IOTC–2016–WPTT18–28
Received: 28 October 2016

Fishers' echo-sounder buoys to estimate biomass of fish species associated with fish aggregating devices in the Indian Ocean

Blanca Orúe[1]*, Jon Lopez[1], Gala Moreno[2], Josu Santiago[1], Maria Soto[3], Hilario Murua[1]

SUMMARY

Most of the drifting fish aggregating devices (DFADs) used by the industrial tropical tuna purse seine fishery are deployed with satellite linked echo-sounder buoys. These echo-sounders provide information on the accurate geo-location of the object and rough estimates of fish biomass aggregated along the trajectory of the FAD. However, current echo-sounder buoys do not provide biomass information by species or size composition under the DFADs. The aim of this study is to progress towards improved remote biomass estimates using echo-sounder buoys and a model based on existing knowledge of the vertical distribution and behavior of non-tuna and tuna species at DFADs and mixed species target strengths (TS) and weights for different depth layers. Results show that manufacturer's biomass estimates, although enhanced, can be further improved, indicating that the large variability in the Indian Ocean is not easily considered with a single model. Potential reasons driving echo-sounder buoy estimates variability, as well as the limitations encountered with these devices are discussed, including the lack of consistent TS values for skipjack, bigeye and yellowfin tunas.

---

[1] AZTI-Tecnalia, Herrera kaia portualdea z/g 20110 Pasaia (Gipuzkoa), Spain.
[2] International Seafood Sustainability Foundation (ISSF) 601 New Jersey Ave NW Suite 220 Washington DC 20001
[3] Instituto Español de Oceanografía, Corazón de María 8, 28002 Madrid, Spain
*corresponding author: borue@azti.es

INTRODUCTION

Floating objects drifting in the surface of tropical waters (also called drifting fish aggregating devices or DFADs) attract hundreds of marine species (Castro et al., 2002), including tunas such as skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye (*Thunnus obesus*). Taking advantage of this associative behavior, fishers have been increasingly deploying artificial DFAD since the 90s to facilitate the aggregation and capture of target species (Fonteneau et al., 2013). It is roughly estimated that ~100,000DFADs are deployed annually worldwide (Baske et al., 2012; Scott and Lopez, 2014; Ushioda, 2015). In the Indian Ocean, around 50% of total tuna catches are made on DFADs by purse seine vessels, exceeding 70% in some years (Dagorn et al., 2012). The rest of the catches on the purse seine fishery come from sets on unassociated schools (also called free-swimming schools, FSC).

Most of the technological changes occurring in the tropical tuna purse seine fishery in the last 20-30 years have been oriented to improve purse seine fishing efficiency, particularly when fishing on DFADs. In that sense, one of the most important technological developments recently introduced by the fleet are the satellite linked echo-sounder buoys. The first buoys equipped with an echo-sounder appeared in the market in the 2000, but fishers did not began using them regularly in their fishing strategy until mid-2000’s (Lopez et al., 2014). Today, their use has rapidly spread between all the purse seine fleets worldwide. The vast majority, if not all, of DFADs used in European fleets are equipped with satellite linked echo-sounder buoys (Lopez et al., 2014). These devices are able to remotely inform in near real-time about the accurate geolocation of the FAD and also provide rough estimates of abundance of fish underneath them.

Because floating objects are very temporary in time and space, the associated human and economic cost of investigating FADs at large scale is certainly high. FADs equipped with satellite linked echo-sounder buoys are continuously streaming information and have the potential of collecting information in a cost effective manner, being privileged observation platforms of the pelagic ecosystem. Recent works have noted the importance these devices may have to investigate several scientific issues, including “fishery” independent abundances and ecological and behavioral investigations of tunas and accompanying species (Dagorn et al., 2006; Moreno et al., 2015; Santiago et al., 2015; Lopez et al., 2016). However, current echo-sounder buoys provide a single biomass value that does not contain information about species or size composition of the fish under the DFADs. As numerous species associate with DFADs, there is a need to better discriminate and understand the specific contribution provided by each tuna and non-tuna species on the acoustic signal recorded by the buoy at DFADs. Lopez et al. (2016) developed a model to improve the biomass estimates of echo-sounder buoys at DFADs by group of species in the Atlantic Ocean, based on existing knowledge of the vertical behavior of tuna and non-tuna species at FADs, and appropriate target strength (TS) and weight values for mixed species aggregations.

This work aims to improve biomass estimation provided by fishers' echo-sounder buoys at FADs using as based model the one proposed by Lopez et al. (2016). This study uses a large sample size and is focused in the Indian Ocean, where the method was applied by zone as species composition and associative behavior patterns may be region and environmental conditions-specific.

MATERIALS AND METHODS

1. Data collection

Echo-sounder buoy data, including tracks (position) and biomass information, was provided to AZTI by a fishing company. The buoy database includes information about principal owner (vessel), buoy code, buoy type, location (latitude and longitude), date and GMT time of sampling, as well as the sea surface temperature (°C). Information on position and echo-sounder data of a total of 2887 buoys from January 2012 to May 2015 was obtained (**Table 1**).

Table 1. Description of buoy dataset

	2012	2013	2014	2015 (January-May)
Number of buoys	1038	749	202	898
Number of position data	273468	408849	113847	143670
Number of sounder data	33920	94788	21255	41860

The fishing and FAD logbooks were also collected for the vessels and periods considered in the present study. Fishing logbooks included information on fishing related activities of the vessels: fishing mode (FAD/FSC), location, catch and size by different categories of tuna. For its part, FAD logbooks provided information on the buoy code, vessel, location, and the activity associated to the FAD (i.e. deployment, visit, fishing, etc.). Information of both logbooks was used to compare the catch of the sets with their corresponding acoustic information from echo-sounder buoys.

2. Identification of sets and their corresponding acoustic signal

Fishing sets and acoustic records were related using the information from the logbooks mentioned above provided by the fishing company. The fishing sets on conducted on FADs by a given vessel were identified based on the information of date, time and position recorded in the logbooks. The acoustic signal for the same location, day/time and vessel was related then with the previously identified catch estimation from the logbooks. This allowed comparing fishing and FAD logbooks data and echo-sounder buoy data. The echo sounder signal with maximum biomass value before the set in the same day or the day before was chosen as the acoustic sample to be used in the analysis.

3. The buoy

The Satlink buoy (SATLINK, Madrid, Spain, www.satlink.es) was selected to be used in the present study as the algorithm to transform the acoustic signal into biomass was available from manufacturers. Besides, Lopez et al. (2016) developed a model for this specific buoy in the Atlantic Ocean. The buoy contained a Simrad ES12 echo-sounder, which operated at a frequency of 190.5 kHz with a power of 140 W (beam angle at –3dB: 20°). The sounder was programmed to operate for 40 seconds. During this period, 32 pings were sent from the transducer and an average of the backscattered acoustic response was computed and stored in the memory of the buoy (hereafter called “acoustic sample”). Volume backscattering strength (Sv, dB re 1 m–1; Maclennan et al. (2002)) values smaller than –45 dB were automatically removed by the internal module of the buoy, as a precautionary measure to eliminate signals that likely corresponded to organisms smaller than tuna (e.g., organisms of the sound scattering layers; Josse et al. (1999); Josse and Bertrand (2000)). The depth observation range extended from 3 to 115 m and was composed of ten homogeneous layers, each with a resolution of 11.2 m (**Figure 1**).

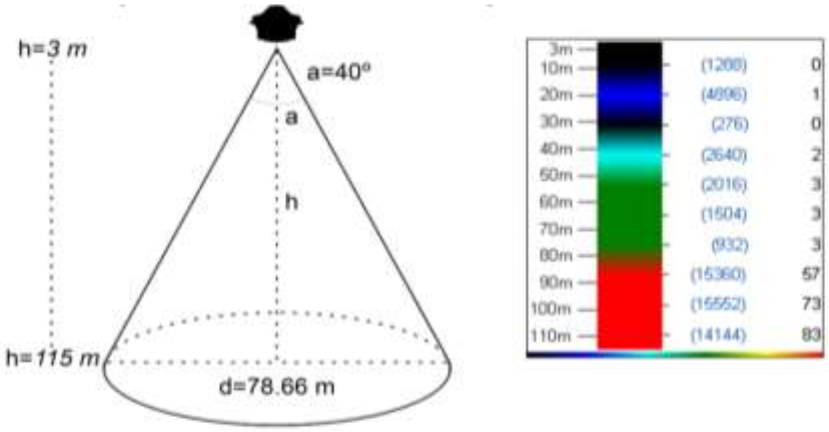

Figure 1.Characteristics of the Satlink echo-sounder buoy: Beam width [or angle] (a), depth range (h), and diameter (d) at 115 m. An example of the echogram display for the 10 depth layers (ranging from 3 m to 115 m) (taken from Lopez et al. 2016)

4. The model

Manufacturer´s method converts raw acoustic data into biomass in tons, using an empiric algorithm based on skipjack tuna, which is the main target species of the purse seine fishery on FADs. Therefore this method does not consider the different species and sizes aggregated around the FAD. To improve the biomass estimates provided by the manufacturer, we followed the model proposed by Lopez et al. (2016) for the Atlantic Ocean. This model was based on best available knowledge on the vertical behavior of species and sizes at FADs, and their corresponding TS and weight values.

The first step was to establish the depth boundary limiting non-tuna from tuna species. Although overlap may exist, the vertical depth limit of 25 m was considered as the potential boundary between tuna and non-tuna species, based on experimental evidences from tagging. (Matsumoto et al., 2006; Dagorn et al., 2007; Moreno et al., 2007; Taquet et al., 2007; Leroy et al., 2009; Govinden et al., 2010; Filmalter et al., 2011; Mitsunaga et al., 2012; Govinden et al., 2013; Schaefer and Fuller, 2013; Matsumoto et al., 2014; Forget et al., 2015). Same buoys used on other scientific studies in the Indian Ocean have also used similar depth limits to separate tuna and non-tuna species (Robert et al., 2013). Secondly , to establish the a vertical boundary between small and large tuna, we choose a preliminary limit at 80 m according with previous studies (Moreno et al., 2007). Then, this limit was re-adjusted using the 141 sets for which information about biomass from echo-sounder and catch data is available.

To appropriately convert acoustic signal into non-tuna biomass (boundary set at 25 m), a TS value of –42 dB was used for the entire group, based on previous field studies (Josse et al., 2000; Doray et al., 2006; 2007; Lopez et al., 2010). The mean weight used for the biomass characterization of this community was 1 kg ind^{-1}, which was estimated from the mean length of most represented non-tuna species at DFADs, and their corresponding weights (Lopez et al., 2016).

Because the 3 tuna species are mixed in similar depth ranges, and no consistent target strenght-length relationships exist for tropical tunas, difficulties are found to know the acoustic signal contribution by each species (Josse and Bertrand, 2000). Thus a TS corresponding to mixed species aggregations was chosen (Moreno et al., 2007) to apply to tuna layers. These TS values were measured *in situ* at DFADs for different acoustic shoals found at different depth ranges (Moreno et al., 2007). Different mixed species acoustic shoals were found at DFADs, with corresponding different TS values: (i) the highest TS values for acoustic shoals occupying deepest layers (-29,9 dB) likely corresponding to large tunas and (ii) lower TS values for acoustic shoals found at shallower-medium depths (-35,1 dB) likely corresponding to small tuna. According to the most common tuna sizes caught at DFADs (Chassot et al., 2013; Fonteneau et al., 2013), the depth range for tuna shoals shallower in the water column was considered to be populated by skipjack, yellowfin and bigeye tuna of a mean mass of 2 kg ind^{-1}, whereas the depth for acoustic shoals found at greater depths was assumed to be occupied by larger yellowfin and bigeye tuna individuals with a mean weight of 21 kg ind^{-1} (**Figure 2**).

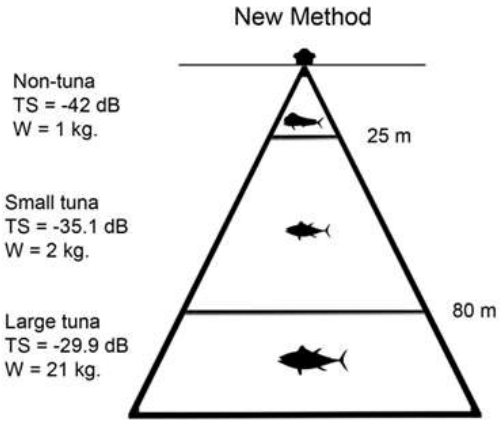

Figure 2.Summary of TS and weights values used to convert acoustic backscatter into biomass

A specific acoustic backscattering cross-section value (σ_{bs} , m^2, TS in linear scale; MacLennan et al., 2002) was used to obtain number of individuals for each of the echo-sounder buoy´s layer (*n*=1, 2, …, 10) according to the presence of each group (non-tuna, tuna at shallow depth layers and tuna at deep layers) in each depth layer. The number of fish per group and layer (*N*[*n*, *gr*]) were estimated as follows:

$$N(n, gr) = \frac{s_{\mathrm{a}}(n)}{\sigma_{\mathrm{bs(gr)}}} \cdot A(n) \qquad (1)$$

Where:

$s_a(n)$ = the TVG-corrected (time-varied-gain, a correction function to compensate the signal for spreading and absorption losses; Simmonds and MacLennan (2005)) area backscattering coefficient (Maclennan et al., 2002) in each layer (*n*);

$\sigma_{(bs(gr))}$ = the mean TS of a group in linear scale and

A(*n*) = the mean cross sectional area sampled by the beam of the cone for each layer (*n*).

Then, the total number of fish per group *N*(gr) were obtained by summing for all layers (2):

$$N(\mathrm{gr}) = \sum\nolimits_n N(n, gr) \qquad (2)$$

The estimated number of fish per group (*N*[gr]) was converted into biomass per group (**B**[gr], in t) by multiplying the total amount of individuals by their corresponding mean weight (w, in kg) and dividing by 1000.

$$B(gr) = \frac{N(gr).w(gr)}{1000} \qquad (3)$$

Where:

B(*gr*) = the biomass estimated per fish group (in t);

N(*gr*) = the number of individuals per group; and

$w(gr)$ = the average weight of an individual of a particular group (in Kg) used to convert number of individuals in weight.

Finally, the total uncorrected predicted tuna biomass (B_u, in t) is the sum of the biomass estimated for the two tuna categories (corresponding to the sum of depth layers 3-10), whereas total biomass of non-tuna species is the estimate obtained for that specific group (sum of layers 1–2).

The echo-integration procedure was conducted repeatedly by applying all possible combinations of depth limits between tunas in shallow and in deep layers in the entire depth range (i.e., having the virtual limit in 25 m (unique layer of tunas from 25 to 115m), 36m, 47m, 59m, 70m, 92m, 104m and 115m. Then, we choose the depth limit with the best value for coefficients of correlation (r) and determination (r^2) between predicted biomass from echo-sounder buoy and catch of the set.

Error (in tons) of the new method was modeled with different regression models (polynomials of order 2 and 3 [POL2 and POL3], generalized linear models [GLM], and generalized additive models [GAM]) as a function of the predicted biomass, which allows correcting the predicted biomass as follows:

$$B_c = B_u - f(B_u) + \mathcal{E}, \qquad (4)$$

where B_c = the corrected predicted biomass;

B_u = uncorrected predicted biomass using different depth boundaries for tunas in shallow layers and tunas in depth layers; and

$f(B_u)$ = the error modeled following different regression methods as a function of predicted biomass

$\mathcal{E}$ is the assumed error (0 in this case).

The method was implemented to all the sets. Moreover, to account for potential spatial differences in species composition and aggregative behavior we applied the method by areas. The regions were based on the ZET (zones d'echantillonnage thonière) areas defined by Petit et al. (2000).

RESULTS

1. Identification of sets with associated acoustic signal

A total of 141 sets were identified in the four regions considered using FAD logbooks, fishing logbooks and buoy data (i.e. acoustic information from echo sounder buoys before the set) provided by the fishing company (**Table 1, Figure 3**).

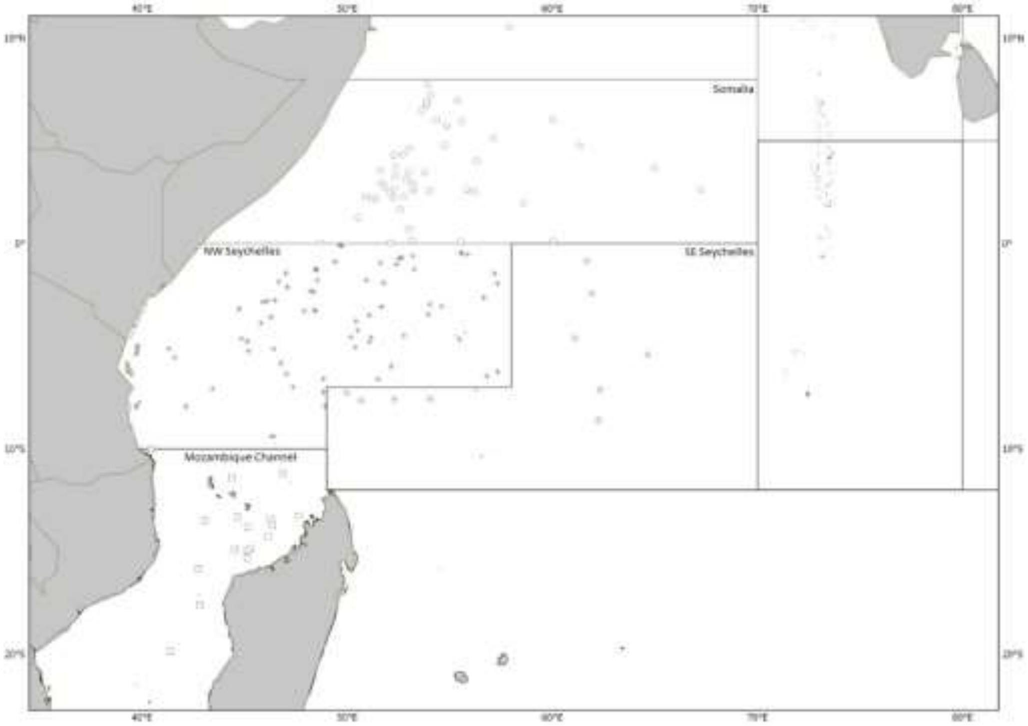

Figure 3. 141 sets identified in the Indian Ocean

Table 1. The sets were made in four zones:

ZET	Number of sets
Somalia	50
Seychelles NW	64
Seychelles SE	10
Mozambique Channel	17

2. Selection of potential depth limit between small and large tunas

After applying all possible combinations of depth limits for tunas occupying shallow layers (likely being smaller) and tuna occupying deeper layers (likely being larger) (**Figure 4**), we select the one with the best value of coefficient of determination (r^2) and correlation coefficient (r) between the uncorrected predicted biomass and catch (**Table 3**).

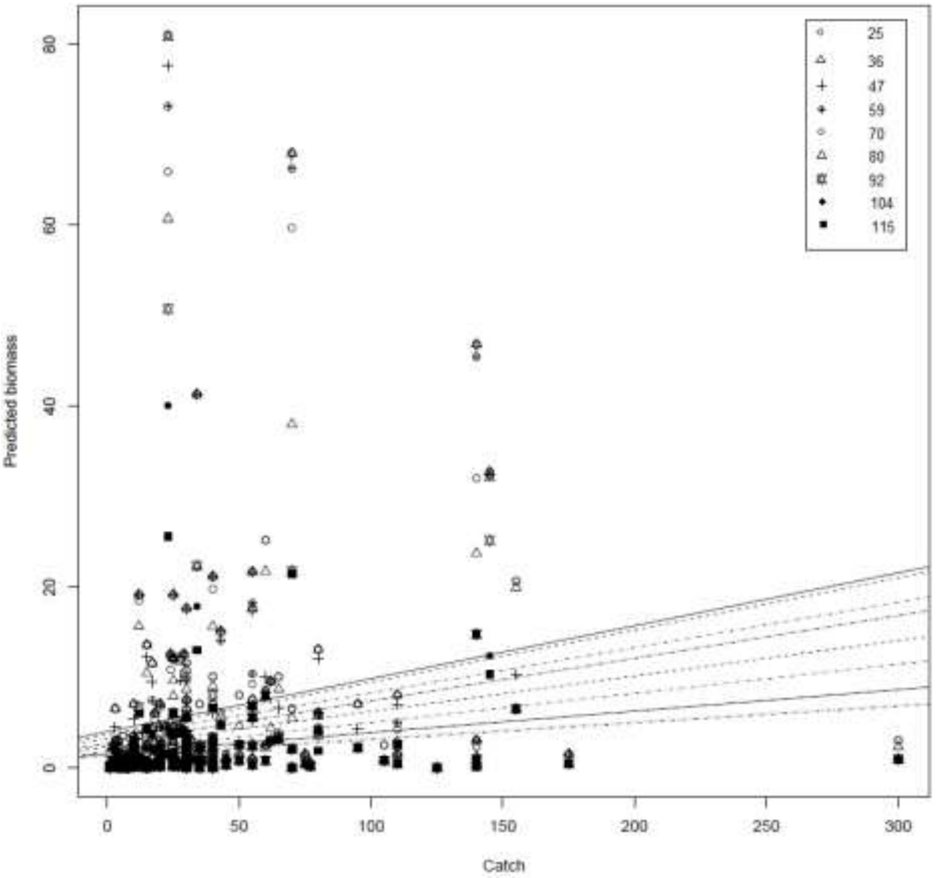

Figure 4. Linear relationships between uncorrected predicted biomasses, obtained from models with different depths to set the limits between small and large tunas, and the real catch for the 141 samples.

Table 3. Coefficient of determination (r^2) and correlation coefficient (r) between the predicted biomass and catch, for different depth limits between the two groups of tunas

		Manuf.	25	36	47	59	70	80	92	104	115
Total (n =141)	**r**	0.214	0.215	0.213	0.190	0.188	0.176	0.184	0.175	0.168	**0.215**
	r^2	0.046	0.046	0.045	0.036	0.035	0.031	0.034	0.031	0.028	**0.046**
Somalia (n=50)	**r**	0.412	0.405	**0.407**	0.363	0.348	0.312	0.362	0.337	0.369	0.405
	r^2	0.170	0.164	**0.166**	0.132	0.121	0.097	0.131	0.114	0.136	0.164
Seychelles NW (n=64)	**r**	0.101	0.105	0.102	0.092	0.093	0.099	0.109	**0.112**	0.071	0.105
	r^2	0.010	0.011	0.010	0.008	0.009	0.010	0.012	**0.013**	0.005	0.011
Seychelles SE (n=10)	**r**	0.612	0.608	0.612	0.640	**0.692**	0.555	0.509	0.596	0.608	0.608
	r^2	0.375	0.370	0.375	0.410	**0.479**	0.308	0.259	0.355	0.370	0.370
Mozambique Channel (n=17)	**r**	0.019	0.035	0.042	**0.042**	-0.010	-0.044	-0.020	0.014	0.018	0.035
	r^2	0.000	0.001	0.002	**0.002**	0.000	0.002	0.000	0.000	0.000	0.001

3. Improve the accuracy of biomass estimation

3.1 All sets

For the 141 sets the best correlation value corresponded to limit at 25m or 115m (r = 0.215, r^2 = 0.046, **Table 3**), which suggests there is not a clear limit between small and large tunas. It seems more coherent to choose the TS and weight values of small tunas for all the range from 25m to 115m as the small tuna usually represent around the 95% of the total tuna catch at DFADs. Table 3 shows the resulting models to correct the biomass.

Table 4.Summary statistics (med=median; min=minimum; max=maximum; SD=standard deviation) of the absolute errors (in metric tons [t]) for the final biomass estimations corrected through different regression models (GLM=generalized linear model; POL2=polynomial of order 2; POL3=polynomial of order 3; GAM=generalized additive model)

Error	Before correction	Manufacturer	GLM	POL2	POL3	GAM
Med (t)	-21.19	-13	12.16	11.25	10.90	12.41
Min(t)	-299.05	-294	-267.04	-267.66	-268.54	-267.59
Max(t)	2.56	138	71.57	47.40	59.97	49.05
SD(t)	40.50	42.32	40.15	39.47	39.25	39.29

The corrected tuna biomass estimates using the different regression models as well as manufacturer biomass estimates were compared with real catches (**Table 5**). In this case, an improvement is observed when the biomass is corrected by polynomial regressions and GAMs. On the other hand the corrected biomass obtained after GLM correction is not better than biomass provided by manufacturer.

Table 5. Coefficients of correlation (r) and determination (r^2), between manufacturer biomass (Manufacturer), predicted biomass (Before correction) and corrected biomass obtained after different corrections.

Parameter	Before correction	Manufacturer	GLM	POL2	POL3	GAM
r	0.214	0.215	0.215	0.280	0.297	0.296
r^2	0.05	0.05	0.05	0.08	0.09	0.09

3.2. Results by regions

The application of the method by areas showed different potential depth limits between small and large tunas for each zone (**Table 6**).

Table 6. Depth limit between tunas occupying shallow layers and tunas occupying chosen for each zone

Zone	Depth limit (m)
Somalia	36
Seychelles NW	92
Seychelles SE	59
Mozambique Channel	47

Then we corrected tuna biomass estimates for the four regions using four regression models (GLM, GAM, POL2 and POL3), obtaining the main statistical data by area as shown in **table 7.**

Table 7. Summary statistics of the absolute errors (in metric tons [t]) for the final biomass estimations by region corrected through different regression models (med=median; min=minimum; max=maximum; SD=standard deviation):

Zone	Error	Before correction	Manufacturer	GLM	POL2	POL3	GAM
Somalia	Med (t)	-23.09	-17.00	8.22	8.08	6.44	7.81
	Min(t)	-135.05	-124	-102.04	-97.41	-95.82	-97.70
	Max(t)	7.28	65	42.30	51.37	60.86	45.23
	SD(t)	31.97	33.82	31.95	31.35	31.22	31.62
Seychelles NW	Med (t)	-17.46	-10.50	16.56	16.73	16.29	11.86
	Min(t)	-299.05	-294	-264.91	-266.67	-266.69	-254.03
	Max(t)	27.72	138	51.73	55.39	47.42	42.33
	SD(t)	49.52	52.49	49.50	47.81	47.62	45.56
Seychelles SE	Med (t)	-14.87	-9	7.17	6.23	3.68	7.17
	Min(t)	-44.34	-43	-26.79	-27.57	-26.77	-26.79
	Max(t)	-8.83	12	8.96	10.38	8.76	8.96
	SD(t)	12.65	14.69	12.06	11.97	11.33	12.06
Mozambique Channel	Med (t)	-12.92	-12	8.07	2.09	6.08	8.32
	Min(t)	-138.84	-139	-112.16	-102.93	-99.87	-110.27
	Max(t)	-5.49	12	21.93	28.93	30.68	23.40
	SD(t)	31.53	32.87	31.33	29.59	29.42	30.71

The **figure 5** show the boxplot of the distribution of the error for the manufacturer´s method and the method corrected through different regression models.

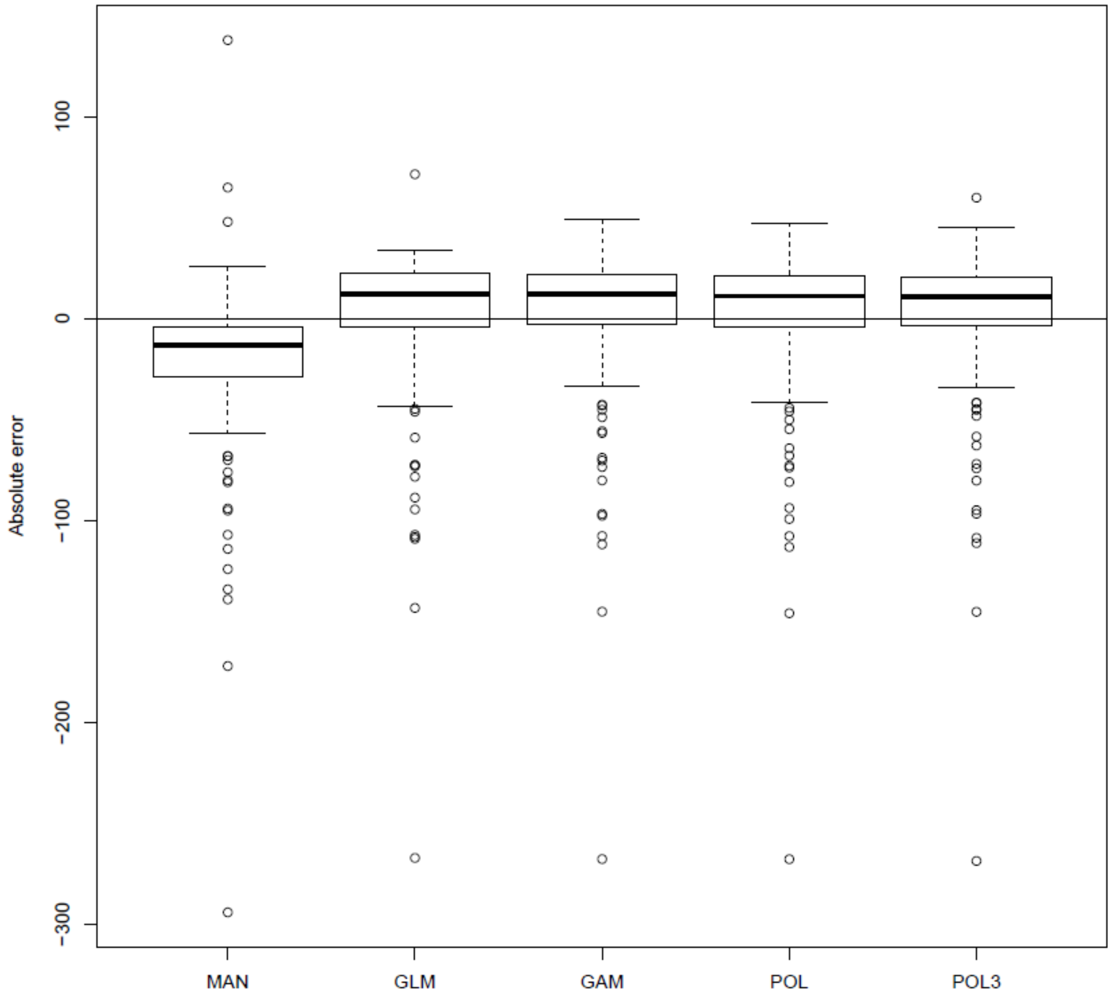

Figure 5. Boxplot of the absolute error (MAN= the error for the manufacturer´s method; the method corrected through different regression models : GLM=generalized linear model; POL2=polynomial of order 2; POL3=polynomial of order 3; GAM=generalized additive model)

The corrected tuna biomass, for each region as well as manufacturer biomass estimates were compared with the real catches (**Table 8**). In this case, the results show considerable improvement over manufacturer estimation for all areas. This improvement is most remarkable in NW Seychelles and in Mozambique Channel.

Table 8. Coefficients of correlation (r) and determination (r^2) by regions.

Zone	Parameter	Before correction	Manuf.	GLM	POL2	POL3	GAM
Somalia	**r**	0.407	0.412	0.407	0.443	0.451	0.428
	r^2	0.166	0.170	0.166	0.196	0.203	0.183
Seychelles NW	**r**	0.112	0.101	0.112	0.281	0.293	0.407
	r^2	0.013	0.010	0.013	0.079	0.086	0.166
Seychelles SE	**r**	0.692	0.612	0.692	0.698	0.735	0.692
	r^2	0.479	0.374	0.479	0.487	0.541	0.479
Mozambique Channel	**r**	0.042	0.0188	0.042	0.331	0.347	0.297
	r^2	0.0018	0.0004	0.0018	0.1098	0.1202	0.0883

Results showed that polynomial regressions (2 and 3) and GAMs improving the accuracy of prediction. We selected polynomial of order 3 as the main model. **Figure 6** illustrates the improvement of correlation between real catch and biomass estimated by manufacturer (Manuf.) and final biomass estimations corrected by polynomial of order 3 (POL3).

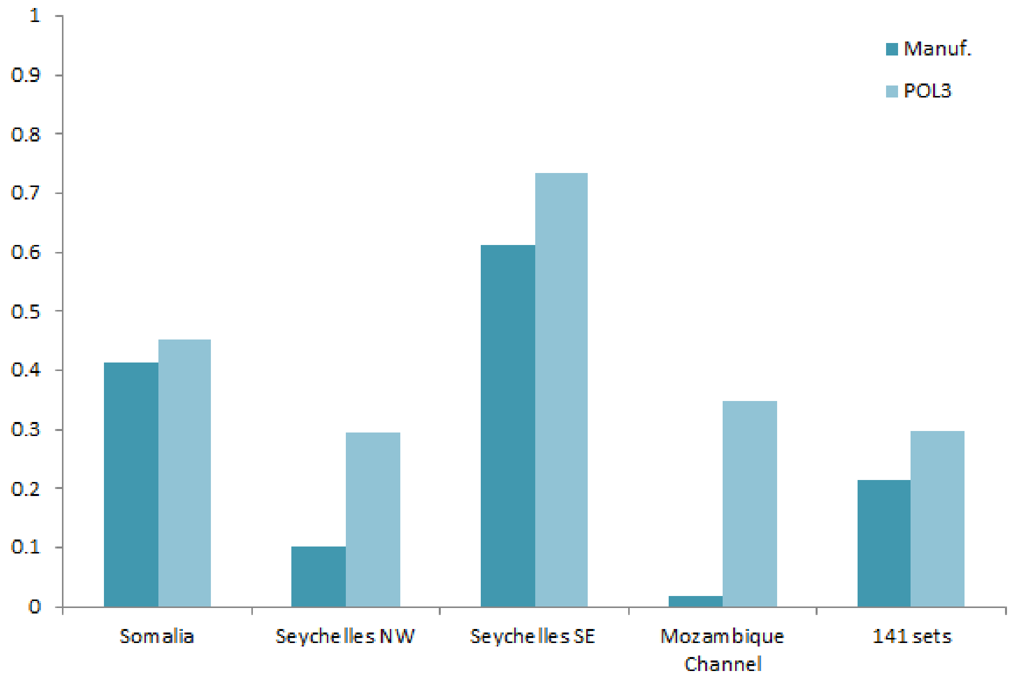

Figure 6. Coefficients of correlation (r) between real catch and biomass estimated by manufacturer (Manuf.) and final biomass estimations corrected by polynomial of order 3 (POL3)

DISCUSSION

Very low coefficients of determination and correlation between the predicted biomass and catch were found when applying the method to all sets found in our database. The correlations obtained by Lopez et al. (2016) are significantly higher albeit the number of samples used for the estimation is much lower (n = 21). This could be explained by several potential sources of variability.

Identification of sets with related acoustic echo-sounder signal

One of the difficulties when building the database was assigning an acoustic measurement to a given set. In this study, not always were found acoustic measurements immediately prior to the set. Because of that, we followed the rule of choose the echo sounder signal with maximum biomass value before the set in the same day or the day before. If buoy signal was available for the same day, we chose the maximum biomass before the set. If this was not the case, we selected the maximum value nearest to sun-rise of the previous day. The vast majority of fishers demand echo-sounder information at dawn, because tuna is supposed to be more aggregated to the DFADs at sunrise. Diel biomass variability of tuna was studied by Lopez et al. (under review) where it can be seen that tuna biomass varies depending on the time of the day and by zone. Thus, the time at which echo-sounder measurement is available is key to compare the sounder biomass signal the catch. Hence, considering that the catch is taken all the tuna aggregation, then the echo-sounder measurement should be received close to the peak of tuna aggregation (ie not dispersed around DFADs) or to the time at which signal is more representative of the biomass around the DFAD. Due to biomass variability at FADs due to dispersion/aggregation processes around DFADs, this means that the biomass acoustic signal should be received when is more aggregated to the DFAD and closes to the time of the catch.

Thus, in order to have the best database, it is essential to take into account diel tuna biomass variability at FADs in a given area so that echo-sounder data can better represent the real abundance around FADs (i.e. the catch).

Spatial and temporal variability

We have an extensive buoy database covering information from January 2012 to May 2015 in different regions. Therefore the sets are from different areas and seasons which could mask the relationship between catch and echo-sounder information as there would be different species/sizes composition by area/time at FADs. Seasonality of the Indian Ocean is marked by monsoon activity (Schott et al., 2009) and this affects the marine ecology (Jury et al., 2010) as well as the presence and relative species composition of an area; which also affect the need of our model to assign a given TS to each depth layer (mixed species TS). The fact that different tuna (smaller or larger) could be occupying FADs differently in the different areas/season suggests to apply the model area specific. The correlations between manufacturer biomass, uncorrected predicted biomass and real catch are very different by area. While Somalia and SE Seychelles had reasonably good correlations, NW Seychelles and Mozambique Channel showed poor correlations. Tuna vertical distribution at DFADs may vary depending on different factors, including oceanographic conditions (thermocline, currents..), total biomass, number species and sizes present at DFADs. Thus depth limits between small and large tuna will be dependent on the area of study. Incorporating new knowledge of vertical distribution of tuna aggregations at FADs for different regions is necessary to improve biomass estimates from echo-sounder buoys.

The best correlation value corresponds to depth limit between small and large tuna at 25m and 115m ($r=0.215$, $r^2=0.046$, **Table 3**) which implies that having no depth limit between large and small tuna makes the best correlation value for our data. Although large tuna may be more time in deeper layers compared to small tuna as observed by different authors (Moreno et al., 2007; Forget et al., 2015), there are evidences that tuna make vertical movements at FADs suggesting that a mixed TS for all the water column is more accurate than assigning a given TS to a specific depth layer. Although an improvement in the estimation of biomass is observed when applying the same TS value from 25 to 115m, the improvement is not as expected and very close to the values given by manufacturer; which underlines the need of more information to improve the analysis. More knowledge about diel biomass variability of tuna or their vertical behavior under DFADs could provide us new data in order to improve the protocol for the model. This would also be very interesting to select the best time at which echo-sounder measurement should be taken.

Future research for remote species classification at FADs

Studying diel tuna biomass at FADs is essential to know the time at which the acoustic sampling should be taken with the echo-sounder buoy. It is desirable to standardize the echo-sounder measurement time. Likewise, having tagging data for tuna vertical behavior would allow obtaining the depths layers at which different tuna species and sizes spend most of the time at FADs depending on the area and period of the year. This information would allow understanding remotely the species present at FADs.

However, recent acoustic research by ISSF (Restrepo et al., 2016) have found different frequency response for skipjack, bigeye and yellowfin tuna, which confirms the potential for tuna species discrimination at FADs, by using simultaneously multiple frequencies incorporated to fishing acoustic equipment. This means that using multiple frequencies at echo-sounder buoys will directly provide with the proportion of the species at FADs. This information together with the TS for each tuna species found would allow having accurate biomass estimates and sizes by tuna species.

References

Baske, A., Gibbon, J., Benn, J., Nickson, A., 2012. Estimating the use of drifting Fish Aggregation Devices (FADs) around the globe. PEW Environmental group, discussion paper, 8p.

Castro, J., Santiago, J., Santana-Ortega, A., 2002. A general theory on fish aggregation to floating objects: an alternative to the meeting point hypothesis. Reviews in Fish Biology and Fisheries 11, 255-277.

Chassot, E., de Molina, A.D., Assan, C., Dewals, P., Cauquil, P., Areso, J., Rahombanjanaharyk, D., Floch, L., 2013. Statistics of the European Union and associated flags purse seine fishing fleet targeting tropical tunas in the Indian Ocean 1981–2012, IOTC-WPTT-13, 44pp.

Dagorn, L., Holland, K.N., Itano, D.G., 2006. Behavior of yellowfin (Thunnus albacares) and bigeye (T. obesus) tuna in a network of fish aggregating devices (FADs). Marine Biology 151, 595-606.

Dagorn, L., Holland, K.N., Restrepo, V., Moreno, G., 2012. Is it good or bad to fish with FADs? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems?
DOI: 10.1111/j.1467-2979.2012.00478.x. Fish and fisheries.

Dagorn, L., Pincock, D., Girard, C., Holland, K., Taquet, M., Sancho, G., Itano, D., Aumeeruddy, R., 2007. Satellite-linked acoustic receivers to observe behavior of fish in remote areas. Aquatic Living Resources 20, 307-312.

Doray, M., Josse, E., Gervain, P., Reynal, L., Chantrel, J., 2006. Acoustic characterisation of pelagic fish aggregations around moored fish aggregating devices in Martinique (Lesser Antilles). Fisheries Research 82, 162-175.

Doray, M., Josse, E., Gervain, P., Reynal, L., Chantrel, J., 2007. Joint use of echosounding, fishing and video techniques to assess the structure of fish aggregations around moored Fish Aggregating Devices in Martinique (Lesser Antilles). Aquatic Living Resources 20, 357-366.

Filmalter, J.D., Dagorn, L., Cowley, P.D., Taquet, M., 2011. First descriptions of the behavior of silky sharks, Carcharhinus falciformis, around drifting fish aggregating devices in the Indian Ocean. Bulletin Of Marine Science 87, 325-337.

Fonteneau, A., Chassot, E., Bodin, N., 2013. Global spatio-temporal patterns in tropical tuna purse seine fisheries on drifting fish aggregating devices (DFADs): Taking a historical perspective to inform current challenges. Aquatic Living Resources 26, 37-48.

Forget, F.G., Capello, M., Filmalter, J.D., Govinden, R., Soria, M., Cowley, P.D., Dagorn, L., 2015. Behaviour and vulnerability of target and non-target species at drifting fish aggregating devices (FADs) in the tropical tuna purse seine fishery determined by acoustic telemetry. Canadian Journal of Fisheries and Aquatic Sciences 72, 1398-1405.

Govinden, R., Dagorn, L., Filmalter, J., Soria, M., 2010. Behaviour of Tuna a ssociated with Drifting Fish Aggregating Devices (FADs) in the Mozambique Channel, IOTC-2010-WPTT-25.

Govinden, R., Jauhary, R., Filmalter, J., Forget, F., Soria, M., Adam, S., Dagorn, L., 2013. Movement behaviour of skipjack (Katsuwonus pelamis) and yellowfin (Thunnus albacares) tuna at anchored fish aggregating devices (FADs) in the Maldives, investigated by acoustic telemetry. Aquatic Living Resources 26, 69-77.

Josse, E., Bertrand, A., 2000. In situ acoustic target strength measurements of tuna associated with a fish aggregating device. ICES Journal of Marine Science 57, 911.

Josse, E., Bertrand, A., Dagorn, L., 1999. An acoustic approach to study tuna aggregated around fish aggregating devices in French Polynesia: methods and validation. Aquat. Living Resour 12, 303-313.

Josse, E., Dagorn, L., Bertrand, A., 2000. Typology and behaviour of tuna aggregations around fish aggregating devices from acoustic surveys in French Polynesia. Aquat. Living Resour 13, 183-192.

Jury, M., McClanahan, T., Maina, J., 2010. West Indian ocean variability and east African fish catch. Marine environmental research 70, 162-170.

Leroy, B., Itano, D.G., Usu, T., Nicol, S.J., Holland, K.N., Hampton, J., 2009. Vertical behavior and the observation of FAD effects on tropical tuna in the warm-pool of the western Pacific Ocean, Tagging and Tracking of Marine Animals with Electronic Devices, Springer, pp. 161-179.

Lopez, J., Moreno, G., Boyra, G., 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.

Lopez, J., Moreno, G., Sancristobal, I., 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.

Lopez, J., Moreno, G., Soria, M., Cotel, P., Dagorn, L., 2010. Remote discrimination of By-cath in purse seine fishery using fishers' echo-sounder buoys. IOTC-2010-WPEB-03.

Maclennan, D.N., Fernandes, P.G., Dalen, J., 2002. A consistent approach to definitions and symbols in fisheries acoustics. ICES Journal of Marine Science: Journal du Conseil 59, 365-369.

Matsumoto, T., Okamoto, H., Toyonaga, M., 2006. Behavioral study of small bigeye, yellowfin and skipjack tunas associated with drifting FADs using ultrasonic coded transmitter in the central Pacific Ocean. second regular session of the scientific committee, Western and Central Pacific Fisheries Commission. Information Paper 7.

Matsumoto, T., Satoh, K., Toyonaga, M., 2014. Behavior of skipjack tuna (Katsuwonus pelamis) associated with a drifting FAD monitored with ultrasonic transmitters in the equatorial central Pacific Ocean. Fisheries Research 157, 78-85.

Mitsunaga, Y., Endo, C., Anraku, K., Selorio Jr, C.M., Babaran, R.P., 2012. Association of early juvenile yellowfin tuna Thunnus albacares with a network of payaos in the Philippines. Fisheries Science 78, 15-22.

Moreno, G., Dagorn, L., Capello, M., Lopez, J., Filmalter, J., Forget, F., Sancristobal, I., Holland, K., 2015. Fish aggregating devices (FADs) as scientific platforms. Fisheries Research 178, 122-129.

Moreno, G., Dagorn, L., Sancho, G., Itano, D., 2007. Fish behaviour from fishers´ knowledge: the case study of tropical tuna around drifting fish aggregating devices (DFADs). Canadian Journal of Fisheries and Aquatic Sciences 64.

Petit, C., Pallarés, P., Pianet, R., 2000. New sampling and data processing strategy for estimating the composition of catches by species and sizes in the European purse seine tropical tuna fisheries.

Restrepo, V., Dagorn, L., Moreno, G., Forget, F., Schaefer, K., Sancristobal, I., Muir, J., Itano, D., 2016. Compendium of ISSF At-Sea Bycatch Mitigation Research Activities as of July, 2016. . ISSF Technical Report 2016-13. International Seafood Sustainability Foundation, McLean, Virginia, USA.

Robert, M., Dagorn, L., Lopez, J., Moreno, G., Deneubourg, J.-L., 2013. Does social behavior influence the dynamics of aggregations formed by tropical tunas around floating objects? An experimental approach. Journal of Experimental Marine Biology and Ecology 440, 238-243.

Santiago, J., Lopez, J., Moreno, G., Murua, H., Quincoces, I., Soto, M., 2015. Towards a Tropical Tuna Buoy-derived Abundance Index (TT-BAI).

Scott, G.P., Lopez, J., 2014. The use of FADs in tuna fisheries. European Parliament. Policy Department B: Structural and Cohesion Policies: Fisheries IP/B/PECH/IC/2013-123, 70p.

Schaefer, K.M., Fuller, D.W., 2013. Simultaneous behavior of skipjack (Katsuwonus pelamis), bigeye (Thunnus obsesus), and yellowfin (T. albacares) tunas, within large multi-species aggregations associated with drifting fish aggregating devices (FADs) in the equatorial eastern Pacific Ocean. Marine Biology 160, 3005-3014.

Schott, F.A., Xie, S.P., McCreary, J.P., 2009. Indian Ocean circulation and climate variability. Reviews of Geophysics 47.

Simmonds, J., MacLennan, D., 2005. Fishery acoustic theory and practice, Blackwell Scientific Publications, Oxford, UK.

Taquet, M., Dagorn, L., Gaertner, J.-C., Girard, C., Aumerruddy, R., Sancho, G., Itano, D., 2007. Behavior of dolphinfish (Coryphaena hippurus) around drifting FADs as observed from automated acoustic receivers. Aquatic Living Resources 20, 323-330.

Ushioda, M., 2015. Estimating The Use of FADS Around the World. PEW Environmental group, discussion paper, 19 p.