *T. obesus* (ECOTAP programme, unpublished data). The swimbladder volume of a 90 cm fork length *T. albacares* with a mean TS of −33.0 dB has been estimated to be 130 cm^3 (Bertrand *et al.*, 1999a, b). Thus the TS values measured in the present study and by Bertrand *et al.* (1999a, b) are consistent. TS value of *T. obesus* increases with the size of the fish and the swimbladder volume.

Biological depth variations

A depth stratification of target strength values was observed during both cruises (Table 4). The stratum close to the surface is characterised by high TS values (−30 dB). When the depth is increasing TS values first decrease until about 50 m (−36 dB) and then increase regularly after this depth (up to −28 dB at 300 m). Parrish (1989) reports that in general smaller fish occupy a higher position in the water column than larger fish; therefore the regular increase in mean TS values with depth observed below the surface stratum during the two cruises could be explained in this way. However it is not eacy to confirm this hypothesis without data on length frequencies per depth strata. The only observations available on fish swimming behaviour inside the aggregation come from the 77 cm fork-length *T. obesus* tracked during the first cruise. This fish, one of the biggest caught during the cruise, did not show a clear swimming depth pattern and was observed in each depth stratum (Fig. 3). However it was mainly swimming between 75 and 125 m, i.e. deeper than the depth of the maximum density of the aggregation as discussed later.

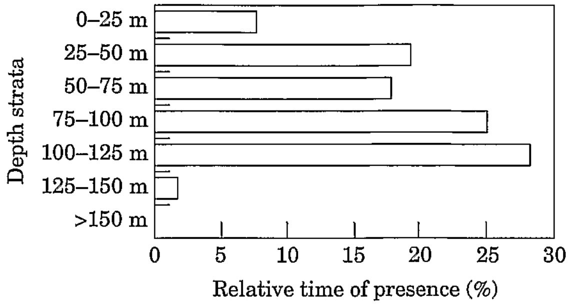

Figure 3. Relative time of presence per depth strata around the TOGA oceanographic buoy in January 1996 of the 77 cm fork length acoustically tracked *T. obesus*.

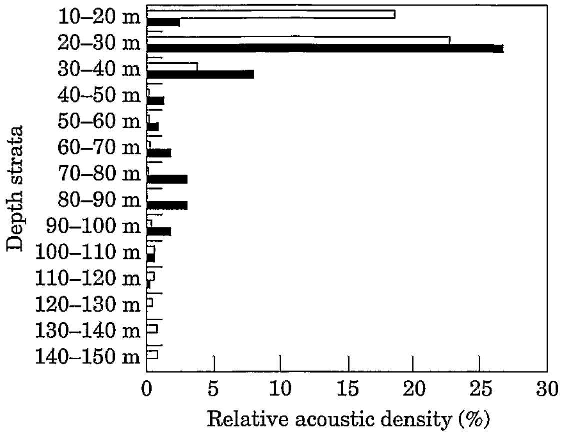

Figure 4. Relative acoustic densities observed by 10 m depth strata around the TOGA oceanographic buoy during surveys 2 performed in January 1996 (open bars) and February 1997 (black bars) (ECOTAP programme, unpublished data).

This observation remains limited. Further acoustic tracking of fish of various lengths would be necessary to confirm or invalidate this hypothesis.

Technical depth variations

Soule *et al.* (1995), studied possible bias in target strength measurements due to the SIMRAD algorithms (version 4.01) used to isolate echoes from single fish. They concluded that, except in cases where the fish are widely separated and differ comparatively little in target strength, the single fish discriminators used in the EK500 are unreliable and an over-estimation of *in situ* TS measurements will occur because of their acceptance of multiple echoes. However, these authors observed no bias with a target of − 33.6 dB and a maximum phase deviation of 2 steps, the settings used in the present study. Hammond (1997) suggests that the average target strength measurement from an aggregation of fish decreases if the fish rise up in the water column or if their school density decreases. Hence as a result of the acceptance of the multiple targets TS measurements would be higher, since the fish will be packed together. Therefore TS measurements made on low-density schools at close range are the most reliable. In order to check these hypotheses acoustic tuna densities by 10 m depth strata in a radius of 0.6 nautical mile around the FAD were extracted using EP500 software (SIMRAD 1994). A − 65 dB integration threshold was applied in order to minimise the integration of small organisms such as small Canrangidae often present in the vicinity of FADs. Results showed that highest densities are observed in the 10–20 m and 20–30 m strata in January 1996, and mainly in the 20–30 stratum in February 1997 (Fig. 4). The high mean TS values observed in the 0–25 m stratum are consistent with Hammond's hypothesis, but the regular increase with depth in mean TS values observed below the surface stratum during the two cruises is not explained by it.

Another hypothesis may be suggested to explain the high mean TS values observed in the depth stratum close to the surface. Numerous parameters have to be considered: the beam angle (6.9°), the ping interval (which depends on the vertical scale) and the boat speed. With the settings used during the different surveys (Table 1) and a 0–500 m scale, the mean ping interval was 0.9 second. At 6 knots ping overlapping began at a depth of 23 m and the boat covered a distance of 2.8 m between two consecutive pings. The probability of a fish being acoustically tracked increased with its length and depth. If a smaller depth scale is used the distance covered by the vessel between two successive pings is reduced. With a 0–150 m scale, the ping interval was 0.3 s. At a speed of 6 knots the distance covered by the vessel between two successive pings was only 0.9 m. Ping overlapping began at a depth of 15 m. The capability for the sounder to track a small fish close to the surface increases. This pattern correspond to the "Trolling 2" survey in February 1997. A 4 dB difference on mean TS values was observed between the 0–25 m and the 25–50 m strata (Table 6). In January 1996 all the measurements were made on a 0–500 m scale and this difference reached 7 dB (Table 4). If, as well as the scale, the speed of the vessel is brought down, the linear distance covered between two successive pings is also reduced. At a speed of 2 knots, with the same settings as before, the vessel covered approximately 0.3 m between two successive pings and ping overlapping started from 2.5 m depth. The ability of the sounder to track individual targets, whatever the size and the depth of the fish, increased. This pattern corresponds to the "Target" survey in February 1997 where a low difference on mean TS values between the 0–25 m and the 25–50 m strata was observed (Table 6).

Part of the differences in mean target strength values observed in February 1997 between the "Target" and "Trolling 2" surveys (Table 6) could be explained by these ideas. The high mean TS values generally observed near the surface disappeared during the "Target" survey.

On the other hand the Hammond hypothesis explains the general trend of TS variation with depth during the "Target" survey (Table 6) if a fish-size stratification with depth occurred. In the first two depth strata 0–25 m and 25–50 m, the mean TS seem to be overestimated compared with the general trend observed in deeper strata. However, the first two strata correspond to the maximum intensity of the aggregation (Fig. 4). Thus some multiple targets may have been accepted during the data processing. However, complete rejection of overlapping echoes is impossible to achieve with single frequency *in situ* TS systems (Soule *et al.*, 1997).

Conclusion

In situ tuna target strength measurements are possible when fish are associated with a FAD. The main difficulty rests in the biological sampling of the aggregation rather than in making the acoustic measurements. For this reason this method specifically applied to small tuna close to the surface that can be caught with a fishing gear like a trolling line.

The observations showed a great stability in average target strengths despite factors such as depth, speed or sounder settings which influence individual TS measurements. The exercise did not show significant differences between TS values obtained during experiments on biomass evaluation and specific TS experiments on the same aggregation.

Two approaches were used: one consisting of *in situ* target strength measurements of a clearly identified tagged fish swimming free in open sea (Bertrand *et al.*, 1999a, b), the other of *in situ* measurements of fish inside an aggregation. Both are complementary and provide valid *in situ* TS values for acoustic biomass estimation. The first one applies more particularly to scattered fish in a large depth range. This is the case for adult tuna. The second is more appropriate when fish, like juvenile tuna are aggregated close to the surface. This approach is the easier of the two to carry out. It can be used not only around an anchored FAD but also each time fish are aggregated. It allows the direct evaluation of a tuna aggregation and may be helpful in the study of its behaviour: school behaviour and cohesiveness, fish length distribution, depth stratification and vessel avoidance.

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