Towards a Tropical Tuna Buoy-derived Abundance Index (TT-BAI)

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Abstract

Around the mid-2000s the tropical tuna purse seine fleet started to regularly use satellite linked echo-sounder buoys in their drifting FADs. This technological development is causing rapid changes in the fishing strategy and fleet behavior due to the possibility of informing remotely and in near real-time about the accurate geo-location of the FAD and the presence and size of tuna aggregations underneath them. Apart from its unquestionable utility as a fishery tool, echo-sounder buoys have also the potential of being a privileged observation platform to evaluate relative abundances of FAD-associated fish using catch-independent data. This paper discusses methodologies to account for covariates that are independent of abundance so that acoustic records derived from echo-sounder buoys can be used as a complementary relative abundance index in the stock assessment of tropical tuna stocks.

Resumen

Alrededor de la década de 2000 la flota de cerqueros dirigidos a túnidos tropicales comenzó a utilizar regularmente boyas con sonda en sus DCPs derivantes. Este desarrollo tecnológico está causando rápidos cambios en la estrategia de pesca y en el comportamiento de la flota debido a la posibilidad de informar remotamente y a tiempo casi-real sobre la geolocalización precisa de los DCPs y la presencia y tamaño de las agregaciones de túnidos bajo ellos. Aparte de esta incuestionable utilidad como una herramienta de pesca, las boyas equipadas con ecosonda tienen asimismo el potencial de ser una plataforma de observación privilegiada para evaluar la abundancia relativa de la biomasa de túnidos asociada a los DCPs utilizando información independiente de la captura. Este documento ilustra metodologías para tener en cuenta covariantes que son independientes de la abundancia de forma que los registros acústicos derivados de las ecosondas de las boyas puedan ser usados como un índice de abundancia relativa complementario en la evaluación de poblaciones de túnidos tropicales.

Introduction

Quantification of abundance, either absolute or relative, is the core element of any fish stock assessment. However, it is one of the most difficult parameters to estimate, especially in the case of highly migratory fish stocks, such as tuna. The conventional fishery-independent surveys used to estimate the abundance of some fish stocks (acoustics, aerial, egg-larval

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surveys) are not practicable for highly migratory widely distributed tuna stocks. And, in the absence of fishery-independent information, Catch per Unit of Effort (CPUE) is the standard abundance index used to guide the assessment of tuna stocks.

Relative abundance indices based on CPUE data are notoriously problematic (Maunder *et al.*, 2006), as catch data is usually biased by fishing effort, coverage, and other limiting factors of fishery data. The use of CPUE as an index of abundance is based on the basic principal that CPUE is proportional to abundance, being catchability (q) - the portion of the stock captured by one unit of effort - the coefficient of proportionality. One of the associated difficulties is that q is rarely constant and depends on a number of different components, such as those related to changes in the fishing efficiency and dynamics of the fleet. This is particularly notorious in the tropical tuna purse seine fishery, where these factors are evolving very rapidly due to the fast technological development and the sharp increase of the use of fish aggregating devices (FADs), which compromises the usefulness of the purse seine derived CPUE indices. Indeed, since the regular introduction of FADs in the early 1990s (Ariz et al, 1999; Hallier and Parajua, 1999), progressively equipped with electronic devices, a fishing effort unit is difficult to be defined for purse seiners. These elements clearly introduced significant improvements in the purse seine efficiency, which resulted in changes in fishing patterns and strategy (Lopez *et al.,* 2014). These changes hinder a proper definition of the effective effort and thus introduce biases and uncertainties to the CPUE-biomass relationship (Fonteneau *et al.*, 2013). It is interesting to note that many of the current stock assessments for tropical tunas use unbalanced CPUE indices based on search time (i.e., the time devoted to the searching of tuna concentrations and the metric traditionally used to reflect nominal effort in the purse seine fishery) or coming from other fisheries such as longline, which significantly differ in the size composition of the caught tunas.

Several attempts have been and are being made by the scientific community in order to better understand and characterize the changes in fishing pattern and strategies, together with the technological developments associated with the FAD fishing activity, to improve the CPUE standardization procedure in tropical tuna purse seine fisheries (Anonymous, 2012; Lopez *et al.*, 2014; Torres-Irineo *et al.*, 2014)). Special reference should be given to the European project CECOFAD (Catch, Effort, and eCOsystem impacts of FAD-fishing), that aims at providing insights into the fishing effort units (for both fishing modes: FADs and free schools) that accounts for different factors influencing catchability(Gaertner *et al.*, 2014).

Prior to the widespread use of DFADs (i.e. 1980-1995), most modifications to purse seine technology were driven by the desire to improve the success rate on free-swimming schools (Itano, 1998). However, in the last 20 years, most of the technological developments in the tropical tuna purse seine fishery were mainly devoted to increase catch rates on FADs (Scott and Lopez, 2014). One of the most important technological developments that have been recently introduced by the purse seine fleet fishing with FADs are the satellite linked echo-sounder buoys. The first buoys equipped with an echo-sounder appeared in the market in the 2000, but they were not started to be regularly used in the fishing operations until mid-2000's, and nowadays, their use have rapidly spread between all the purse seine fleets worldwide. As Lopez et al. (2014) demonstrated, this technological development is causing rapid changes in the fishing strategy and fleet behavior, due to the possibility of remotely informing in near real-time about the accurate geolocation of the FAD and the presence and abundance of tuna aggregations underneath them.

However, apart from its unquestionable impact in the conception of a useful CPUE index for this fleet, echo-sounder buoys have also the potential of being a privileged observation platform to evaluate abundances of tunas and accompanying species using catch-independent data. According to Baske *et al.* (2012), buoy manufacturers sell approximately 47000 to 70000 buoys per year, many of them fitted with echo-sounders. This potential utility as a tool to evaluate the abundance of tropical tunas has already been suggested by several authors (Dagorn *et al.*, 2006; Lopez *et al.*, 2013). This paper presents an initial examination of some of the features of the information potentially available from satellite tracking echo-sounder buoys used by the Spanish tropical tuna purse seiners and associated fleet with special attention to those equipped with echo-sounders.

In order to conduct this preliminary evaluation, vessel owners from the Spanish ANABAC & OPAGAC organizations have provided information associated to one month of the buoy activity of their vessels. This limited dataset has been used to define formats and identify variables and factors to be considered or excluded in future analysis with the complete bulk of data available. The authors want to express their gratitude to the vessel owners of both organizations for facilitating access to this important historical information and for their disposition to provide all the available buoy-derived data under the agreed confidentiality rules.

Material and methods

At the time of the data collection (2011), three were the brands of buoys used by the Spanish and associated purse seine fleet (Table 1). The main characteristics of these buoys are shown below:

Brand A: These buoys are equipped with a 50 KHz/500 W echo-sounder. The range extends from 6 to 150 m, with a blanking zone of 6 m. At an angle of 42°, the cone of observation under the buoy has a diameter of 116 m at a depth of 150 m. The echo-sounder provides acoustic information in 50 different vertical layers, each with a resolution of 3 m.

Brand B: This buoy is equipped with a sounder, which operates at a frequency of 190.5 kHz with a power of 140 W. The range extends from 3 to 115 m, with a transducer blanking zone running from 0 to 3 m. At an angle of 40°, the cone of observation under the buoy has a diameter of 78.6 m at a depth of 115 m. The echo-sounder provides acoustic information in 10 different vertical layers, each with a resolution of 11.2 m.

Brand C: This buoy is equipped with a sounder, which operates at a frequency of 120 kHz with a power of 400 W. The range extends from 0 to 100 m. At an angle of 45°, the cone of observation under the buoy has a diameter of 111 m at a depth of 100 m. The echo-sounder provides acoustic information in x different vertical layers, each with a resolution of xx.x m.

The sampling configuration (number of emitted pings, sampling duration, time of the day in which the acoustic sample is taken, etc.) or the technical specifications of the echo-sounder buoys (beam angle, transducer frequency, etc.) are brand-specific. The progresses of the internal algorithms used to conduct the echo-integration are proprietary for each manufacturer as well. This implies different units of measurements and outputs by brand, which hinders easy systematic comparisons between the raw acoustic samples and estimates of the different products.

The information provided in this document comes from analyses of three different data sets corresponding to three different buoy manufacturers. Description of these data sets and the corresponding preliminary analyses are summarized in Table 2. Table 2 shows the number of vessels included in the database, buoys and buoys equipped with echo-sounder for the Atlantic Ocean in March 2011 and for all the oceans (Atlantic Ocean-Pacific Ocean: March 2011; Indian Ocean: October 2011), number of total records, records with echo-sounder data, number of records with daily maximum echo-sounder values, number of positive observations and proportion of positives samples. The data shown in Table 2 are structured according to the three brands of echo-sounder buoys used by the Spanish tropical tuna purse seine fleet. The total number of records available for 1 month (March 2011) in the Atlantic Ocean reached 427,050 samples, of which 140,592 included echo-sounder measurements.

The descriptive analysis shown in this document has been done using R (Team, 2013). Based in the descriptive analysis we discuss ways to integrate buoy information into a catch-independent abundance index for tropical tuna, including filtering for acoustic data reductions and exclusions and the rational used. Finally we identify those factors that should be considered in the analysis, either because they may affect the assumption that the acoustic records are proportional to tropical tuna abundance or may influence the coefficient of proportionality (φ).

Results and discussion

The total number of acoustic records analyzed rose to 140,592 which were integrated into a total of 21,872 daily records. A daily record for a particular buoy was obtained as the maximum value of all observed records by the buoy in a particular day. After a preliminary analysis of the data and following Lopez (2015) echoes from layers of depth lower than 25 m were excluded from the estimations because echoes from these shallow layers are more likely to correspond to non-tuna species. Similar depths were assumed in other studies using the same echo-sounder buoys to separate tuna from non-tuna species (Robert *et al.*, 2013). This adjustment could be done with the data coming from brands A and B because brand C did not provide layer-specific values. Figures 1a-c shows the frequency distribution of the acoustic records for the three different brands; they will require additional data cleaning and transformation for further modelling.

The spatial distribution of the number of daily acoustic records is shown in Figure 2.

The model we propose is based in an assumption very similar to the fundamental relationship among CPUE and abundance widely used in quantitative fisheries analysis. In our case we built the index based on the assumption that the signal from the echo-sounder is proportional to the abundance of fish.

$$BAI_t = \varphi \, . B_t$$

where BAI_t is the Buoy-derived Abundance Index and B_t is the abundance in time t.

Similarly to the catchability, the coefficient of proportionality φ is not constant for many reasons. In order to ensure that φ can be assumed to be constant (i.e. to control the effects other than those caused by changes in the abundance of the population) a standardization analysis should be performed aiming to remove factors other than changes in abundance of the population. This can be performed standardizing nominal measurements of the echo-sounders using a Generalized Linear Mixed Modelling approach.

Because of the significant proportion of records with zero abundance (18% on average in the tropical Atlantic Ocean in March 2011), the standardization process proposed is a Delta method (Lo *et al.*, 1992) that can take into account zero observations. The Delta model estimates the predicted abundances as the result of two processes: i) the probability of encounter tropical tuna in the acoustic observations (proportion of positives) and, ii) the mean relative abundance given that a positive observation has been realized. Then the estimated Buoy-derived Abundance Indices (BAI) are the product of these two processes.

Considerations for the exclusion of records

Typical data cleaning will be conducted including the removal of outliers (invalid, impossible or extreme values) related to bad geolocation, time, or other general variables. Apart of the regular exclusions due to inconsistencies, the following considerations are proposed for accepting the data for the standardization analysis:

- **Time after deployment (or fishing event)**: records with less than 5 days after deployment, or after a known fishing event, will be excluded. According to Hall (2011) and Moreno et al. (2007b) DFADs are deployed and left to drift freely with the intention of being exclusively used by the boat or fleet that set them afloat after a certain period of time, usually 3 to 5 weeks.
- **Vertical range of the buoy**: exclude acoustic information from the shallower layers, <25m. According to Lopez (2015); Robert *et al.* (2013), the vertical boundary between non-tuna species and tunas can be considered at about 25 m. Excluding the first layers we try to eliminate the noise from the non-tuna species associated to the DFAD.
- **Time of the day** : The frequency at which fishers ask for acoustic data varies between regions, companies, and used brand, but the vast majority of them always request eco-sounder information at dawn (Lopez *et al.*, 2014). According to fishers' belief, tuna could be more concentrated under the FAD at sunrise. It will be interesting to try to reduce the effect of local time by including in the analyses only the acoustic data recorded by the buoys at a common particular time. To properly reach this objective, it is important to change first GMT times to local times, as many of the new buoys are set to automatically sample at sunrise according to their spatial location.

- **Bottom depth:** Using high resolution bathymetry data (British Oceanographic Data Centre, UK, www.gebco.net), acoustic records from buoys located in areas with a bottom depth shallower than 200 m will be excluded. The rational of this exclusion is not to incorporate acoustic records of FADs that have drifted to coastal areas and that can provide with false positives.
- **Speed of the buoy:** Satellite linked buoys automatically records information on their trajectory values (speed and bearing). As buoys are usually turned on minutes or hours prior to their deployments and are turned off after an uncertain period of time, some of their acoustic measurements could be compromised and correspond to false positives as well. Surface currents in the tropical oceans rarely exceeds 3 knots of speed (Lumpkin and Garzoli, 2005; Sikhakolli *et al.*, 2013) and thus, higher values could give us information on the deployment status of the DFAD (onboard/deployed), and consequently, on the useful acoustic records.

Variables to be considered in the standardization

Variables to be considered in the analysis apart from year, month and area will be:

- **Soak time:** The time spent by the buoy in the water since initial deployment. Only valid for virgin FADs or for FADs for which the time at sea is known.
- **Buoy type**: Brand and model of the buoy. Very different technical specifications and operation procedures can be found between companies and models. Among the most important features, the followings should also be considered as relevant covariates in the standardization:
    - **Frequencies at which buoys are operating**: A priori, different frequencies provide with non-comparable and non-storable pool of acoustic measurements that should be treated in advance to obtain common signals.
    - **Units provided by the buoy:** Because the raw acoustic information used by the buoys, the echo-integration procedure and final outcomes significantly differ between brands and buoy models, it is of primary importance to investigate the relationship among them. Recent works are studying these differences to try to standardize and better understand these inter and intra-buoy differences (Sancristobal *et al.,* 2014)
    - **Sampled volume:** Beam angle and ranges are brand-specific as well, which lead us to include this proportionality relationship in the standardization process.
    - **Acoustic filters automatically applied by the buoy:** Some buoys use an internal automatic filter to try to reduce the noise produced by non-tuna individuals at FADs, which also could lead to lose a very interesting part of the information. These differences should be taken into account and, if possible, compensated or corrected.
- **Depth of the acoustic layers**: Two sections of the observed water column will be considered in the analysis: 25-80 m and >80 m. According to Lopez (2015), there seems to be a boundary between small and large tunas at about 80 m.

- **Bearing and speed** of the FAD: according to Lopez (2015) bearing and speed of the FAD are key drivers to determine the non-tuna species and small tunas presence and biomass densities at FADs.
- **Density of FADs**: A measure of the number of FADs in a particular surrounding area of the buoy (number in a radius of nm to be decided)
- **Environmental variables:** As fishers have stated, oceanographic conditions can also affect buoys' accuracy. In addition, environmental factors such as SST, SLA, Chl.a, mixed-layer depth, wind speed and/or Beafort , etc. seem to affect fish presence at FADs, as well as their associative behavior.
- **Species composition underneath the FAD:** The size and species composition of the associated aggregation can also imply changes in the acoustic record. Investigating the catch composition of a particular spatial-temporal set or strata could introduce significant advantages in the standardization process. Studying FAD inter-variability in terms of size and species composition would also be an advantage.

The use of echo-sounder buoys by the tropical tuna purse seine fleet has significantly increased in the last 10 years (Lopez et al, 2014). Recent studies have already used buoys to ecologically investigate FADs (Lopez, 2015, Robert *et al.,* 2013). However, and despite first efforts are being conducted by scientific community to obtain relative biomass abundances of tunas, reliable indices are still difficult to achieve. Capello *et al.* (2013) proposed a method to estimate BAI using behavioral assumptions coming from tagging. We here present the first steps to remotely estimate a BAI in a more CPUE-oriented way, showing the basic notions and accounting with the most significant features to be considered along the standardization process.

The large disparity between brands and buoy models significantly increases the difficulty of obtaining a reliable BAI for tuna species. As previously mentioned, significant efforts are being conducted by scientist at sea to better understand inter-buoy variability. However, and in an absence of accurate results in this area, works like this document are of primary importance because they set the foundations for future investigations and open new lines of investigations and scientific discussion. Although obtaining accurate BAI is extremely demanding due to the previously listed difficultues, the huge potential of these buoys to actively sample vast extensions in a cost-effective manner show the usefulness of these buoys to be used in scientific studies. Unlike catch data, buoy derived data is not so affected by some fishery-data limitations like coverage or fishing effort, among others, which provide with obvious advantages. We extremely believe that the BAI should be further developed in the near future due to the high resolution data they can provide in a non-invasive way. These advancements could provide significant information to complement current stock assessments of some tuna fisheries, improving the knowledge between the biomass-CPUE relationship while providing indices less dependent on other fisheries data or less affected by changes in the fishing technology or the fishing effort.

Acknowledgements

We would like to thank the collaboration of the Spanish vessel-owners of ANABAC and OPAGAC for providing the historic information recorded by the echo-sounders buoys. This work is part of the project CECOFAD (Catch, Effort, and eCOsystem impacts of FAD-fishing), co-financed by the European Union as a project promoting science-industry partnership.

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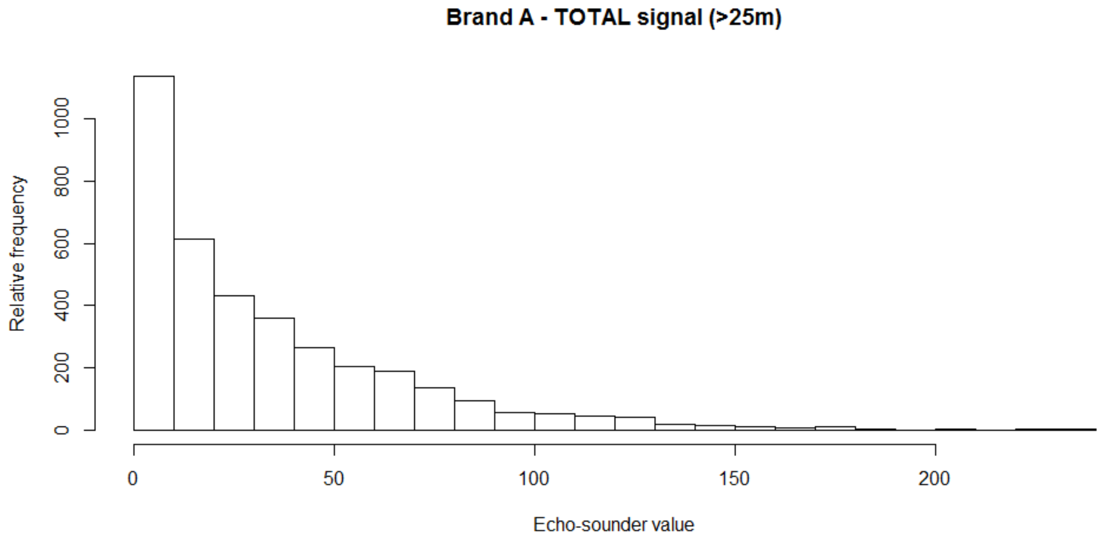
	Brand A	Brand B	Brand C
Operating frequency (kHz)	50	190.5	130
Range (m)	150	115	100
Number of layers	50	10	XX
Energy source	Solar panels	Battery	Solar panels

Table 1. Main characteristics of the three echo-sounder buoys brands used by the Spanish fleet during the period of reference (adapted from Lopez et al, 2014)

	BRAND A		BRAND B		BRAND C		ALL	
	All	EPO	All	EPO	All	EPO	All	EPO
Vessels	-	-	38	17	31	14	38	17
Buoys	1,634	186	5,522	1,339	4,549	475	11,705	2,000
Buoys with echo-sounder	1,634	186	2,271	558	291	0	4,196	744
% Buoys with echo-sounder	100	100	41,1	41.7	6,4	0	35,8	37%
Number of records	575,966	66,701	262,361	77,342	459,915	58,485	1,298,242	202,528
Acoustic records	486,109	56,864	28,528	10,409	53,368	0	568,005	67,273
Daily acoustic records	38,799	4,909	17,902	6,806	7,825	0	64,526	11,715
Daily positive records	23,443	3,683	14,247	5,638	6,792	-	44,482	9,321
% positives	60%	75%	80%	83%	87%	-	69%	80%

Table 2. Number of vessels, buoys and buoys with echo-sounder in the eastern Pacific Ocean in March 2011 and in all the oceans (AO-PO: March 2011; IO: October 2011), number of total records, records with echo-sounder data, number of records with daily maximum echo-sounder values, number of positive observations and proportion of positives.



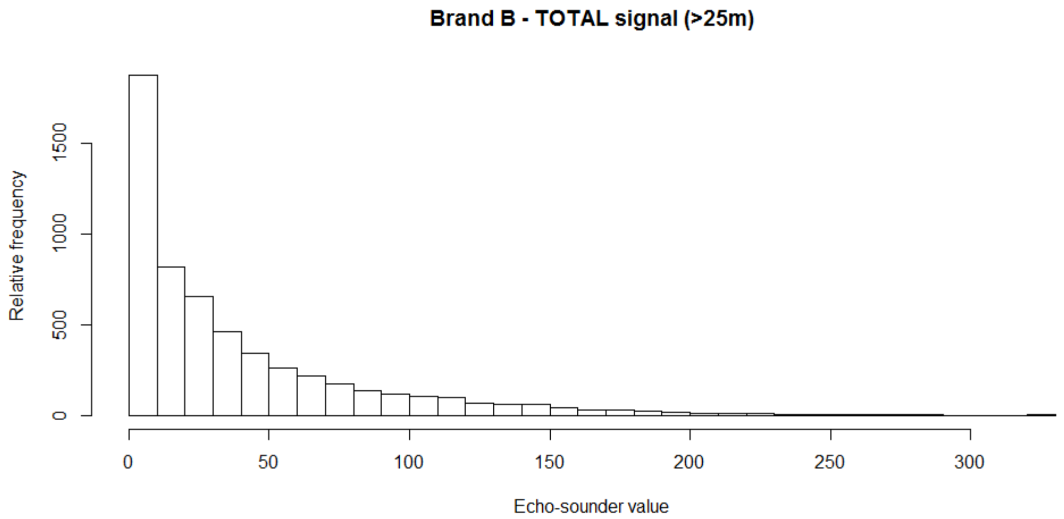


Figure 1. Histograms of the daily values provided by the echo-sounder buoys in March 2011. SOURCE: Fleet associated to the Spanish organizations ANABAC and OPAGAC fishing in the Pacific Ocean

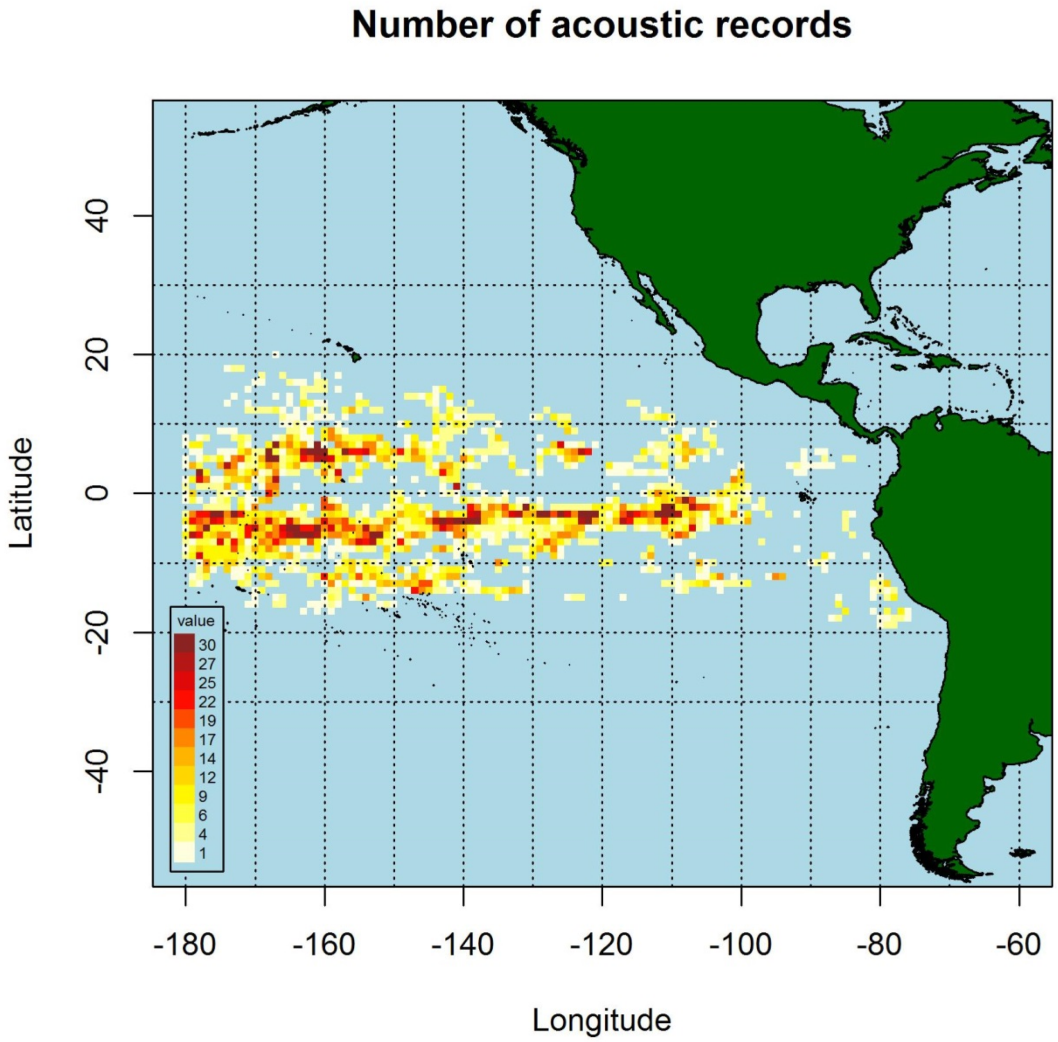


Figure 2. Number of echo-sounder daily records by rectangles of 1°x1° in March 2011. SOURCE: Fleet associated to organization OPAGAC fishing in the Pacific Ocean