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ACOUSTIC-BASED FISHERY-INDEPENDENT ABUNDANCE INDEX OF JUVENILE BLUEFIN TUNAS IN THE BAY OF BISCAY: RESULTS FROM THE FIRST FIVE SURVEYS

N. Goñi[1], J. Uranga[1], I. Arregui[1], I. Onandia[2],
U. Martinez[1], G. Boyra[1], G.D. Melvin[3], I. Godard, H. Arrizabalaga[1]

SUMMARY

An acoustic survey was performed in the Bay of Biscay (usual summer feeding area for bluefin tunas) during July 2015 to 2019 on-board a baitboat fishing vessel, using a long-range 90kHz sonar and a SIMRAD EK60 scientific echosounder (upgraded to EK80 in 2018) working at three frequencies, of which 38 kHz, used for echointegration. The survey followed systematic transects defined according to 2000-2011 baitboat catch locations. All bluefin detections by sonar and echosounder were recorded. In each aggregation, species identification or size-sampling were performed through no-kill fishing events, stereoscopic camera and/or multibeam sonar. The spatial distribution of detected bluefin schools is shown, as well as the estimated number and size of individuals in the detected schools, and the estimated number of individuals by age-group. The detected abundance and distribution of bluefin tuna is analyzed by size-group and in terms of spatial variability. The goal of this survey is to produce an acoustics-based, fishery independent abundance index in the Bay of Biscay as an alternative to the current one, based on catch rates, that is being used in the stock assessment.

RÉSUMÉ

Une prospection acoustique a été réalisée dans le golfe de Gascogne (zone de fourrage estivale habituelle du thon rouge) entre le mois de juillet 2015 et 2019 à bord d'un canneur, utilisant un sonar à longue portée de 90kHz et d'un échosondeur scientifique SIMRAD EK60 (mis à niveau à EK80 en 2018) travaillant à trois fréquences, dont 38 kHz, pour l'échointégration. La prospection a suivi des transects systématiques définis selon les lieux de capture des canneurs de 2000 à 2011. Toutes les détections de thon rouge effectuées par sonar et sondeur ont été enregistrées. Dans chaque agrégation, l'identification des espèces ou l'échantillonnage de taille a été effectué par le biais d'opérations de pêche sans mise à mort, d'une caméra stéréoscopique et/ou d'un sonar multifaisceaux. La distribution spatiale des bancs de thon rouge détectés est consignée, et le nombre et la taille estimés des spécimens dans les bancs détectés sont fournis ainsi que le nombre estimé de spécimens par groupe d'âge. L'abondance et la distribution détectées du thon rouge sont analysées par groupe de tailles et en termes de variabilité spatiale. L'objectif de cette étude est de produire un indice d'abondance acoustique, indépendant des pêcheries, dans le golfe de Gascogne, qui soit une alternative à l'indice actuel, basé sur les taux de capture, qui est utilisé dans l'évaluation des stocks.

RESUMEN

Se llevó a cabo una prospección acústica en el golfo de Vizcaya (zona usual de alimentación del atún rojo en verano) durante julio de 2015 hasta 2019 a bordo de un cañero utilizando un sonar de 90 kHz de largo alcance y una ecosonda científica SIMRAD EK60 (actualizada a EK80 en 2018) trabajando en tres frecuencias, de las cuales 38 kHz se utilizaron para la ecointegración. La prospección siguió transectos sistemáticos definidos de conformidad con las localizaciones de la captura del cebo vivo en 2000-2011. Se consignaron todas las detecciones de atún rojo mediante el sonar y la ecosonda. En cada agregación, se llevó a cabo la

[1] AZTI, Marine Research division; Herrera kaia, portualdea z/g; 20110 Pasaia (Gipuzkoa), Spain; Corresponding author: e-mail ngoni@azti.es ; phone +34667174423 ; fax: +34946572555
[2] AZTI, Marine Research division; Txatxarramendi ugartea z/g, 48395 Sukarrieta (Bizkaia), Spain
[3] Fisheries and Oceans Canada, 531 Brandy Cove Road, St. Andrews, New Brunswick, Canada

identificación de especies y el muestreo de tallas mediante eventos de pesca sin muerte, cámaras estereoscópicas y/o sonar multihaz. Se muestra la distribución espacial de los bancos de atún rojo detectados, y se facilita el número y talla estimados de los ejemplares de los bancos detectados, así como el número estimado de ejemplares por grupo de edad. La abundancia detectada y la distribución del atún rojo se analizan por grupo de tallas y en términos de variabilidad espacial. El objetivo de esta prospección es elaborar un índice de abundancia basado en la acústica independiente de la pesquería en el golfo de Vizcaya como una alternativa al actual, basado en tasas de captura, que se está utilizando en la evaluación del stock.

KEYWORDS

Abundance index, acoustics, Atlantic, Bay of Biscay, bluefin tuna

1. Introduction

The Bay of Biscay is a well-known summer feeding ground for juvenile bluefin tuna (*Thunnus thynnus*) (Cort, 1990). Juvenile bluefin tunas display a high level of residence in the Bay of Biscay, with majority of juvenile fish recurrently migrating to this area during consecutive summers and displaying no significant migrating behavior when residing in the area (Arregui *et al.*, 2015). Their usual presence in this area in summer months allowed the development of a baitboat fishery since the late 1940s. The bluefin tuna fishery has traditionally taken place in the south-eastern part of the Bay of Biscay from June to October. Most of the catches are composed by juveniles (1-4 years) (Santiago *et al.*, 2015).

The baitboat fishery in the Bay of Biscay has provided so far one of longest abundance indices for juvenile bluefin tunas (Santiago *et al.*, 2015). However, in recent years, the local Spanish baitboat fleet sold up to 100% of its quotas, jeopardizing the continuity of the catch per unit of effort (CPUE) series used to build the abundance index.

Moreover, the use of standardized CPUE data as abundance indices usually relies on an assumption of constant catchability (Gulland, 1983). However, environmental effects on fish distribution and/or behavior can often influence catchability. Consequently, standardized CPUEs can be biased if these environmental effects are not properly taken into account during the standardization process (Fréon and Misund, 1999). In the case of fisheries using baited gears such as baitboat, catchability is directly influenced by the feeding behavior of fish (Stoner, 2004).

These uncertainties regarding the reliability of fishery-dependent abundance indices raise the need to develop fishery-independent abundance indices for this species. In the Bay of Biscay, acoustics were identified as the most feasible tool to develop a fishery-independent abundance index for bluefin tuna (Goñi *et al.*, 2009). As most large schooling marine predators, bluefin tuna usually display a heterogeneous ("patchy") distribution and fast displacements, which can challenge the use of an acoustic survey to monitor its abundance. However, bluefin tunas in the Bay of Biscay are usually concentrated in a very limited area of the Bay of Biscay (south of 45°15'N and east of 3°30W, **Figures 1 and 2**) in which 85% of the catch occurs. Out of this area, the majority of the catch of the baitboat fleet is composed of albacore, and bluefin are scarce or absent (**Figure 1**).

Based on this usual concentration of bluefin tuna in this reduced area of the Bay of Biscay, we designed an acoustic survey with the objective of getting an abundance index for this species in this region. This document presents the first results and perspectives of this survey.

2. Material and methods

2.1 Survey design

We based our survey design on the distribution of bluefin tuna catch locations by Basque baitboat vessels during the years 2002-2011 (**Figures 2 and 3a**), considering that the distribution of catches is representative of bluefin tuna distribution in the area (**Figure 3a**). A zig-zag design was chosen, starting and ending near the base port (**Figure 3b**). The zig-zag design was preferred to parallel transects because it optimizes the time spent cruising, i.e. no inter-transect time needs to be used. The choice of starting and ending near the base port also allowed dedicating almost all cruising time to the acoustic survey, i.e. the traveling time to start point and back from end point could be reduced. Moreover, with this design the survey has no trended displacement, which avoids any bias that could derive from the interaction between vessel displacement and tuna displacement.

The acoustic survey is performed during 10 consecutive days, following the defined transects (**Figure 3b**). The total covered distance is 960 nautical miles. This corresponds to an average daily cruising distance of 96 nautical miles, i.e. 12 hours of cruising at 8 knots.

2.2 Vessel and Equipment

The survey was led using the F/V Nuevo Horizonte Abierto in 2015 and 2019, and the F/V Txingudi in 2016 to 2018, two baitboat vessels based in Hondarribia (Basque Country). Both are equipped with a MAQ long-range sonar, from which screen dumps were recorded with a time interval of one second. During the whole survey the tilt angle of the sonar was set to -8º and its detection range to 320 meters (**Figure 4**).

A SIMRAD EK-60 echosounder comprising a set of two transducers (frequencies 38 and 200 kHz) was also installed on the vessel for the survey. The 38kHz transducer was oriented vertically and the 200 kHz transducer was oriented laterally (with an inclination of 7º), to allow observing the vertical and horizontal dimensions of the tuna schools detected. In 2018, a SIMRAD EK-80 was used, comprising a set of five transducers (frequencies 38, 70, 120, and two transducers of 200 kHz).

An AM-100 stereoscopic camera is also used to help species identification and fish measurement in the 2016 and 2018 surveys, a M3 sonar was also used in complement to the echosounder and of the stereoscopic camera, to get size measurements of the tunas detected.

During all the survey, two trolling lines were also fishing at the stern of the boat.

2.3 Data registered on board

Along the transects, all bluefin tuna detections by sonar or echosounder or visual detection were registered, and no-kill fishing events were done to identify the species and to sample the sizes of the individuals present in each aggregation. When fishing was not possible (i.e. tunas not interested in the live bait), the identification of the species was made either visually by observing fish jumping at the surface or through a stereoscopic camera, which also allowed size-measurements. In the case of small tuna aggregations for which the vessel was not stopping, the skipper's knowledge as well as Wesmar 165 sonars (part of the vessel's equipment) were used to discriminate bluefin tuna from albacore when the latter was present.

To avoid double counts of the same aggregation, observations were skipped in two situations:

- after direction changes at the beginning of each transect, when a school encountered at the end of the previous transect could potentially be encountered again-after fishing events,
- when the vessel stays enough time at reduced speed to allow a tuna school to be detected a second time if encountered again.

In these situations, each detection by sonar was removed when the time and straight distance from a previous detection were sufficient for a displacement of the tunas, based on swimming speeds observed by Brill *et al.* (2002).

2.4 Processing of sonar screenshots

To analyze sonar screen dumps, we use a semi-automatic image processing method through which tuna schools are morphologically classified.

First, the sonar screenshots of detected schools are pre-processed and segmented (Fig.5), and the characteristics of the regions obtained through the segmentation are extracted. Through this extraction, we obtain 20 morphologic characteristics of the regions. The morphological characteristics of regions corresponding to tuna schools will be used to calculate their dimensions and area.

In a second step, in order to cross-check the detections registered by scientists on board, a tuna labelling classification model is validated based on a semi-automatic image processing tool. For this, these morphologic characteristics are grouped in a database that is based on an equivalent number of cases of bluefin tuna presence and absence.

The 20 morphologic characteristics are analyzed through a comparative study of supervised classification, using classifiers of different families such as: *Random forest* (RF) [Breiman, 2001], *Multilayer perceptron* (MLP) [Bishop1995], *k-Nearest Neighbors algorithm* (IBk) [Fix1951], the decision tree J48 [Quinlan1996] and the *Support Vector Machine* (SVM) [Burges1998]. To assess the efficiency and effectiveness of the different classification methods, the average values of the following indices were calculated: Kappa [Cohen, 1960], Sensitivity [Fielding, 1997], Specificity [Hanley, 1982] and AUC (ROC curve) [Hanley, 1982]. The results of the experiments are analyzed based on the minimum, maximum, mean and standard deviation of these indices.

Furthermore, an OCR application (Optical Character Recognition) developed using the software R (R development core team, 2015) will be used to extract data relevant for tuna detections (**Figure 6**), and Kalman filter based temporal study for tracks detection will be used. Through Kalman filters the current position of an object is estimated (in our case the object is one of the regions extracted from the preprocessing of images), based on non-precise measurements and on the position in anterior states. Combining the potential of the tuna classification model, tuna detection from OCR applications, and Kalman filters, automatic counting and sizing tuna schools is feasible. In particular, the estimation of the school diameter from sonar screen dumps allows us to cross-validate the diameter estimated from the 200 kHz echosounder (see section 2.5).

2.5 Processing of echosounder data

The echosounder recordings are used to determine the dimensions, volume, and number of individuals in each bluefin tuna aggregation observed. The combined use of a vertically oriented and a laterally oriented transducer provides us with the vertical dimension and one of the horizontal dimensions of the tuna schools, together with the school diameter measured from sonar screenshots. Due to the reduced speed of the vessel during fishing events (or when the vessel was approaching the school even when no fishing was possible) the second horizontal dimension of the school could not be directly observed and will therefore be estimated assuming a horizontal isotropy of the tuna schools. It will also be cross-validated with the horizontal dimension derived from sonar image analyses.

The software used to process echosounder data is Echoview™ (v. 5.4). First, all tuna schools are identified on the echograms, based on real time information recorded during detection on board the fishing vessel. In the records corresponding to the vertically oriented echosounder (i.e. 38 kHz), an echointegration by layer of each ping is done, with a -55dB threshold. After the echointegration, the data are post-processed so as to keep only pings containing acoustic backscattering corresponding to tuna aggregations, by keeping only non-zero echointegration pings. This produces an along-track compacted echogram from which we obtain the mean density of the school calculated as the mean of the volume backscattering coefficient (s_v; Maclennan *et al.* 2002) of the non-zero pings. The shape of the schools is assumed to be a revolution ellipsoid with horizontal isotropy, i.e., with circular horizontal cross section. The estimated volume of each detected school is calculated as:

$$Volume = (4.\pi/3).(Y_{max}/2)^2. (Z_{max}/2)$$

Where, Z_{max} is the vertical diameter of the school, and where Y_{max} is the horizontal diameter.

The density, number of tunas per unit volume by school is calculated from the 38 kHz echogram with the formula:

$$N/V = s_v / <\sigma_{bs}>$$

Where V is the volume of the tuna school, s_v the mean volume backscattering coefficient of the school (MacLennan *et al.*,2002) given by the echointegration at the 38 kHz echogram, and $<\sigma_{bs}>$ the backscattering cross section, i.e., the fraction of energy backscattered by a single individual, which is function of the species and size of the individuals. To calculate $<\sigma_{bs}>$, we use bluefin tuna TS data (target strength, $TS=10log_{10}(\sigma_{bs})$, Maclennan *et al.*, 2002) and the equation:

$$TS = 20 \log FL + b_{20}$$

Where, *TS* is the individual target strength, *FL* the fork length of the fish and b_{20} is a constant parameter known as the reduced target strength (Simmonds and MacLennan, 2005). The b_{20} value was calculated based on TS analyses of recordings from the 2016 survey, its value is -63.88 dB. Finally, an abundance estimate is calculated for each school, multiplying the density times the school volume.

The echointegration of schools for which no sampling could be done was also performed. For these schools the vessel speed during detection was 8 knots, so a simple echointegration by layer was performed. These results were combined with data from echointegrations of sampled schools (at low speed).

3. Results and Discussion

3.1 Tuna schools detected

After removing the possible double-counts, 106 bluefin tuna schools could be detected during the 2015 survey, 83 during the 2016 survey, 77 during the 2017 survey, 34 during the 2018 survey and 61 during the 2019 survey. The spatial distribution of tuna detections was heterogeneous in the three years (**Figure 7a,b,c,d**), combining long distances without detections and zones of high density of presence of bluefin tuna in which numerous consecutive schools were detected in relatively short distance ranges (**Table 1**). This heterogeneity of the spatial distribution is a typical feature of this species.

In an important part of the tuna schools detected, fishing was not possible. The tunas were not reactive to the live bait, and thus measured through the M3 sonar. This is a clear illustration of the variability of tuna catchability related to their biotic environment and feeding behavior and confirms the need to develop fishery-independent abundance indices for bluefin tuna in this area.

3.2 Number and size of individuals by school detected, spatial density

In the sampled detections, an abundance of up to 12 876 individuals by school was estimated (namely in 2016). The abundance by school was highly variable and the estimated abundance was below 40 individuals for 50% of the schools (**Figure 7 a, b, c, d**).

Fish size ranged from 64 to 158 cm in 2015 and 57 to 175 in 2016, but age-1 and age-2 individuals were absent from the 2017 survey, in which the size-range was 111 to 160 cm. In all years, the largest fish were observed in the northern part (**Figure 8 a, b, c, d**), and almost no school was detected in the southern part in 2017, in which age-1 and age-2 individuals were absent (**Table 2**). During the 2018 survey, age-1 individuals were detected again, and the size range was 65 to 173 cm, like the years 2015 and 2016.

The average spatial density of tunas (all age groups) ranged from 7.36 tunas / km^2 (in 2018) to 48.44 tunas / km^2 (in 2016).

3.3 Further steps

To address this spatial heterogeneity issue, resampling can be used to assess the precision of the spatial distribution of the estimated tuna biomass. Universal kriging (Doray *et al.*, 2008) can also be used to model the spatio-temporal variability in the estimated biomass of tuna aggregations recorded during the survey. Further than giving an abundance index, these tools would allow us to interpolate and map the estimated biomass of bluefin tunas detected in their core area in the Bay of Biscay.

Finally, the potential environmental effects on bluefin tuna presence and distribution, as well as the absence of some age-groups during given years, can also be further investigated.

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Table 1. Summary of bluefin tuna detections made by sonar during the surveys done since 2019.

Transect start point	***longitude***	***latitude***	***Distance to next point (n.m.)***	***Detections by nautical mile (2015)***	***Detections by nautical mile (2016)***	***Detections by nautical mile (2017)***	***Detections by nautical mile (2018)***	***Detections by nautical mile (2019)***
1	-1.91668	43.50	24.7	0	0	0	0	0
2	-2.47039	43.60	18.72	0.053	0.053	0	0.267	0.107
3	-2.06300	43.70	35.98	0	0.139	0	0	0.056
4	-2.87940	43.80	33.01	0.121	0.182	0	0	0.061
5	-2.13100	43.90	41.75	0	0.024	0	0.024	0.048
6	-3.08500	44.00	41.69	0	0	0	0.024	0.048
7	-2.13080	44.10	38.78	0	0	0	0	0
8	-3.01800	44.20	35.77	0	0.028	0	0	0.028
9	-2.20000	44.30	27.12	0.074	0.074	0	0	0.111
10	-2.81500	44.40	24.23	0	0.041	0	0	0.041
11	-2.26800	44.50	30.32	0	0.033	0.066	0	0.066
12	-2.96188	44.60	30.29	0	0.033	0.297	0	0
13	-2.26800	44.70	24.13	0.124	0.041	0.290	0.041	0.083
14	-2.81500	44.80	15.97	0.125	0	0.376	0	0
15	-2.46804	44.90	30.75	0.163	0	0.065	0.066	0
16	-3.15755	45.05	9.3	0	0	0.215	0	0.108
17	-3.36300	45.00	21.27	0	0	0.047	0	0
18	-2.88359	44.90	12.16	0.164	0	0	0.082	0
19	-3.15755	44.85	9.39	0.106	0	0	0	0.319
20	-3.36300	44.90	30.58	0	0.098	0	0.066	0.065
21	-2.67618	45.05	6.47	0	0	0.464	0.155	0.155
22	-2.54114	45.00	13.11	0	0	0.534	0	0.076
23	-2.81500	44.90	24.08	0	0	0.623	0.042	0
24	-2.26800	44.80	24.12	0.124	0.083	0.332	0.166	0
25	-2.81500	44.70	27	0.185	0	0	0	0.074
26	-2.20000	44.60	27.04	0.259	0	0.259	0.037	0
27	-2.81500	44.50	27.08	0.332	0	0	0	0.185
28	-2.20000	44.40	24.31	0.535	0	0	0.082	0
29	-2.75000	44.30	27.24	0.220	0.110	0	0.037	0.184
30	-2.13109	44.20	41.62	0.336	0.048	0	0	0.120
31	-3.08500	44.10	38.74	0.103	0.026	0	0.077	0.103
32	-2.20000	44.00	35.93	0	0	0	0	0.223
33	-3.01800	43.90	41.83	0.120	0.024	0.024	0.024	0.072
34	-2.06300	43.80	27.37	0.292	0	0.183	0.073	0.073
35	-2.67766	43.70	35.25	0.085	0.057	0.057	0.142	0.085

Table 2. estimated total number of individuals by age-group in the schools detected during the surveys 2015 to 2018.

	2015	***2016***	***2017***	***2018***
age 1	2808	3033	-	64
age 2	5848	-	-	4
age 3	-	18450	2765	-
age 4	13944	7869	-	1632
age 5+	32582	25765	24355	6673

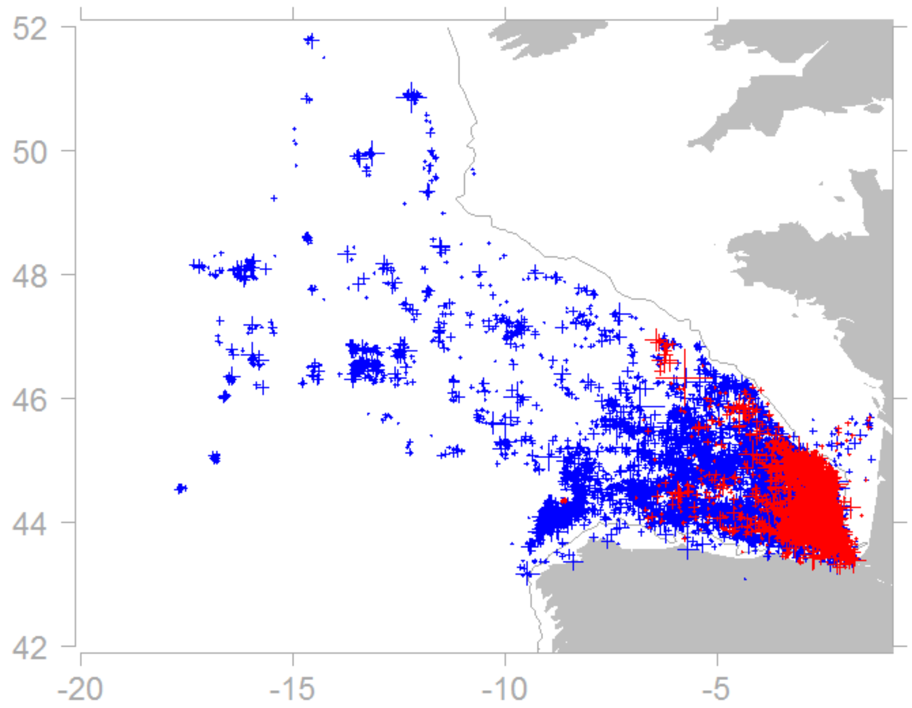

Figure 1. Spatial distribution of BFT (in red) and ALB (in blue) catches by the baitboat fleet of Gipuzkoa and Bizkaia in the Bay of Biscay in the period 2000-2014.

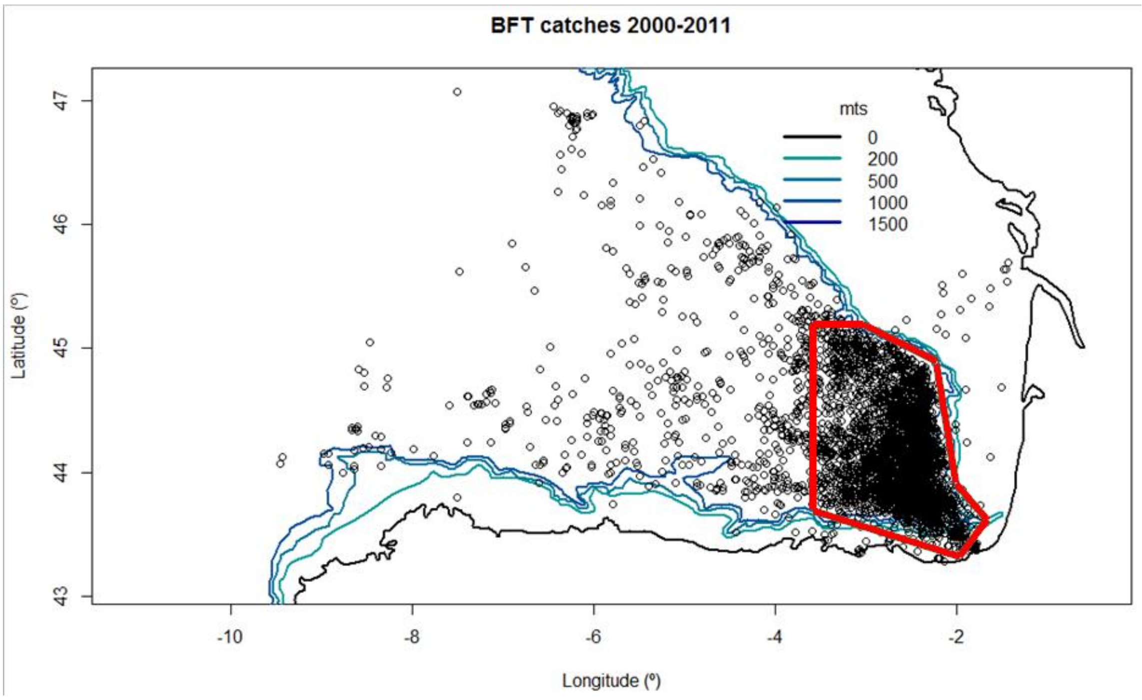

Figure 2. Spatial distribution of bluefin tuna catches by the baitboat fleet in the Bay of Biscay in the years 2000-2011 and spatial definition of the zone of highest catches (84.5% of fishing events and 85.5% of catch weight), delimited by red line.

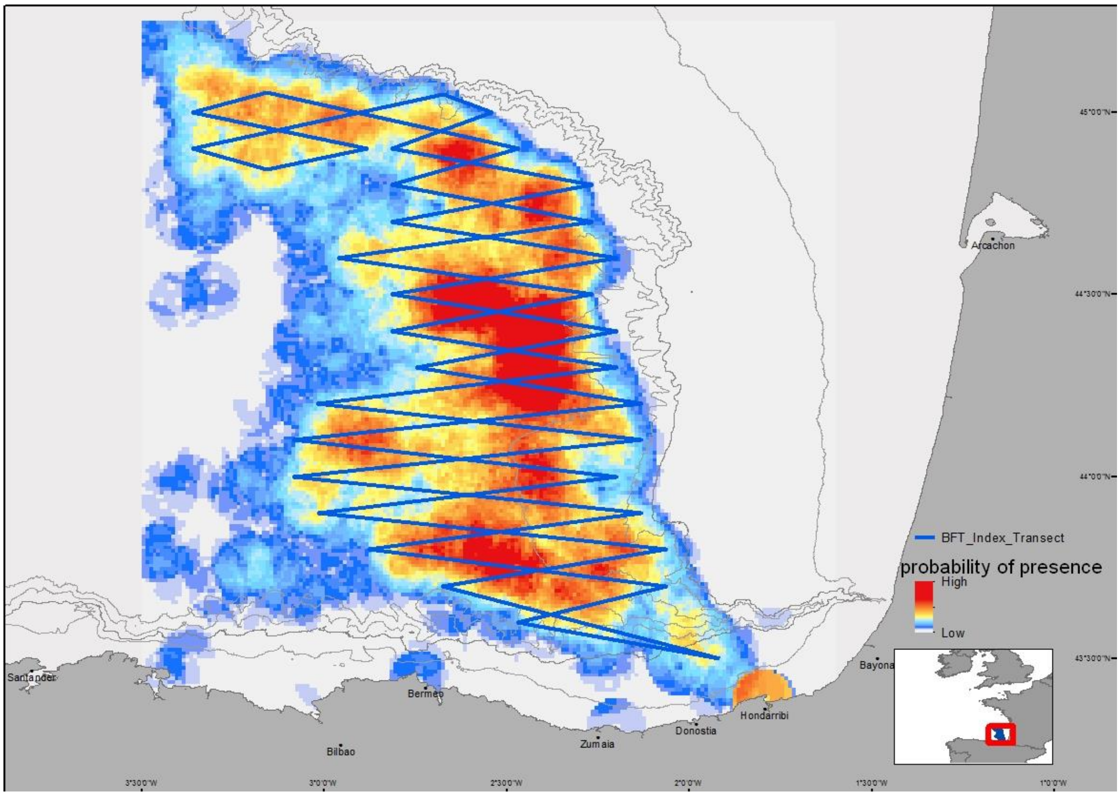

Figure 3a. Probability of bluefin tuna presence according to the Basque baitboat catch data for the period 2000-2011, and spatial definition of the transects followed during the survey.

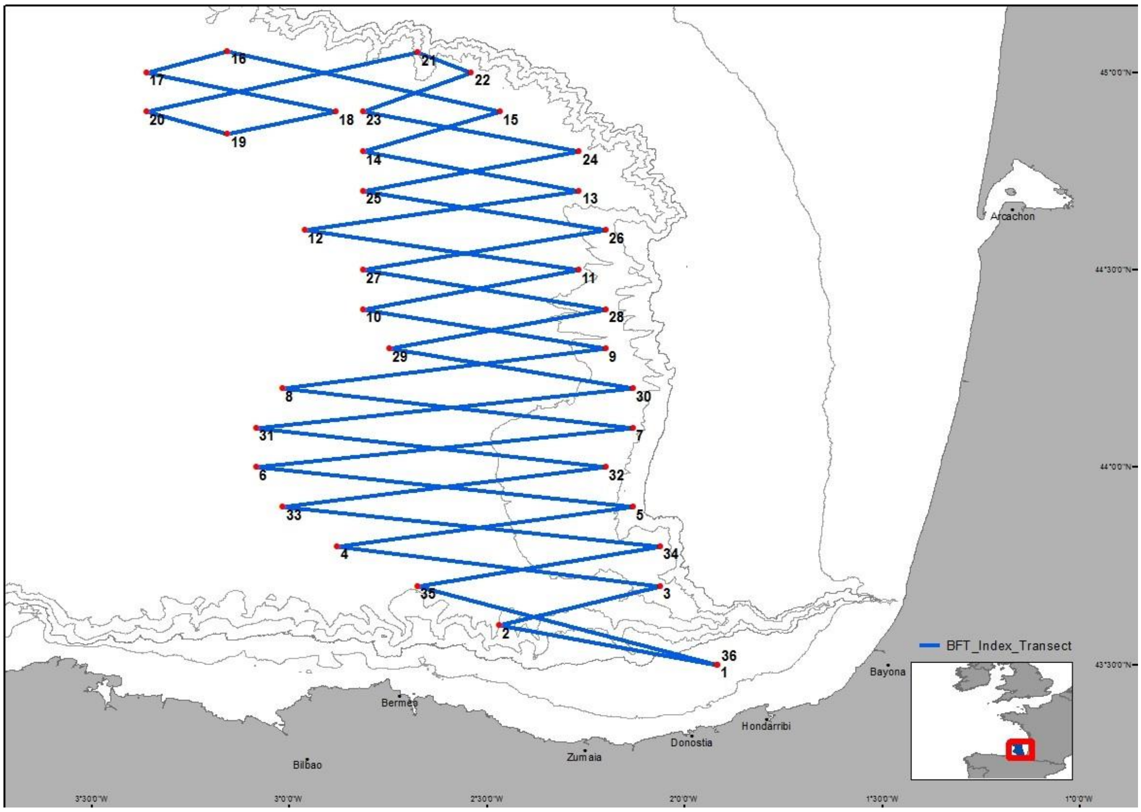

Figure 3b. Spatial definition of the transects followed during the survey, with identification of the 36 waypoints.

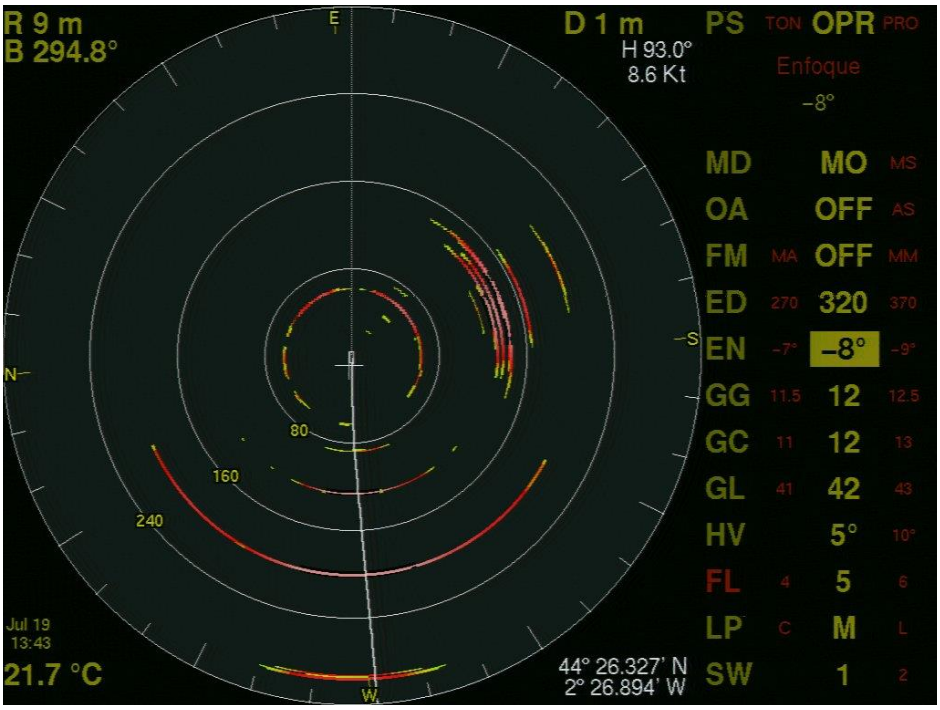

Figure 4. Example of detection of a bluefin tuna school by sonar (right part of the screenshot).

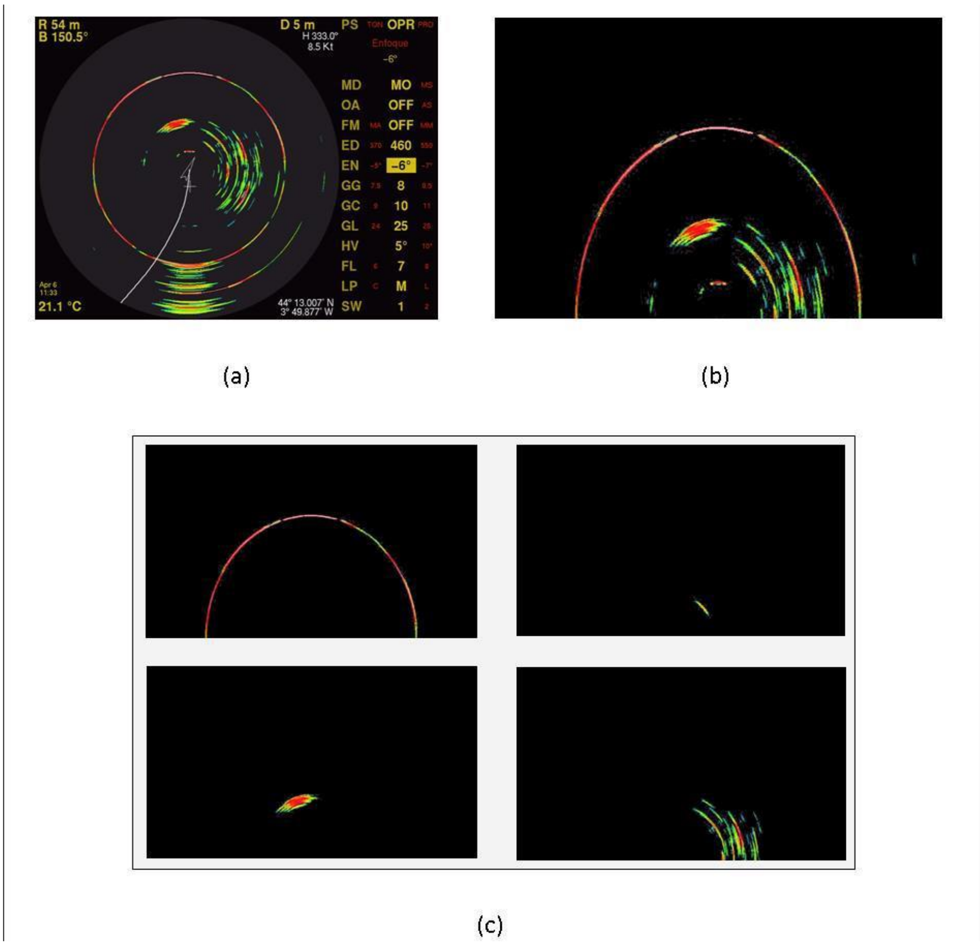

Figure 5. Example of preprocessing of sonar screenshots. a): raw screenshot; b): selection of the zone of interest; c): segmentation.

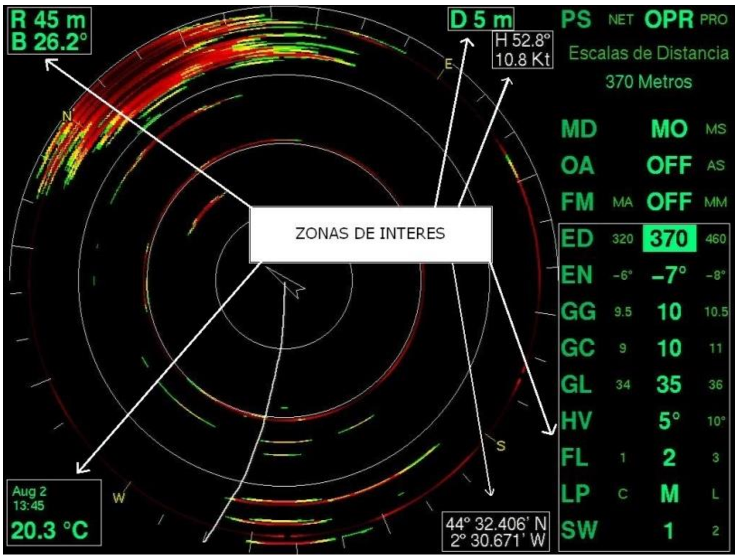

Figure 6. Zones of interest identified through Optical Character Recognition (OCR).

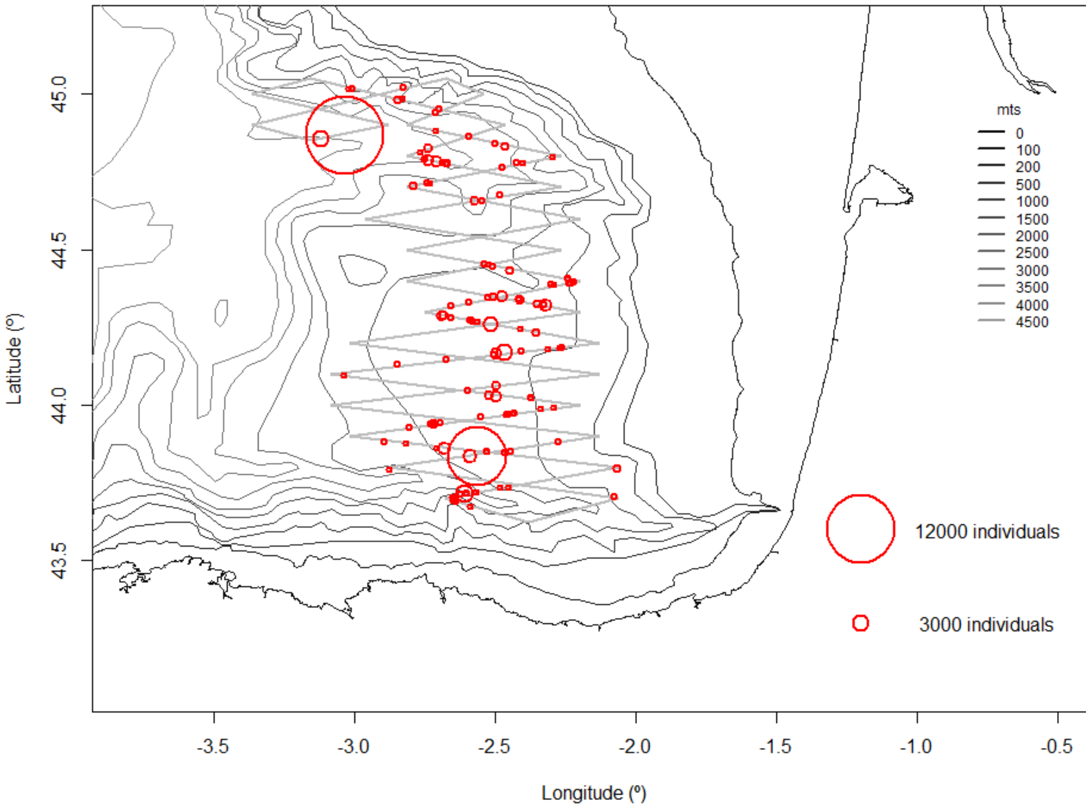

Figure 7a. Estimations of the number of individuals in the bluefin tuna schools sampled during the 2015 survey.

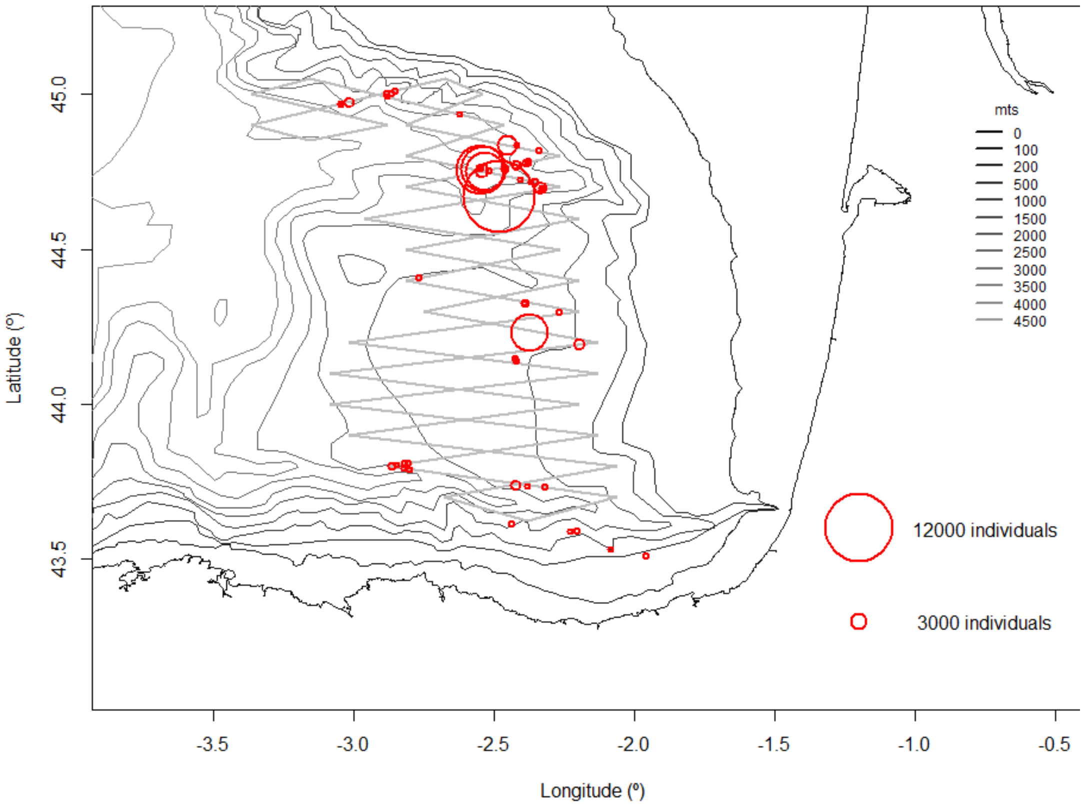

Figure 7b. Estimations of the number of individuals in the bluefin tuna schools sampled during the 2016 survey.

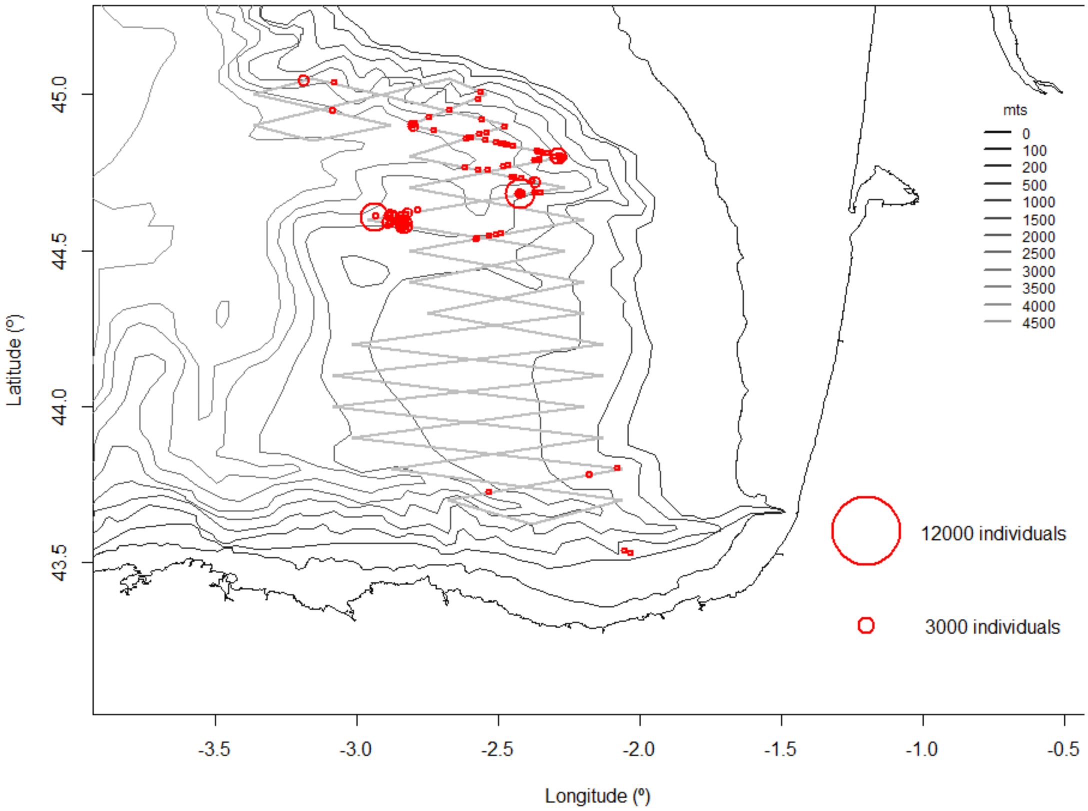

Figure 7c. Estimations of the number of individuals in the bluefin tuna schools sampled during the 2017 survey.

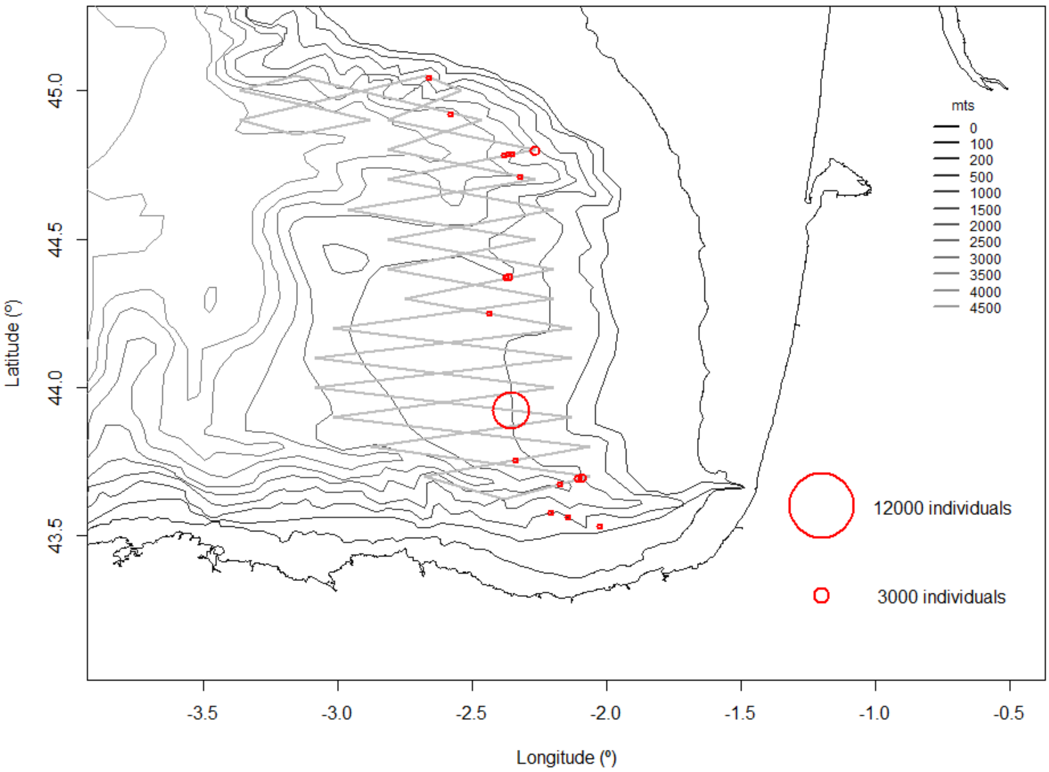

Figure 7d. Estimations of the number of individuals in the bluefin tuna schools sampled during the 2018 survey.

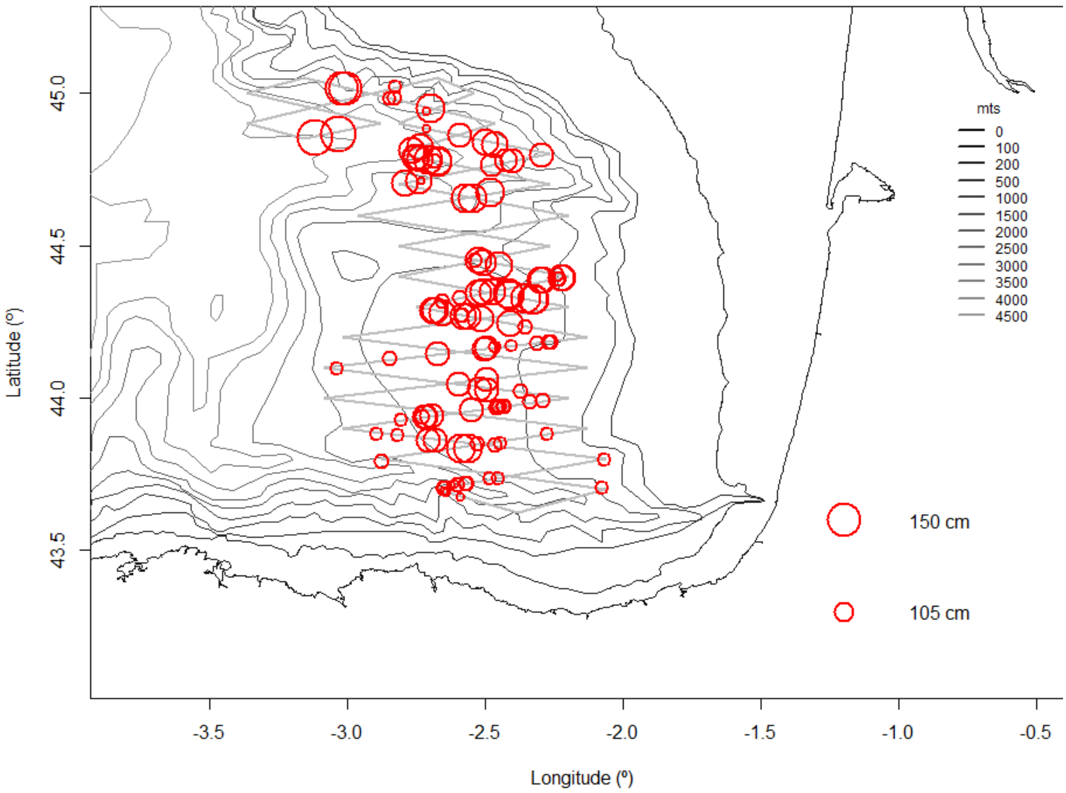

Figure 8a. Sizes of individuals in the bluefin tuna schools sampled during the 2015 survey.

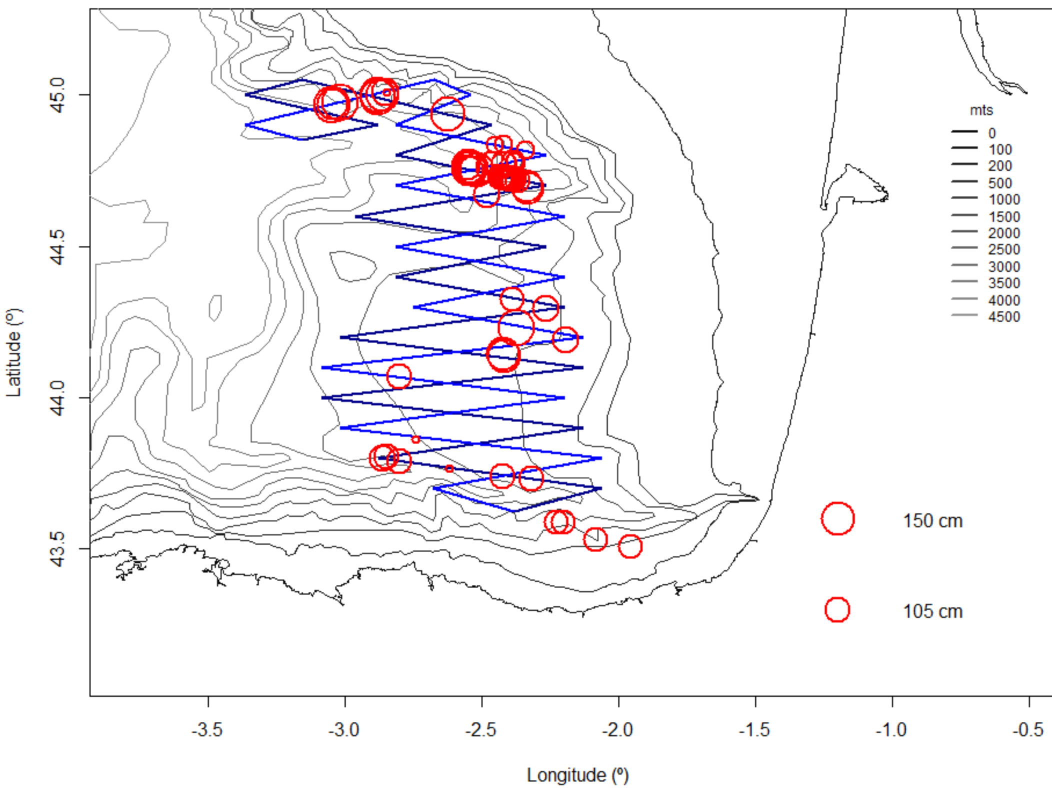

Figure 8b. Sizes of individuals in the bluefin tuna schools sampled during the 2016 survey.

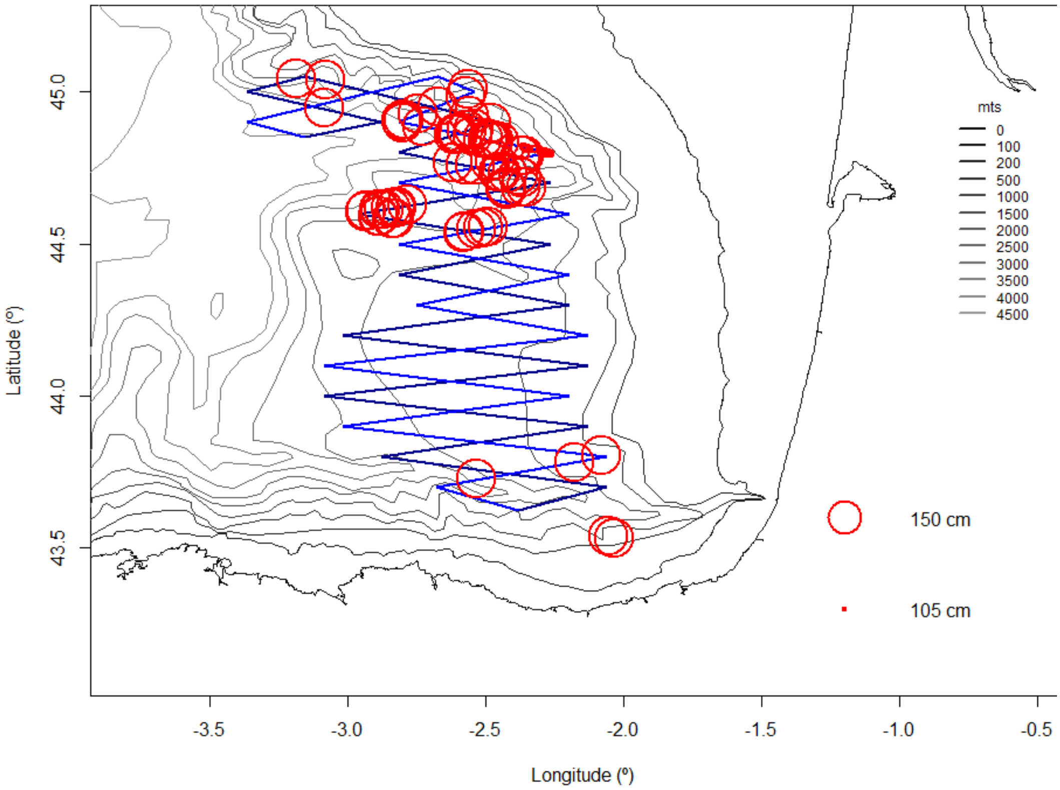

Figure 8c. Sizes of individuals in the bluefin tuna schools sampled during the 2017 survey.

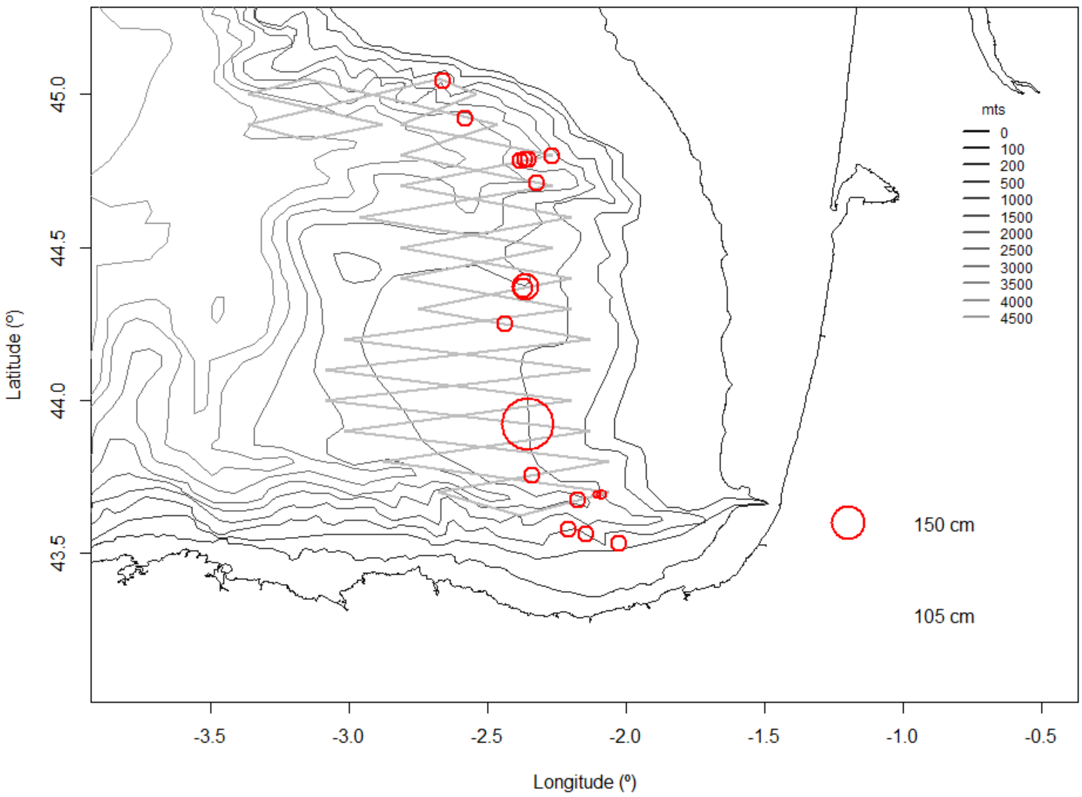

Figure 8d. Sizes of individuals in the bluefin tuna schools sampled during the 2018 survey.