IN SITU TARGET STRENGTH OF BIGEYE TUNA (*THUNNUS OBESUS*) AT FADS

PACS: 43.30.Vh Sistemas de sonar activo

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Palabras Clave: Target strength, bigeye, biomass, tropical tuna, FAD, acoustics, selectivity, frequency response.

ABSTRACT

This paper measures in situ target-strength (TS) values and explores the frequency response of bigeye tuna at fish aggregatign devices (FADs) in the Central Pacific Ocean, to discriminate it from other tuna species using three different frequencies. TS-length relationships were obtained at each frequency by a curve fitting method comparing observed in situ TS distributions and predicted ones based on length distributions caught in each set. For the mean body length caught of ~71 cm, the obtained mean TS values were -27, -28.5 and -35 dB for 38, 120 and 200 kHz respectively, yielding corresponding b20 values of -64, -65.5 and -72 dB.

RESUMEN

Este trabajo mide valores de fuerza del blanco (target strength o TS) y respuesta acústica en frecuencia de atún patudo en dispositivos concentradores de peces (FADs por su acrónimo en inglés) en el Oceano Pacífico Central usando tres frecuencias distintas. Las relaciones TS-talla se obtuvieron para cada especie usando un método de ajuste de curvas comparando distribuciones observadas (TS in situ) y esperadas, basadas en las distribuciónes de tallas de los atunes capturados. Para la talla media de los atunes de 71 cm aproximadamente, los TS obtenidos fueron -27, -28.5 y -35 dB para 38, 120 y 200 kHz respectivamente, proporcionando valores b_{20} de -64, -65.5 y -72 dB.

Introduction

Bigeye tuna (*Thunnus obesus*) is a high value commercial species present in the subtropical and tropical areas of the Atlantic, Indian and Pacific Oceans. Bigeye can be observed either in free schools or associated with floating objects. Juvenile bigeye tuna schools are found with juvenile yellowfin and skipjack tuna schools. Smaller bigeye is also caught on the surface by a range of gears including handline, ringnet and purse seine and are used mainly for canning, while most of larger/older fish are caught by longline fisheries for the sashimi market.

Juveniles of bigeye tuna are normally caught associated with fish aggregating devices (FADs) which are artificial floating objects built by fishers to aggregate tuna (Kingsford, 1993; Parin and Fedoryako, 1999). Nowadays FADs are geolocated with a buoy equipped with an echo-sounder to provide remote estimates of the amount of tuna aggregated around the FAD (Moreno *et al.*, 2008; Lopez *et al.*, 2014). Currently, catches around FADs represent around 65% of the tuna catches of purse seiners (average for the 3 tropical oceans) (Scott and Lopez, 2014).

The most recent estimate from the assessment of the bigeye stock in the Eastern Pacific Ocean (EPO) indicates that the bigeye stock is not overfished, but that overfishing is taking place (Xu *et al.*, 2018). In the Western and Central Pacific Fisheries Commission (WCPFC), a change in the latest assessment, using a revised growth curve and a new regional structure in the model, has yielded in a more optimistic bigeye tuna stock status, relative to previous stock assessments, indicating that the Western Pacific bigeye tuna stock is not overfished (ISSF, 2017). In the Atlantic Ocean, the latest stock assessment indicated that overfishing is occurring and that the stock is in an overfished state. Only in the Indian Ocean the stock of bigeye tuna is estimated to be in good condition. Stock assessment requires a substantial amount of information. Data on retained catch, discards, catch per unit of effort (CPUE), and size compositions of the catches from several different fisheries are typically used. Several assumptions regarding processes such as growth, recruitment, movement, natural mortality (M), and fishing mortality (F), are also done. The interpretations of stock status are strongly dependent on those assumptions.

Due to the uncertainty derived from tropical tuna stock assessments, an important effort towards the use of direct acoustic tuna biomass estimates to complement traditional stock assessment is being conducted (Capello *et al.*, 2016; Moreno *et al.*, 2016; Boyra *et al.*, 2018). Direct estimates of abundance are already undertaken in other fisheries and have been proven to be effective for scientific advising the management. It is the case, for example, of anchovy and sardine in the SW Europe, where a series of acoustic and Daily Egg Production Method surveys (Massé and Uriarte, 2016) provide assessment information on the state of the stocks in different regions to the managers (Ibaibarriaga *et al.*, 2008). In the case of tropical tuna, biomass provided by echo-sounder buoys in quasi-real time could also be used to develop management measures (e.g. Santiago *et al.*, 2017), as dynamic time area closures.

FADs do not only aggregate bigeye tuna: they aggregate other tuna species, as skipjack (*Katsuwonus pelamis*), which is the main target species of purse seiners working with FADs, and yellowfin (*Thunnus albacares*), so that the three species can regularly be found together in a single FAD. Over-exploitation of bigeye tuna is in part due to the by-catch of small individuals by purse seiners at FADs that also target the other two tuna species (Pons *et al.*, 2016). Given that the majority of purse seine catches are conducted around FADs (that simultaneously aggregate the 3 species) one of the challenges that fishers, scientists and managers are facing is how to continue fishing at FADs, target species in good stock condition while avoiding the catch of species that are subject to conservation measures.

Acoustics used by fishers may represent one of the key tools not only to obtain direct indices of tropical tuna abundance, independent from catch data, but also to discriminate tuna species found at FADs before the net is set. One of the prerequisites to discriminate tuna species and asses their biomass is knowing the target strength (TS; dB re 1 m), TS-length (L; cm) and TS-frequency (f; kHz) for the 3 species found at FADs. From the three species, the frequency response of skipjack tuna, a bladderless species, has been recently published (Boyra *et al.*, 2018), whereas bigeye and yellowfin tuna, swimbladder bearing species, have been less studied. For these species, while there are published TS(L) relations, those are preliminary due to the small number of observations (Bertrand and Josse, 2000) and TS(f) relations are absent from bibliography.

Recent efforts by International Seafood Sustainability Foundation (ISSF) with the aim of developing acoustic methodologies to help discrimination of tropical tuna species around FADs have comprised research cruises to measure *in situ* TS of tropical tunas at FADs. As a result, methodologies for analyzing TS at FADs have recently been set up and skipjack tuna measurements of TS(L) and TS(f) have been provided (Boyra et al., 2018). The objective of this study is the application of some of those methodologies to obtain *in situ* TS measurements, TS-length relationship and frequency response of bigeye tuna found associated with FADs. The acoustic characteristics of bigeye tuna will represent another step beyond in the objective of achieving discrimination and abundance estimation of the main tuna species caught at FADs.

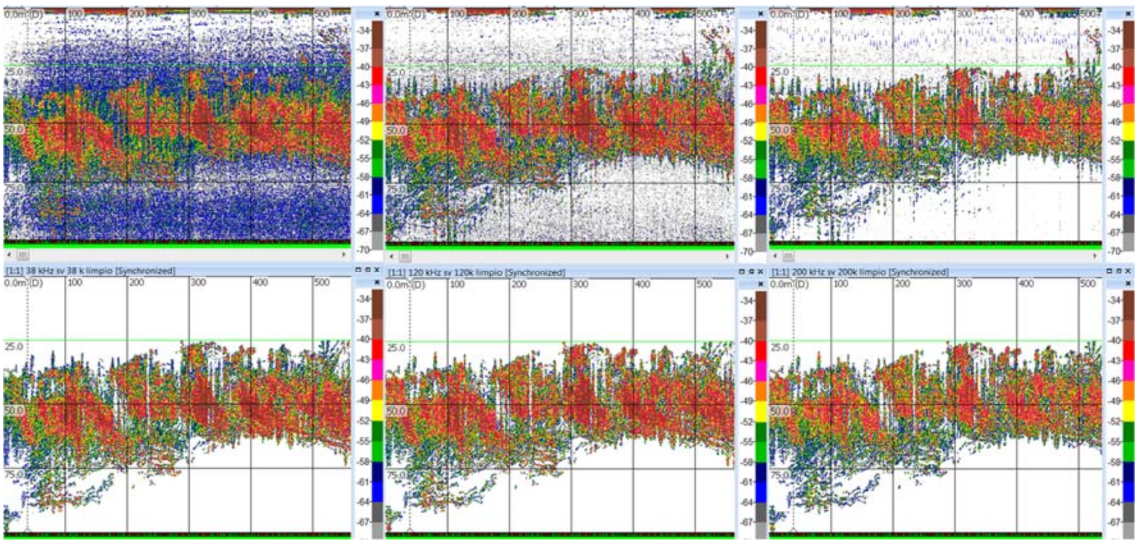

Figure 1. Sample echogram of set number 6 for the three frequencies, 38, 120 and 200 kHz from left to right. The upper panels show the raw echograms and the lower panels the echograms after the plankton / micronekton filtering.

Methods

Data collection

The cruise took place in May 2014 in the Central Pacific Ocean aboard the Albatun 3, a 115 m and 4,406 GT Spanish-flagged purse seiner. The cruise started in Christmas Is. (Kiribati) on May 3rd and ended in Tarawa Is. (Kiribati) on May 31st. Meteorological and oceanographic information was obtained from the CLS (Collecte Location Satellites, France, https://www.cls.fr). During the selected sets the conditions were 7-10 knot of wind (beaufort 3) and 1-1.5 m of swell. Acoustic data was registered during the purse-seine sets at 20 different FADs, followed by intensive spill sampling (Lawson, 2009) to compare acoustic data and species composition caught. The strategy to collect the data from the purse seiner are thoroughly detailed in Boyra *et al.* (2018).

Acoustic data

About ten minutes before the start of each of the purse-seine sets, a workboat was attached to the drifting FAD and slowly towed it to maintain it separated from the net and the vessel. The workboat was equipped with acoustic sensors and, during the ~60 min duration of the sets, it registered TS and volume backscattering strength (S_V; dB re 1 m^{-1}) data from 5 to 200 m depth. Acoustic data were collected with a Simrad EK60 echo-sounder with 38 kHz, 120 kHz and 200 kHz split-beam transducers (Simmonds and Maclennan, 2005), focused vertically (Figure 1) and working with a pulse duration of 0.512 ms (Table 1). The calibration was done at the beginning of the survey, following the standard target procedure (Foote, 1987a; Demer *et al.*, 2015) with a tungsten carbide sphere of 38.1 mm.

Table 1:

Configuration of the acoustic equipment and calibration parameters.

Frequency (kHz)	38	120	200
Pulse duration (µs)	512	512	512
Power (W)	2000	250	150
Gain (dB)	26.16	25.96	27.09
SaCorrection (dB)	-0.86	-0.39	-0.34
Ath. Beam Angle (deg)	6.92	6.38	6.43
Along Beam Angle (deg)	6.94	6.39	6.37
Ref. target TS (dB)	-42.3	-40	-39.9
TS deviation (dB)	5	5	5
RMS beam model	0.19	0.18	0.20
RMS polynomial model	0.16	0.16	0.15

Purse-seine catch data

Purse-seine sets, performed with a 1800 m length x 310 m height gear, were followed by intensive sampling of the catch (between 1 and 2 tons per set) once the aggregation was lifted onboard. Fish samples for sorting were selected randomly to avoid bias. Species were identified and each fish in the sample measured to the nearest centimeter on flat measuring boards. The weights of sampled individuals were estimated using length-weight relations available for each species (Caverivière, 1975; Parks *et al.*, 1982). These proportions by weight were then extrapolated to the total tonnage of each set, as estimated by the fishing master. The sets with more than 90% of bigeye (Table 2) were selected for acoustic analysis to extract its *TS*-length relationship and acoustic frequency response.

Table 2:

Summary of the main tuna species composition in weight (w) and in numbers (n) of the two used fishing sets. FAO codes used for the species: SKJ for skipjack, BET for bigeye and YFT for yellowfin tuna.

Set	Catch (tones)	Sample_w (kg)	Sample_n	SKJ_w (%)	BET_w (%)	YFT_w (%)	SKJ_n (%)	BET_n (%)	YFT_n (%)
6	25	1783	186	1	99	0	5	94	1
7	95	3102	499	7	91	2	21	75	5

Data analysis

Acoustic data were processed from the beginning of the set until the moment in which the net was visible in the echogram. To avoid echoes from bycatch fish species, S_V and TS data were excluded if shallower than 25-m (Forget et al., 2015; Muir *et al.*, 2012). Then, the TS echograms at each frequency were processed using a single-target detection algorithm (Simrad, 1996; Soule *et al.*, 1997) with the following settings: minimum threshold = -80 dB; normalized pulse durations = 0.9 to 1.5; maximum off-axis angles = 3º; and maximum standard deviations of phase = 0.6º.

The application of a series of target selection filters followed to try to remove everything except single targets of bigeye tuna:

1. *School masking*: A school detection algorithm (Lawson *et al.*, 2001) was used to retain the main aggregation. The rejected echoes from outside the aggregation were considered echoes of plankton and/or micronekton. After smoothing by a 5x5 convolution, "schools" (i.e., the main aggregations around the FAD) were selected using: minimum total school length and height = 0.2 m; minimum candidate length and height = 0.1 m; and maximum vertical and horizontal linking distances = 5 and 20 m, respectively. The school detection was applied on *TS* echograms, and data from within the schools were attributed to tuna (Fig. 2).

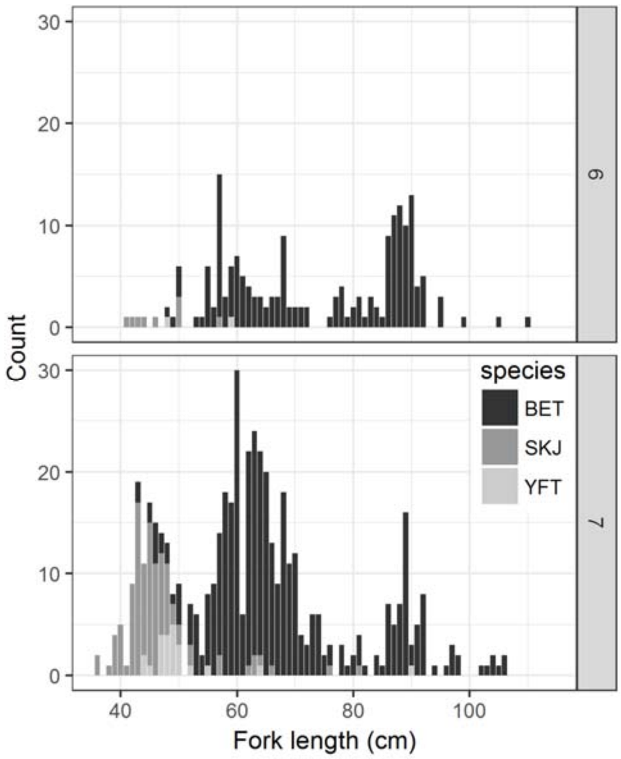

Figure 2. Histogram of body length of the main tuna species captured in each set. Species are named with their FAO (Fi codes: BET for bigeye tuna, SKJ for skipjack and YFT for yellowfin tuna.

2. *Multifrequency simultaneity (MFS)*: To remove potential unresolved multiple targets, we applied a methodology developed by Demer *et al.* (1999) and Conti *et al.* (2005) that requires the TS values to pass the single target criteria in at least two frequencies simultaneously to be considered valid. After setting the targets at all frequencies in the same reference system, for each target detected at one frequency, the method identifies the closest target in the other two. Then it defines a minimum distance between two detections at two different frequencies to consider them the same simultaneously detected target, discarding those targets whose closest detenctions are above the threshold. The method was applied as in Boyra *et al.* (2018), including a sensitivity analysis that tested the impact on the mean filtered TS of this distance threshold and hence help establishing it with objective criteria (Fig. 3).

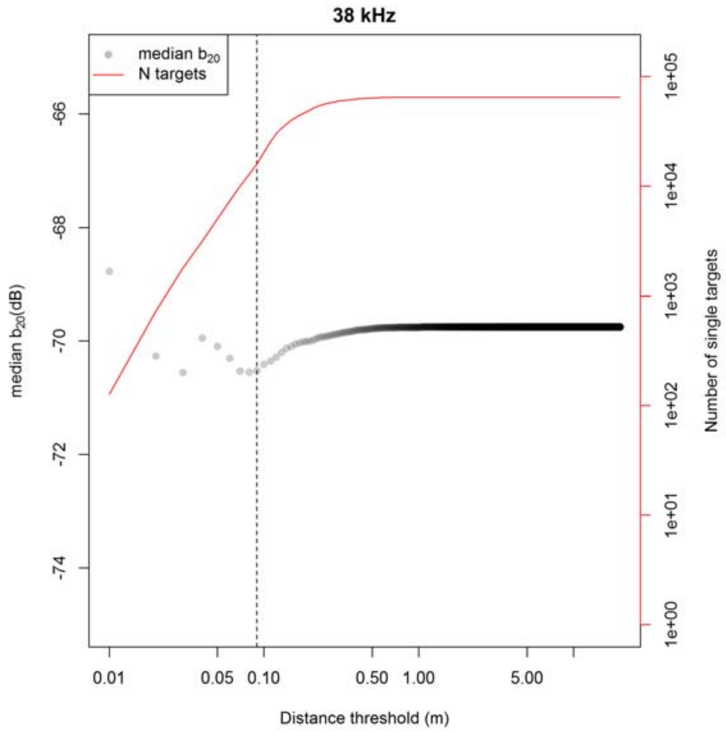

Figure 3. Illustration of the sensitivity analysis to the distance threshold of the MSF for targets detected at 38 kHz with concurrent detections at 120 kHz. The graph shows median b_{20} values for the targets remaining after the application of the filter for different distance thresholds. The filter is increasingly strict for smaller values towards the left part of the graph. At the right side, both the number of targets and the median b_{20} values remain constant because the distance threshold is too big to be effective. For distances less than 0.5 m both the number of targets and the median b_{20} start to decrease because, below this threshold, the concurrent targets are more likely to be simultaneous detections of the same fish and the filter starts to have the desired effect. At about 0.1 m, the median b_{20} stabilizes for a while and then increases, becoming erratic (presumably due to the excessive reduction of number of targets, which increases the uncertainty). Hence, the optimum distance threshold is set at the point of stabilization (dashed line).

The single target detection algorithm and the school processing were applied using Echoview (Myriax inc.) software. The remaining data processing was carried out on the exported csv files using R (R Core Team, 2014).

Determining $TS(L)$ and $TS(f)$ relationships

The relation between TS and fork length (L; cm) is normally assumed to be (Simmonds and MacLennan, 2005):

$$\mathrm{TS} = a \cdot \log(L) + b, \qquad (1)$$

In our case, it was modelled as:

$$TS = 20 \cdot \log(L) + b_{20} + \varepsilon \qquad (2)$$

i.e., considering a fixed slope of 20 due to the small number of sets (two) and adding an error term ε to account for the natural variability of TS. For each frequency, b_{20} was estimated by fitting the observed *TS* distributions of *in situ* bigeye and the predicted TS distributions based on the measured L from the purse-seine catches, using a curve fitting method similar to that of MacLennan and Menz (1996) or Gastauer *et al.* (2017).

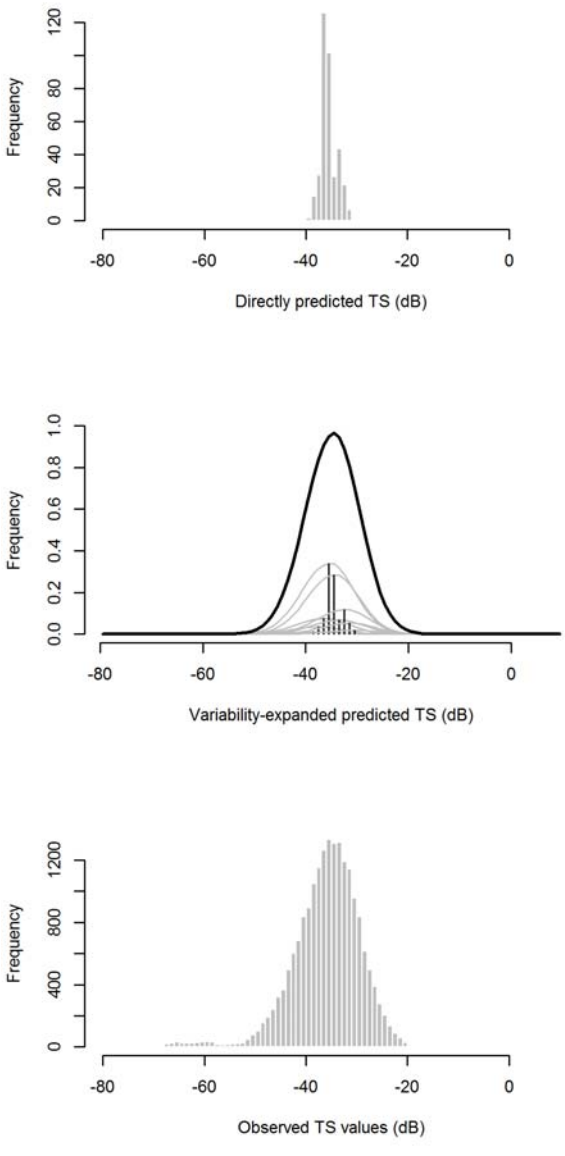

Figure 4. Illustration of the curve fitting procedure used to estimate b_{20} from the observed length and TS distributions. The example corresponds to the 200 kHz frequency at set number 7. Top panel: predicted TS distributions as directly converted from the bigeye tuna length distribution (Fig. 2) using Eq. (1) and a slope of 20. Central panel: predicted TS distributions (grey curves) using Eq. (2), i.e., allowing a variability around the predicted TS value of each bin (black vertical lines). The thick black curve is the proposed predicted TS distribution, built as the sum of the individual bin curves. Bottom panel: observed TS distributions. Model parameters (b_{20}, standard deviation and skewness) are obtained by adjustment between the observed TS distribution and the predicted TS distribution in the central panel.

The bigeye tuna body length distributions were converted to predicted TS distributions using Eq. (2) (Figure 4). For the error term, two alternative curve types were used: a simple normal function, $\varepsilon = N(\mu=0,\ sd)$, and a two-folded (skewed) normal, $\varepsilon = N_s(\mu=0,\ sd,\ s)$, included to increase the accuracy of the estimated b_{20} values in cases of asymmetric observed TS distributions. An optimization process was run for the parameters of Eq. (2) using sequences of b_{20}, (from -80 to 0 in intervals of 0.1 dB), standard deviation, sd, (from 0 to 20 in intervals of 0.1 dB) and, in the case of the two-folded normal, percentage of skewness, *s*, (from -100% -left sided- to 100% -right sided- in intervals of 5%), being the resulting functions fitted to the observed TS distributions. For each curve type, all the combinations of parameters were computed and the one with the highest coefficient of determination was chosen. Then, the choice of curve type was done based on AIC (Akaike Information Criterion, Akaike, 1973) to allow penalization for the extra parameter of the two-folded gaussian. The curves obtained with this optimization procedure were the proposed predicted TS distributions. Standard deviations, calculated with the R package "Seewave" (Sueur *et al.*, 2013), confidence intervals of the *TS* distributions, and coefficient of determination values of the fit between observed and predicted *TS* distributions were calculated to evaluate the goodness of the obtained *TS(L)* relationships.

The TS(f) relationship was calculated as the succession of b_{20} values at the three available frequencies. The TS(f) relationship was calculated for the two sets together as well as per individual set to try to assess the incidence of the relatively low predominance of bigeye tuna in set 7 (91%) with respect to set 6 (99%).

Table 3:

Summary of the results of the least square adjustment procedure. "Freq" stands for acoustic frequency, "L" for fork length, "sd" for standard deviation, "CI" for 95% confidence interval and "R^2" for adjusted coefficient of determination.

Set	Freq	L	sd_L	N	TS	b_{20}	sd	CI		R^2
	(kHz)	(cm)	(cm)		(dB)	(dB)	(dB)	(dB)	(dB)	(%)
6	38	75	8	7307	-26	-65	9			88
7	38	68	6	8555	-28	-63	9			83
All	38	71	7	15862	-27	-64	9	-64.1	-63.9	85
6	120	75	8	8732	-28	-65	8			90
7	120	68	6	10325	-29	-66	7			88
All	120	71	7	19057	-29	-65.5	8	-65.6	-65.4	89
6	200	75	8	8870	-34	-71	7			91
7	200	68	6	10513	-36	-73	7			91
All	200	71	7	19383	-35	-72	7	-72.1	-71.9	91

Results

Size distribution

From the 20 sets done in the survey, only two (sets 6 and 7) had more than 90% in mass of bigeye tuna (Table 2) and were hence used for this study. The average bigeye tuna sizes were 75 and 68 cm with 8 and 6 cm standard deviation respectively (Table 3). The length distributions were bimodal in both cases with modes centred in ~60 and ~90 cm respectively (Figure 2).

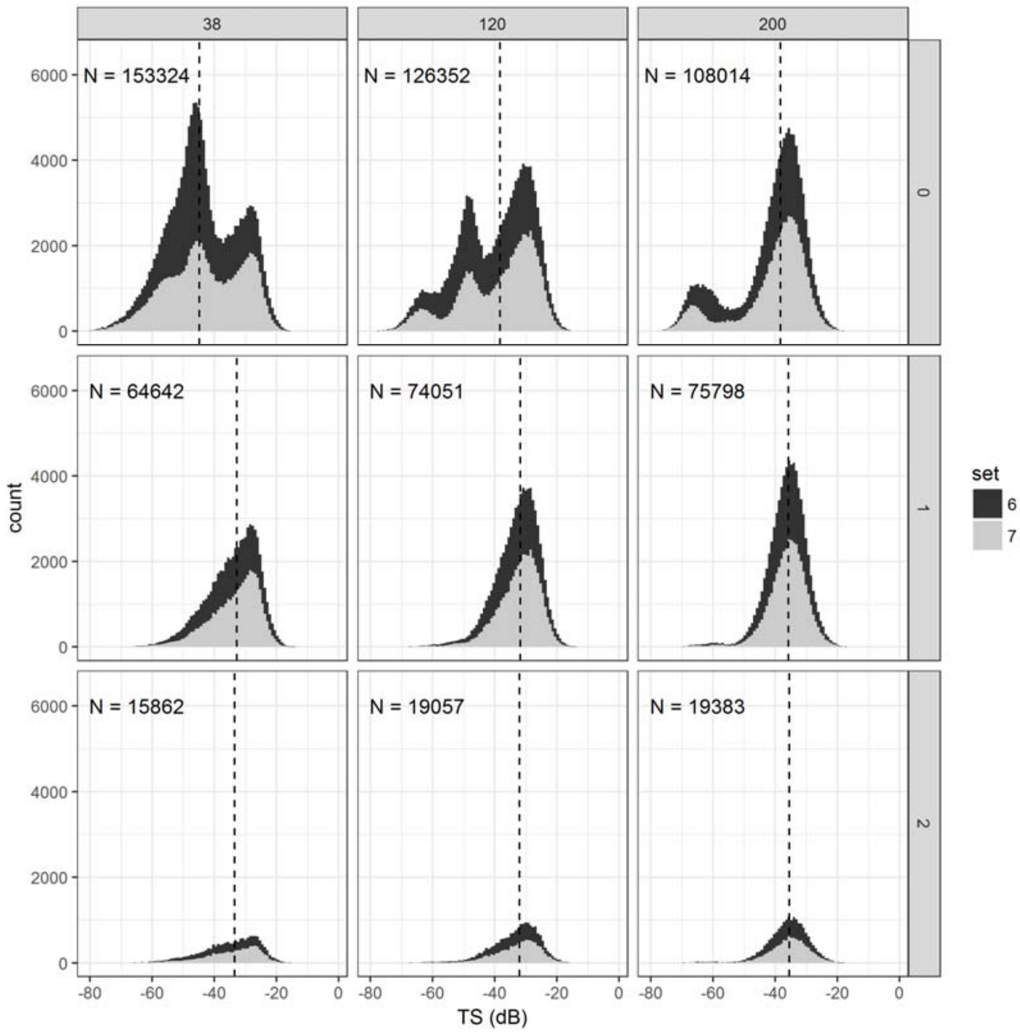

Figure 5. Histograms of TS values at the three frequencies for the incremental layers of filtering: (0) raw TS distribution without filtering; (1) filtered with the school masking; and (2) school masking plus multifrequency simultaneity requirement. Vertical dashed lines represent the median TS value and N is the remaining number of single targets in each step.

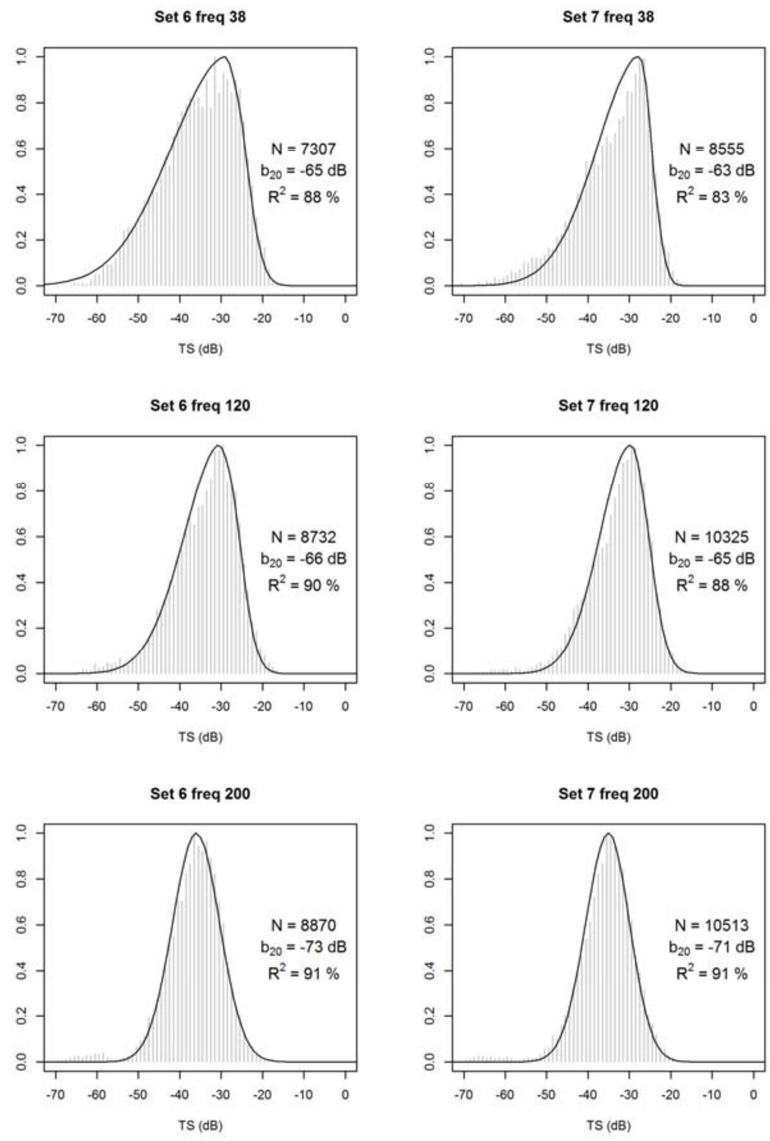

Figure 6. Observed (grey bars) against predicted (continuous line) TS distribution of the curve fitting procedure used to estimate b_{20} for each set and acoustic frequency.

TS filtering steps

The initial TS distributions had multiple modes at all frequencies but after the school masking, the lower TS modes (presumably plankton and/or micronekton) were removed, increasing the mean value in more than 5 dB and changing the TS distributions into monomodal ones (Figure 5). The MFS sensitivity analysis showed a reduction of TS with the distance threshold until reaching stabilization at the three frequencies (Figure 3; only the 38 kHz case is shown), based on which, a distance threshold of 0.09 m was applied at all frequencies. The simultaneous detection requirement caused small change on the mean TS. Overall, the TS filtering steps reduced the number of single targets in one order of magnitude at all frequencies. The mean TS values observed after all the filtering procedures were -27, -28.5 and -35 dB at 38, 120 and 200 kHz respectively (Table 3).

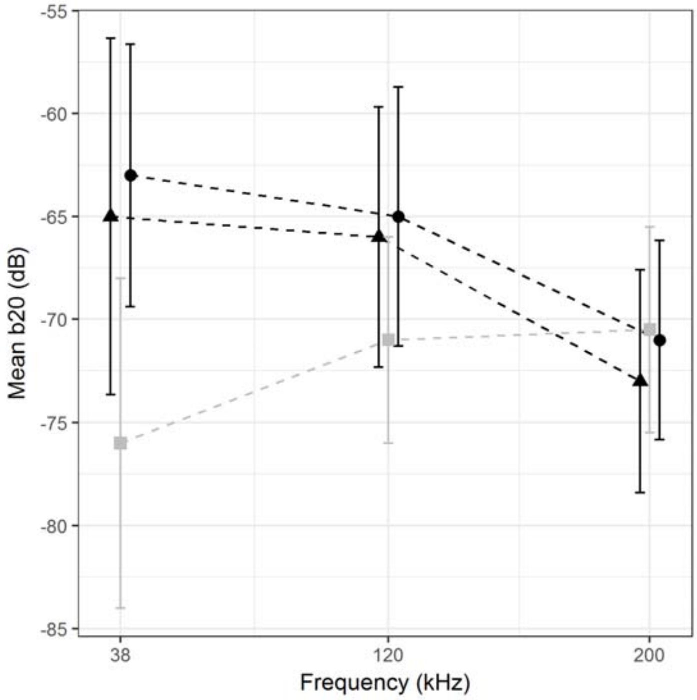

Figure 7. TS frequency response of bigeye tuna (black), triangles representing set 6 and circles set 7. In grey squares, TS frequency response of skipjack tuna, redrawn from Boyra *et al.* (2018). Error bars represent standard deviation.

TS-L and TS-f relationships

The fit between modelled and observed TS distributions had coefficients of determination well over 80% (Table 3; Figure 6). The fitted TS-length relationship in Eq. (1) had intercepts of -64, -65.5 and -72 dB respectively at 38, 120 and 200 kHz, with uncertainties of ~7.5, 6 and 5 dB. The frequency response was monotonously decreasing with the increasing frequency, the 38 kHz being ~1.5 dB higher than 120 kHz and ~8 dB higher than 200 kHz (Figure 7).

Funding

This work was supported by the International Seafood Sustainability Foundation (ISSF) and conducted independently by the authors. The report and its results, professional opinions and conclusions are solely the work of the authors.

Aknowledgements

We thank the following organizations and people for their support of this work: the governments of Kiribati, Tuvalu, and Tokelau which permitted this research in their EEZs; Albacora for allowing this work aboard F/V *ALBATUN TRES*; Fishing Master Euken Mujika; the captain and crew; the divers and scientist J. Filmalter and F. Forget are thanked for invaluable insight about fish behaviour, vertical stratification and non-target species composition at FADs.

References

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. In: Petran, B., Csaaki, F. (Eds.), International Symposium on Information Theory. Akadeemiai Kiadi, Budapest, Hungary, pp. 267–281.

Bertrand, A., Borgne, R. Le, and Josse, E. 1999a. Acoustic characterization of micronekton distribution in French Polynesia. Mar. Ecol. Prog. Ser, 191: 127–140.

Bertrand, A., Josse, E., and Massé, J. 1999b. Preliminary results of acoustic target strength measurements of bigeye (Thunnus obesus) and yellowfin tuna (Thunnus albacares). *In* Proc. 5th lndo-Pac. Fish Conj., pp. 443–450.

Bertrand, A., Josse, E., and Massé, J. 1999c. In situ acoustic target-strength measurement of bigeye (Thunnus obesus) and yellowfin tuna (Thunnus albacares) by coupling split-beam echosounder observations and sonic tracking. ICES J. Mar. Sci, 56: 51–60.

Bertrand, A., and Josse, E. 2000. Tuna target-strength related to fish length and swimbladder volume. ICES Journal of Marine Science, 57: 1143–1146. http://icesjms.oxfordjournals.org/cgi/doi/10.1006/jmsc.2000.0881 (Accessed 29 May 2014).

Boyra, G., Moreno, G., Sobradillo, B., Pe, I., Sancristobal, I., and Demer, D. A. 2018. Target strength of skipjack tuna (Katsuwanus pelamis) associated with fish aggregating devices (FADs). ICES Journal of Marine Science.

Capello, M., Den, J. L., Robert, M., Holland, K. N., Schaefer, K. M., and Dagorn, L. 2016. Population assessment of tropical tuna based on their associative behavior around floating objects: 1–14.

Caverivière. 1975. Longeur predorsale, longeur a la fourche et poids des albacores (Thunnus albacares) de lÁtlantique. Rapport prelimminaire. Document SCRS/75/73, unpublished.

Conti, S. G., Demer, D. A., Soule, M. A., and Conti, J. H. E. 2005. An improved multiple-frequency method for measuring in-situ target strengths. ICES Journal of Marine Science, 62: 1636–1646.

Demer, D. a., Berger, L., Bernasconi, M., Bethke, E., Boswell, K. M., Chu, D., Domokos, R., *et al.* 2015. Calibration of acoustic instruments. ICES Cooperative Research Report, 326: 133.

Demer, D. A., Soule, M. A., and Hewitt, R. P. 1999. A multiple-frequency method for potentially improving the accuracy and precision of in situ target strength measurements. The Journal of the Acoustical Society of America, 105: 2359–2376. http://link.aip.org/link/?JASMAN/105/2359/1 (Accessed 6 February 2012).

Fernandes, A., Masse, J., Iglesias, M., Diner, N., and Ona, E. 2006. The SIMFAMI project: species identification methods from acoustic multi-frequency information. Aberdeen, UK. 486 pp. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Species+Identification+Methods+From+Acoustic+Multi-frequency+Information#2.

Foote, K. 1987a. Calibration of acoustic instruments for fish density estimation: a practical guide. International Council for the Exploration of the Sea. 81 pp. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Calibration+of+acoustic+instruments+for+fish+density+estimation:+a+practical+guide#0 (Accessed 18 November 2010).

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

Gastauer, S., Scoulding, B., and Parsons, M. 2017. Estimates of variability of goldband snapper target strength and biomass in three fishing regions within the Northern Demersal Scalefish Fishery (Western Australia). Fisheries Research, 193: 250–262. Elsevier. http://dx.doi.org/10.1016/j.fishres.2017.05.001.

Ibaibarriaga, L., Fernandez, C., Uriarte, A., Roel, B. a., Ibaibarriaga, L., and Ferna, C. 2008. A two-stage biomass dynamic model for Bay of Biscay anchovy: a Bayesian approach. ICES Journal of Marine Science, 65: 191. http://icesjms.oxfordjournals.org/cgi/doi/10.1093/icesjms/fsn002.

ICES. 2006. Report of the Working Group on Acoustic and Egg Surveys for Sardine and Anchovy in ICES Areas VIII and IX (WGACEGG). ICES CM, LRC:18: 169.

ISSF. 2017. ISSF Tuna Stock Status Update, 2017: Status of the world fisheries for tuna. ISSF Technical Report 2017-02. International Seafood Sustainability Foundation, Washington, D.C., USA.

Josse, E., and Bertrand, A. 2000. In situ acoustic target strength measurements of tuna associated with a fish aggregating device. ICES J. Mar. Sci, 57: 911–918.

Kingsford, M. J. 1993. Biotic and abiotic structure in the pelagic environment: importance to small fish. Bull. Mar. Sci., 53: 393–415.

Korneliussen, R., and Ona, E. 2003. Synthetic echograms generated from the relative frequency response. ICES Journal of Marine Science, 60: 636–640. http://icesjms.oxfordjournals.org/cgi/doi/10.1016/S1054-3139(03)00035-3 (Accessed 25 June 2010).

Lawson, G. L., Barange, M., Freon, P., and Fre, P. 2001. Species identification of pelagic fish schools on the South African continental shelf using acoustic descriptors and ancillary information. ICES Journal of Marine Science, 58: 275–287.

Lawson, T. 2009. Selectivity bias in grab samples and other factors affecting the analysis of species composition data collected by observers on purse seiners in the Western and Central Pacific Ocean. *In* WCPFC-SC5-2009/ST-WP-03, p. 45 pp.

Lopez, J., Moreno, G., Sancristobal, I., and Murua, J. 2014. Evolution and current state of the technology of echo-sounder buoys used by Spanish tropical tuna purse seiners in the Atlantic, Indian and Pacific Oceans. Fisheries Research, 155: 127–137. Elsevier B.V. http://dx.doi.org/10.1016/j.fishres.2014.02.033.

Lopez, J., Moreno, G., Boyra, G., and Dagorn, L. 2016. A model based on data from echosounder buoys to estimate biomass of fish species associated with fish aggregating devices. Fishery Bulletin, 114.

MacLennan, D., and Menz, A. 1996. Interpretation of in situ target-strength data. ICES Journal of Marine Science, 53: 233. http://icesjms.oxfordjournals.org/cgi/content/abstract/53/2/233.

Massé, J., and Uriarte, A. 2016. Pelagic surveys for sardine and anchovy in ICES areas 8 and 9 (WGACEGG) - Towards and ecosystem approach. ICES CRR 332.

Mcclatchie, S., Macaulay, G. J., and Coombs, R. F. 2003. A requiem for the use of 20 log 10 Length for acoustic target strength with special reference to deep-sea fishes. ICES Journal of Marine Science, 60: 419–428.

Moreno, G., Josse, E., Brehmer, P., Nøttestad, L., and Us, C. D. B. 2008. Echotrace classification and spatial distribution of pelagic fish aggregations around drifting fish aggregating devices (DFAD). Aquatic Living Resources, 356: 343–356.

Moreno, G., Dagorn, L., Capello, M., Lopez, J., Filmalter, J., Forget, F., Sancristobal, I., *et al.* 2016. Fish aggregating devices (FADs) as scientific platforms. Fisheries Research, 178: 122–129.

Muir, J., Itano, D., Hutchinson, M., Leroy, B., and Holland, K. 2012. Behavior of target and non-target species on drifting FADs and when encircled by purse seine gear. *In* Western and Central Pacific Fisheries Commision - Scientific Committee 8, p. 8 pp.

Oshima, T. 2008. Target strength of Bigeye, Yellowfin and Skipjack measured by split beam echo sounder in a cage. Iotc, WPTT-22: 4.

Parin, N. V., and Fedoryako, B. I. 1999. Pelagic fish communities around floating objects in the open ocean. In: Scott M.D., Bayliff W.H., Lennert-Cody C.E. and Schaefer K.M. (eds.), Proceedings of the international Workshop on the Ecology and Fisheries for Tunas Associated with Floating Objects: 447–458.

Parks, W., Bard, F. X., Cayré, P., and Kume, S. 1982. Length-weight relations for bigeye tuna captured in the eastern Atlantic Ocean. . Col.Vol.Sci.Pap. ICCAT, 17: 214–225.

Pons, M., Branch, T. A., Melnychuk, M. C., Jensen, O. P., Brodziak, J., Fromentin, J. M., Harley, S. J., *et al.* 2016. Effects of biological , economic and management factors on tuna and bill fi sh stock status. Fish and Fisheries: 1–21.

R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.r-project.org/.

Santiago, J., Murua, H., and Quincoces, I. 2017. Joint t-RFMO FAD Working Group meeting

Joint t-RFMO FAD Working Group meeting, 2017: 5–9.

Scott, G., and Lopez, J. 2014. The use of FADs in tuna fisheries. IP/B/PECH/IC/2013-123.Available at: http://www.europarl.europa.eu/studies.

Simmonds, J. E., and Maclennan, D. N. 2005. Fisheries Acoustics Theory and Practice. Second Edition. Chapman & Hall, New York: 472pp.

SIMRAD. 1996. Simrad EK500 Scientific Echosounder Instruction Manual. Simrad Subsea A/S, Horten, Norway.

Soule, M., Barange, M., Solli, H., and Hampton, I. 1997. Performance of a new phase algorithm for discriminating between single and overlapping echoes in a split-beam echosounder. ICES Journal of Marine Science, 54: 934–938.

Sueur, J., Aubin, T., and Simonis, C. 2013. Seewave: a free modular tool for sound analysis and synthesis. Bioacouistics, 18: 213–226. http://isyeb.mnhn.fr/IMG/pdf/sueuretal_bioacoustics_2008.pdf.

Xu, H., Minete-Vera, C., Maunder, M., and Aires-da-Silva, A. 2018. Status of Bigeye tuna in the Eastern Pacific Ocean. IATTC, SAC-09-05.