 Collect. Vol. Sci. Pap. ICCAT, 73(6): 2044-2057 (2017)

ACOUSTIC-BASED FISHERY-INDEPENDENT ABUNDANCE INDEX OF JUVENILE BLUEFIN TUNAS IN THE BAY OF BISCAY: 2015 AND 2016 SURVEYS

Nicolas Goñi[1], Iñigo Onandia[2], Jon Lopez[1], Igor Arregui[1], Jon Uranga[1],
Gary D. Melvin[3], Guillermo Boyra[1], Haritz Arrizabalaga[1], Josu Santiago[2]

SUMMARY

Uncertainties regarding the Atlantic bluefin tuna stock state and regarding the reliability of fishery-dependent abundance indices raise the need to develop fishery-independent abundance indices for this species. An acoustic survey was performed in the Bay of Biscay during July 2015 and 2016 on-board a baitboat fishing vessel, using a long-range sonar and an echosounder comprising a set of two vertically and horizontally oriented transducers. The survey followed systematic transects defined according to bluefin tuna catch locations by baitboat in the 2000-2011 period. Along these transects, all bluefin tuna detections by sonar and echosounder were recorded, and no-kill fishing events were done in order to identify the species and sample the sizes of the individuals present in each aggregation. In this document the detections by day are shown for 2015 and 2016 surveys. For the 2015 survey, we also present the analyses done to determine the dimensions, volume, number of individuals in each bluefin tuna aggregation observed, as well as an estimation of the spatial density of bluefin tuna.

RÉSUMÉ

Les incertitudes planant sur l'état de stocks de thon rouge de l'Atlantique et sur la fiabilité des indices d'abondance dépendant des pêcheries soulèvent la nécessité d'élaborer des indices d'abondance indépendants des pêcheries pour cette espèce. Une prospection acoustique a été réalisée dans le golfe de Gascogne au mois de juillet 2015 et 2016 à bord d'un canneur, à l'aide d'un sonar à longue portée et d'un échosondeur comprenant un jeu de deux transducteurs orientés verticalement et horizontalement. La prospection a suivi des transects systématiques définis en fonction des lieux de capture du thon rouge par les canneurs entre 2000 et 2011. Le long de ces transects, toutes les détections des thons rouges par sonar et échosondeur ont été enregistrées, et aucune opération de pêche entraînant la mort n'a été réalisée afin d'identifier les espèces et d'échantillonner les tailles des spécimens présents dans chaque concentration. Dans le présent document, les détections par jour sont montrées pour les prospections de 2015 et de 2016. Pour la prospection de 2015, nous présentons aussi les analyses réalisées pour déterminer les dimensions, le volume, le nombre de spécimens dans chaque concentration observée de thons rouges, ainsi qu'une estimation de la densité spatiale du thon rouge.

RESUMEN

Las incertidumbres sobre el estado del stock de atún rojo del Atlántico y sobre la fiabilidad de los índices de abundancia dependientes de la pesquería plantean la necesidad de elaborar índices de abundancia independientes de la pesquería para esta especie. Se llevó a cabo una prospección acústica en el golfo de Vizcaya durante julio de 2015 y 2016 a bordo de un cañero utilizando un sonar de largo alcance y una ecosonda compuesta por un conjunto de dos transductores orientados vertical y horizontalmente. La prospección siguió transectos sistemáticos definidos de acuerdo con las ubicaciones de captura de atún rojo por parte del cañero en el periodo 2000-2011. A lo largo de dichos transectos, todas las detecciones de atún rojo por parte del sonar y la ecosonda fueron grabadas y no se realizaron operaciones pesqueras con muerte con el fin de identificar las especies y muestrear las tallas de los ejemplares presentes en cada concentración.

[1]AZTI, Marine Research division; Herrera kaia, portualdea z/g; 20110 Pasaia (Gipuzkoa), Spain. Corresponding author: e-mail ngoni@azti.es; phone +34 667 174 423 ; fax: +34 946 572 555.

[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

En este documento se muestran las detecciones por día para las prospecciones de 2015 y 2016. Para la prospección de 2015, presentamos también los análisis realizados para determinar las dimensiones, el volumen y el número de ejemplares en cada concentración de atún rojo observada, así como una estimación de la densidad espacial de atún rojo.

KEYWORDS

Bluefin tuna, acoustics, abundance index, Atlantic, Bay of Biscay

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 as a whole has no trended displacement, which avoids any bias that could derive from the interaction between vessel displacement and tuna displacement.

The acoustic survey was performed during 10 consecutive days from 13th to 22nd of July 2015, following the defined transects (figure 3b). The total covered distance was 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 lead using the F/V Nuevo Horizonte Abierto in 2015 and the F/V Txingudi in 2016, 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), in order to allow observing the vertical and horizontal dimensions of the tuna schools detected.

In the 2016 survey, a M30 sonar was also used in complement to the echosounder, to get size measurements of the tunas detected.

2.3 Data registered on board and preliminary analyses

Along the transects, all bluefin tuna detections by sonar or echosounder or visual detection were registered, and no-kill fishing events were done in order 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 visually by observing fish jumping at the surface, and a size-category was estimated. When tunas were observed only by sonar, the skipper's knowledge as well as Wesmar 165 sonars were used to discriminate tunas from other fish aggregations (e.g. anchovy) and to discriminate bluefin tuna from albacore when the latter was present. The unidirectional Wesmar 165 sonar (part of the vessel's equipment) was also used to discriminate bluefin tuna from albacore.

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

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 (**Figure 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) (Bishop, 1995), *k-Nearest Neighbors algorithm* (IBk) (Fix1951), the decision tree J48 (Quinlan, 1996) and the *Support Vector Machine* (SVM) (Burges, 1998). 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.

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) from Sainz-Pardo Martí (2010) 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 -65.75 dB. Finally, an abundance index 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 by sonar during the 2015 survey and 34 during the 2016 survey. The spatial distribution of tuna detections was heterogeneous (**Figure 7**), combining long distances without detections and zones of high density of presence of bluefin tuna (particularly in 2015) in which numerous consecutive schools were detected in relatively short distance ranges. This variability also appears on a temporal level in 2015: we could observe a relatively low number of tuna schools detections in the first half of the survey and a higher number during the second half (**Figure 8, Table 1**) while cruising in the same zone. This heterogeneity of the 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. This is a clear illustration of the variability of tuna catchability related to their biotic environment and feeding behavior. This 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 (2015 survey)

In the sampled detections, an abundance of up to 21 300 individuals by school was estimated. The abundance by school was highly variable and the estimated abundance was below 70 individuals for 50% of the schools (**Figure 9**).

Fish size ranged from 64 to 158 cm. The largest fish were observed in the northern part (**Figure 10**), although no significant difference in tune size was observed between the different sections of the survey.

The spatial density of tunas was estimated to 80.6 tunas / km^2 (ranging between 0 and 1871 tunas/km^2 in the different transects).

3.3 Further steps

The echointegration of 2016 echosounder data was done, and the volume and number of individuals of each school will also be calculated. By visual inspection during echointegration, the volume of the schools seemed more important in 2016 than in 2015, which suggests a more aggregated distribution of the bluefin tunas in 2016 *versus* 2015. After post-processing, we expect the volume data to confirm this visual guess.

Fish size distribution of both years will also be compared, as well as the spatial density of tunas.

The spatial heterogeneity of the school detections is the most striking feature of these surveys, especially in the 2015 survey, in which the number of schools detected in the second half of the survey was one order of magnitude higher than in the first half. To address this issue, resampling can be used in order 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.

Acknowledgements

The Basque Government (Department of Agriculture, Fisheries and Food), together with the European Union, promoted and financed this project.

We are grateful to the crew of the F/V Nuevo Horizonte Abierto and of the F/V Txingudi for their collaboration and help in this project, and especially to Aitor Olaskoaga and Jose Antonio Aguirre for their advice in the identification of tuna schools on the sonar screen. We also thank warmly Iñaki Rico; the surveys would not have been possible without his participation.

References

Arregui I., Galuardi B., Goñi N., Arrizabalaga H., Lam C.H., Fraile I., Santiago J., Lutcavage M., 2015. Movements and geographic distribution of juvenile bluefin tunas in the North Atlantic, described through electronic tags. Document SCRS/2015/044 (withdrawn).

Bishop, C. M. 1995. Neural networks for pattern recognition. Oxford university press.

Breiman, L. 2001. Random Forests. Mach. Learn. 45: 5-32.

Burges, C. J. C. 1998. A Tutorial on Support Vector Machines for Pattern Recognition. Data Mining and Knowledge Discovery 2: 121-167.

Brill R., Lutcavage M., Metzger G., Bushnell P., Arendt M., Lucy J., Watson C., Foley D., 2002. Horizontal and vertical movements of juvenile bluefin tuna (*Thunnus thynnus*), in relation to oceanographic conditions of the western North Atlantic, determined with ultrasonic telemetry. Fishery Bulletin US, 100: 155-167.

Cohen, W. W. 1995. Fast Effective Rule Induction. In: Proceedings of the Twelfth International Conference on Machine Learning, Lake Tahoe, California, USA. p 115-123.

Cort, J.L., 1990. Biología y pesca del atún rojo, (*Thunnus thynnus L.*) del mar Cantábrico. Tesis doctoral. Publicaciones Especiales – Instituto Español de Oceanografia (in Spanish).

Doray M., Petitgas P., Josse E., 2008. A geostatistical method for assessing biomass of tuna aggregations around moored fish aggregating devices with star acoustic surveys. Canadian Journal of Fisheries and Aquatic Sciences 65(6), 1193-1205.

Fielding, A. H., and J. F. Bell. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental conservation 24: 38-49.

Fréon P. and Misund O. A., 1999. Dynamics of Pelagic Fish Distribution and Behaviour: Effects on Fisheries and Stock Assessment. Blackwell Science, London. 348 pp.

Goñi N., Fraile I., Arregui I., Santiago J., Boyra G., Irigoien X., Lutcavage M., Galuardi B., Logan J.M., Estonba A., Zudaire I., Grande M., Murua H., Arrizabalaga H., 2010. Ongoing bluefin tuna research in the Bay of Biscay (Northeast Atlantic): the “Hegalabur 2009” project. ICCAT Col. Vol. Sci. Pap. 65(3): 755-769

Gulland, J. A. 1983. Fish stock assessment, a manual of basic methods. FAO/Wiley Series on Food and Agriculture, vol. 1. 233 pp.

Hanley, J. A., and B. J. McNeil. 1982. The meaning and use of the area under a receiver operating characteristic (ROC) curve. Radiology 142: 29-36.

MacLennan, D.N., Fernandes, P.G., Dalen, J., 2002. A consistent approach to definitions and symbols in fisheries acoustics, ICES J. Mar. Sci. 59, 365-369.

Quinlan, J. R. 1993. C4.5: programs for machine learning. Morgan Kaufmann Publishers Inc., San Mateo, CA.
R Development Core Team, 2015. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria

Sainz-Pardo Martí, S., 2010. Análisis de medidas de Target Strength dorsal y del comportamiento del atún rojo (*Thunnus thynnus*) en jaulas marinas in Escuela Politécnica Superior de Gandía, p. 49. Universidad Politécnica de Valencia, Gandía.

Santiago J., Arrizabalaga H., Ortiz M., Goñi N., 2015. Updated standardized bluefin tuna CPUE index of the Bay of Biscay baitboat fishery (1952-2014). SCRS/2015/169

Simmonds, J., MacLennan, D.N., 2005. Fisheries acoustics: theory and practice, 2nd edition. 456 pp., August 2005, Wiley-Blackwell.

Stoner A.W., 2004. Effects of environmental variables on fish feeding ecology: implications for the performance of baited fishing gear and stock assessment. *Journal of Fish Biology* 65, 1445-1471.

Table 1. Summary of bluefin tuna detections made by sonar during both surveys.

Transect start point	*longitude*	*latitude*	*Distance to next point (n.m.)*	*Detections on transect distance (2015)*	*Detections by nautical mile (2015)*	*Detections on transect distance (2016)*	*Detections by nautical mile (2016)*
1	-1.91668	43.50000	24.7	0	0	0	0
2	-2.47039	43.60000	18.72	1	0.053	1	0.053
3	-2.06300	43.70000	35.98	0	0	5	0.139
4	-2.87940	43.80000	33.01	4	0.121	6	0.182
5	-2.13100	43.90000	41.75	0	0	1	0.024
6	-3.08500	44.00000	41.69	0	0	0	0
7	-2.13080	44.10000	38.78	0	0	0	0
8	-3.01800	44.20000	35.77	0	0	1	0.028
9	-2.20000	44.30000	27.12	2	0.074	2	0.074
10	-2.81500	44.40000	24.23	0	0	1	0.041
11	-2.26800	44.50000	30.32	0	0	1	0.033
12	-2.96188	44.60000	30.29	0	0	1	0.033
13	-2.26800	44.70000	24.13	3	0.124	1	0.041
14	-2.81500	44.80000	15.97	2	0.125	0	0
15	-2.46804	44.90000	30.75	5	0.163	0	0
16	-3.15755	45.05000	9.3	0	0	0	0
17	-3.36300	45.00000	21.27	0	0	0	0
18	-2.88359	44.90000	12.16	2	0.164	0	0
19	-3.15755	44.85000	9.39	1	0.106	0	0
20	-3.36300	44.90000	30.58	0	0	3	0.098
21	-2.67618	45.05000	6.47	0	0	0	0
22	-2.54114	45.00000	13.11	0	0	0	0
23	-2.81500	44.90000	24.08	0	0	0	0
24	-2.26800	44.80000	24.12	3	0.124	2	0.083
25	-2.81500	44.70000	27	5	0.185	0	0
26	-2.20000	44.60000	27.04	7	0.259	0	0
27	-2.81500	44.50000	27.08	9	0.332	0	0
28	-2.20000	44.40000	24.31	13	0.535	0	0
29	-2.75000	44.30000	27.24	6	0.220	3	0.110
30	-2.13109	44.20000	41.62	14	0.336	2	0.048
31	-3.08500	44.10000	38.74	4	0.103	1	0.026
32	-2.20000	44.00000	35.93	0	0	0	0
33	-3.01800	43.90000	41.83	5	0.120	1	0.024
34	-2.06300	43.80000	27.37	8	0.292	0	0
35	-2.67766	43.70000	35.25	3	0.085	2	0.057

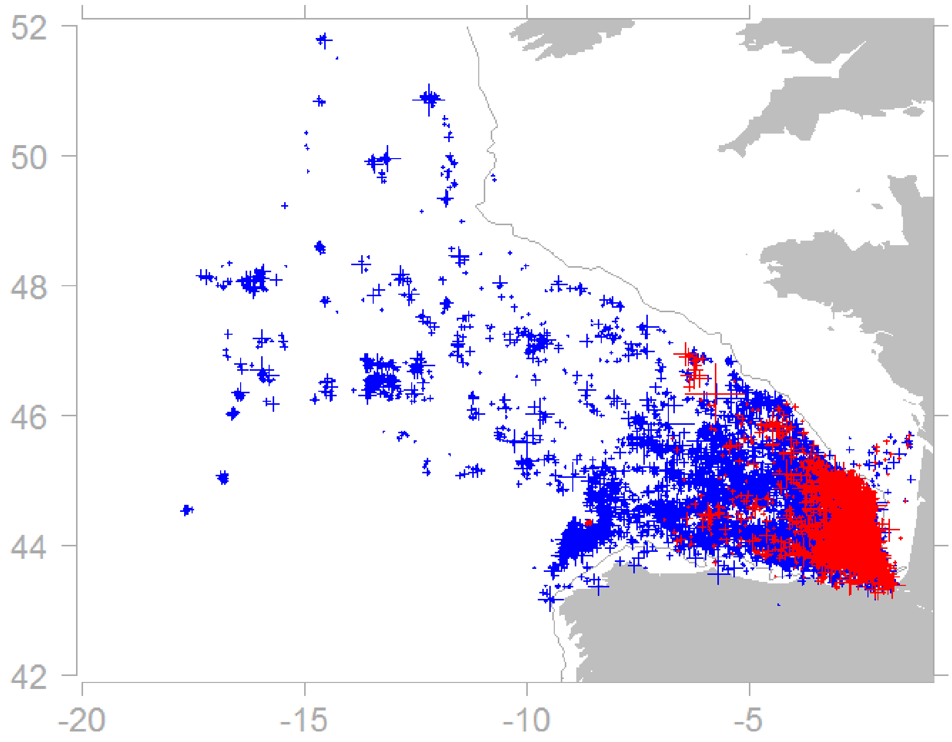


Figure 1. Spatial distribution of BFT (in red) and ALB (in blue) catches by the baitboat fleet of Gipuzkoa and Bizkaia in the Bay of Biscay in the period 2000-2014.

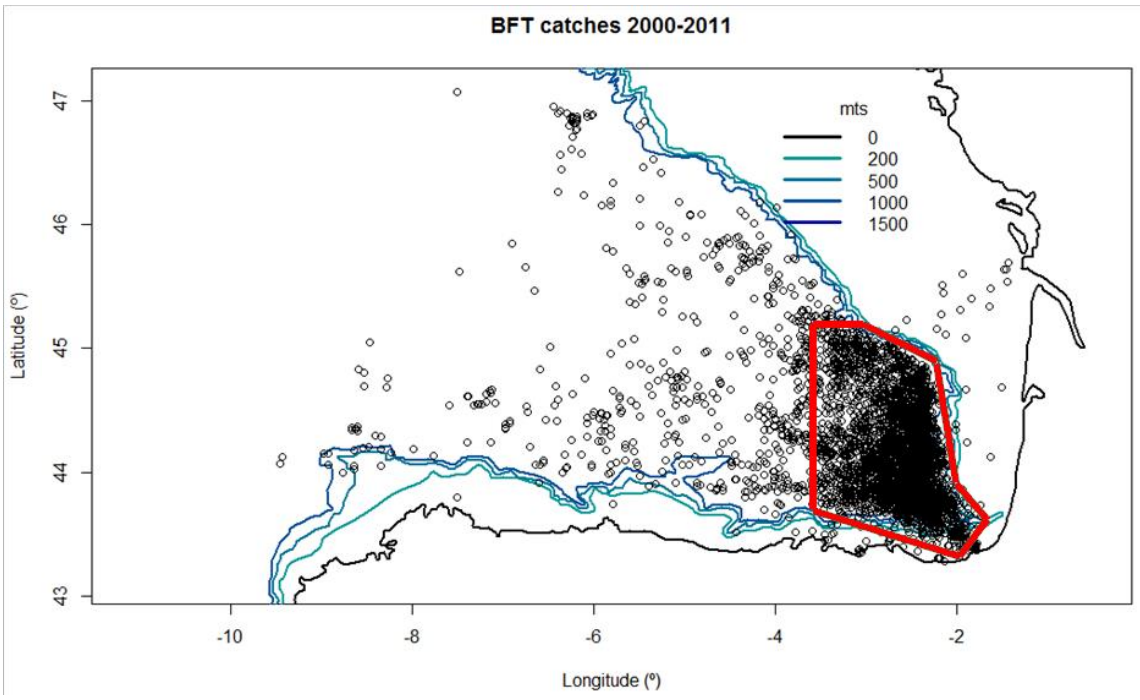


Figure 2. Spatial distribution of bluefin tuna catches by the baitboat fleet in the Bay of Biscay in the years 2000-2011 and spatial definition of the zone of highest catches (84.5% of fishing events and 85.5% of catch weight), delimited by red line.

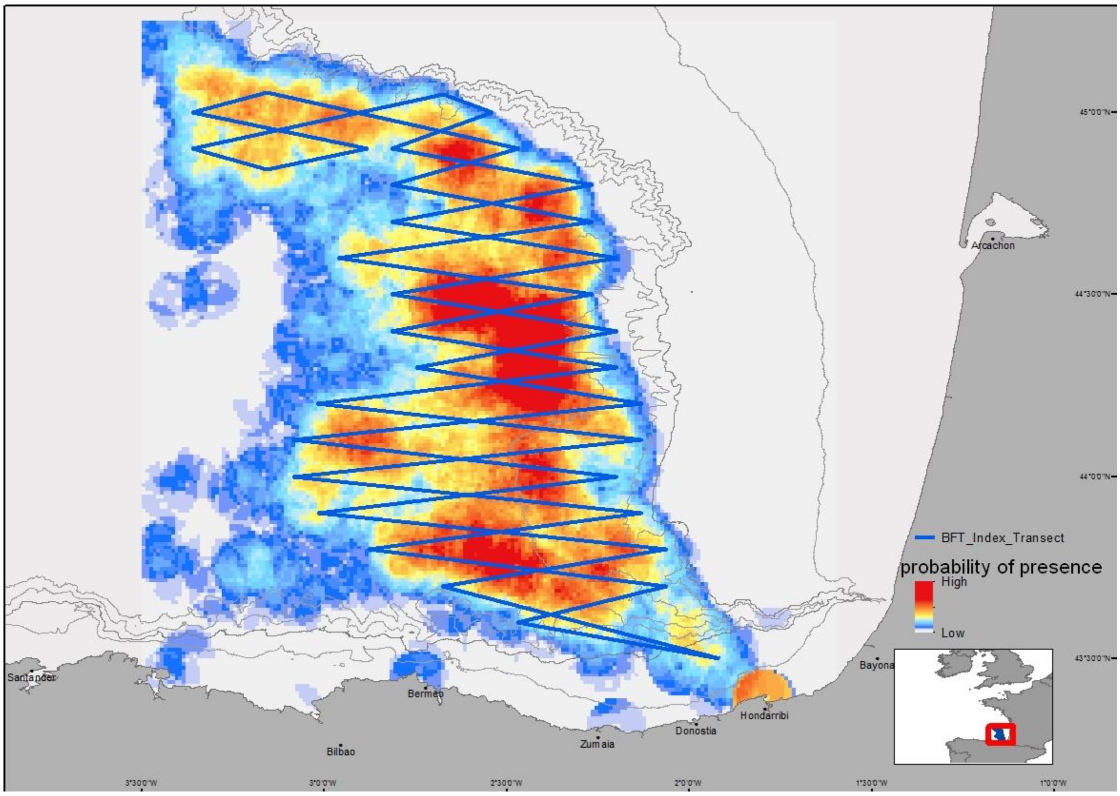


Figure 3a. Probability of bluefin tuna presence according to the Basque baitboat catch data for the period 2000-2011, and spatial definition of the transects followed during the survey.

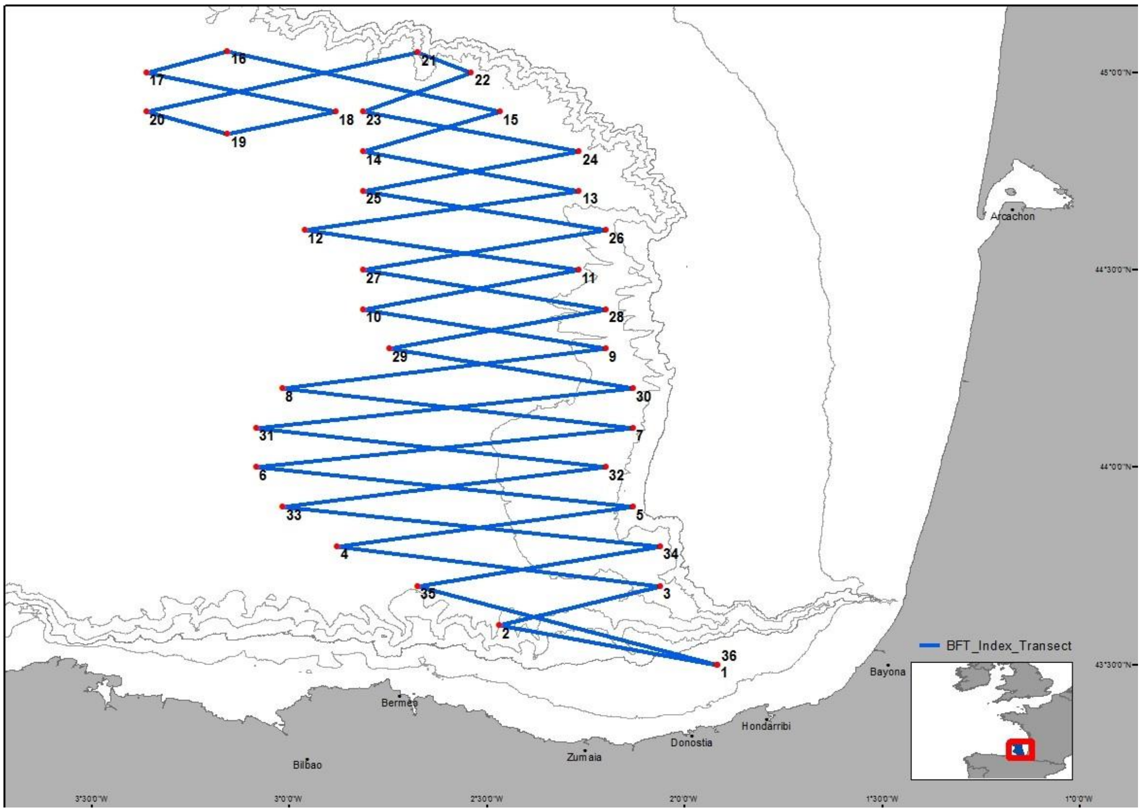


Figure 3b. Spatial definition of the transects followed during the survey, with identification of the 36 waypoints.

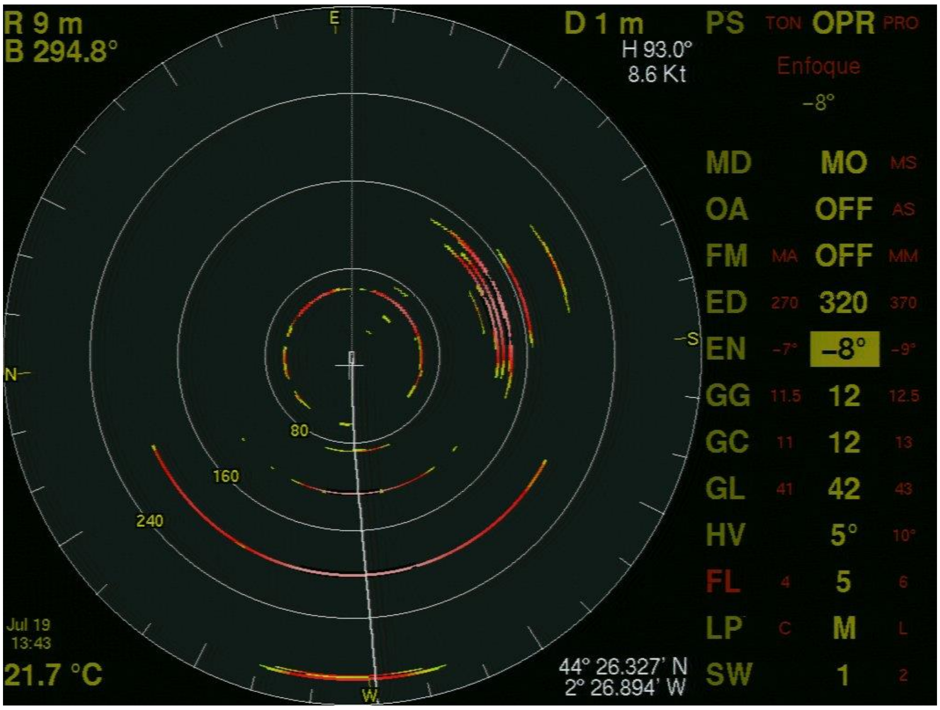


Figure 4. Example of detection of a bluefin tuna school by sonar (right part of the screenshot).

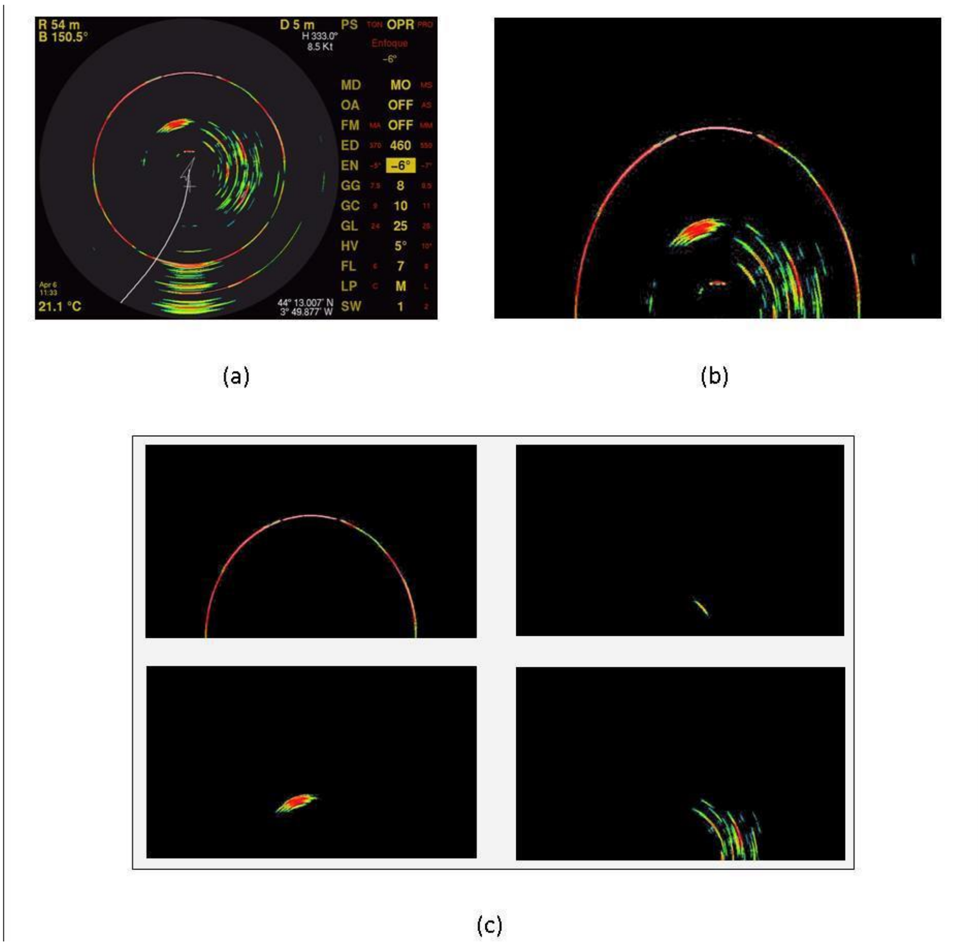


Figure 5. Example of preprocessing of sonar screenshots: a) raw screenshot; b) selection of the zone of interest; c) segmentation.

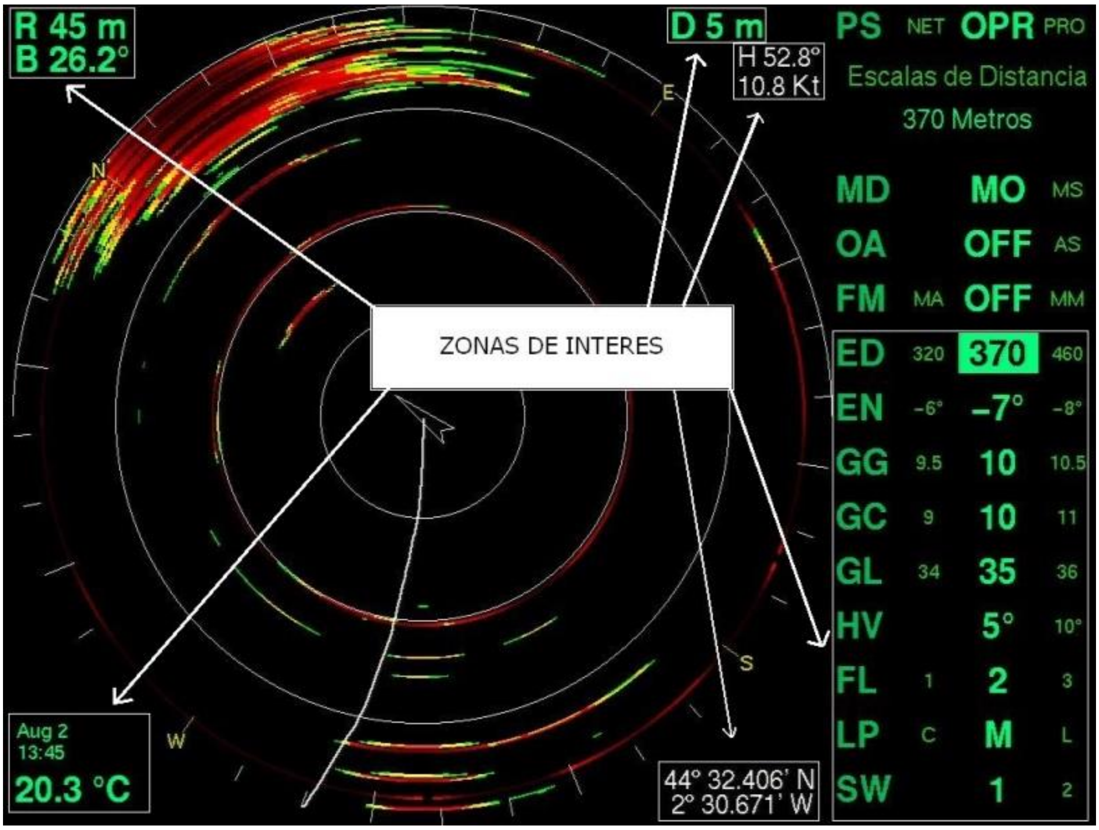


Figure 6. Zones of interest identified through Optical Character Recognition (OCR)

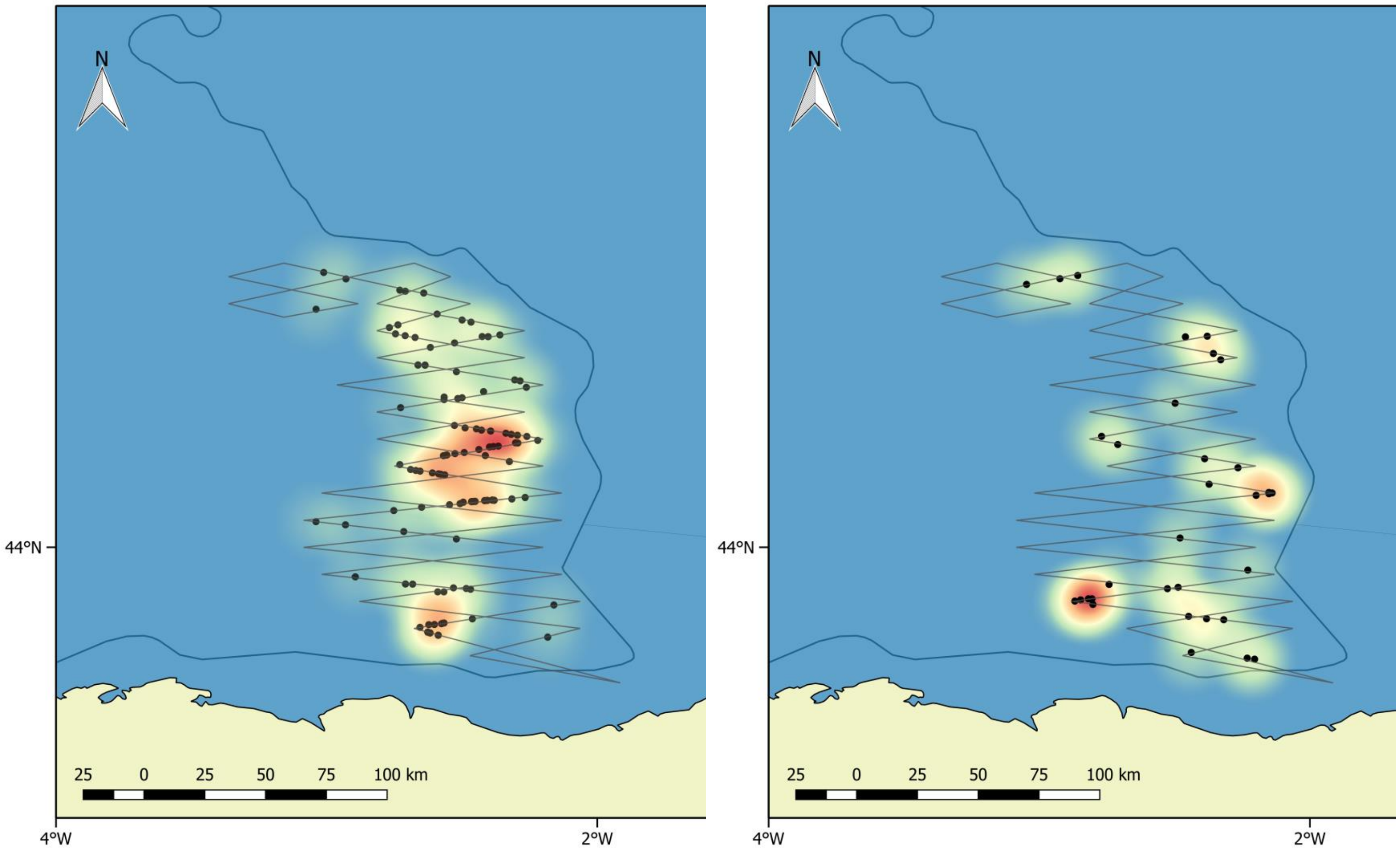
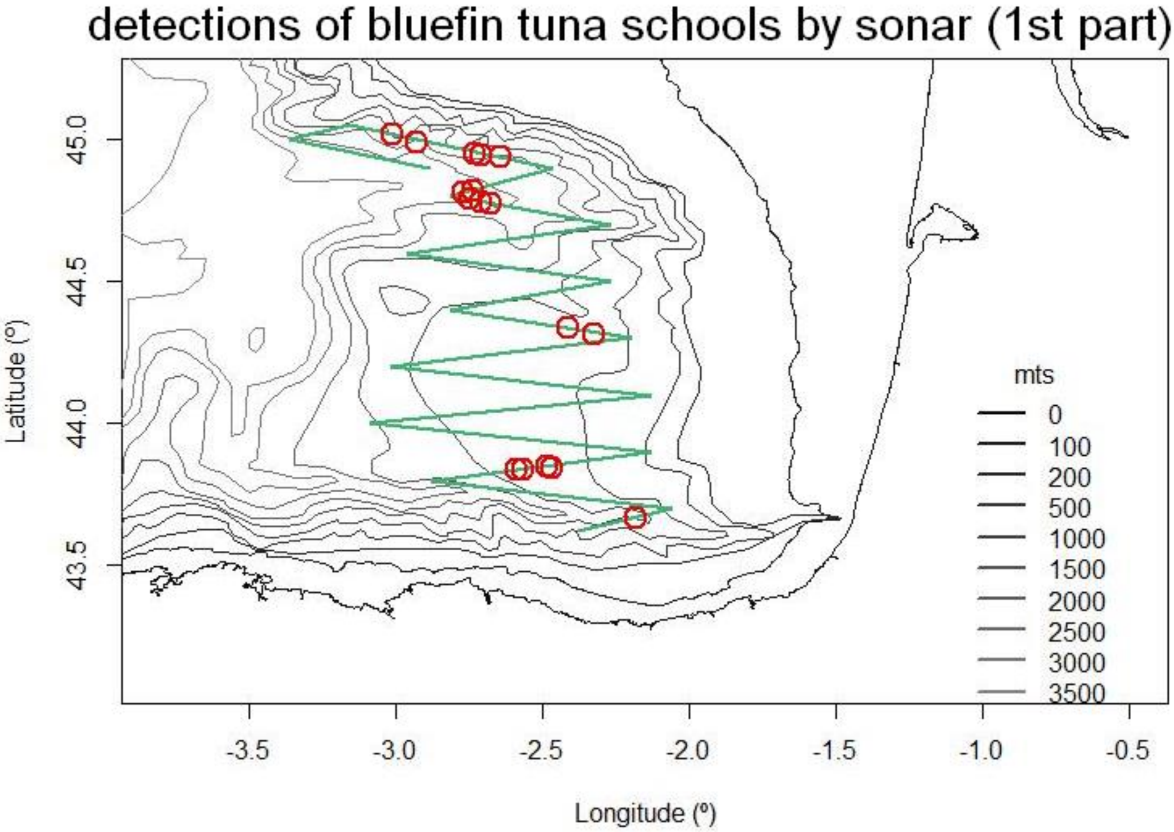


Figure 7. Detections and spatial density of the tuna schools observed during the survey in 2015 (left panel) and 2016 (right panel).



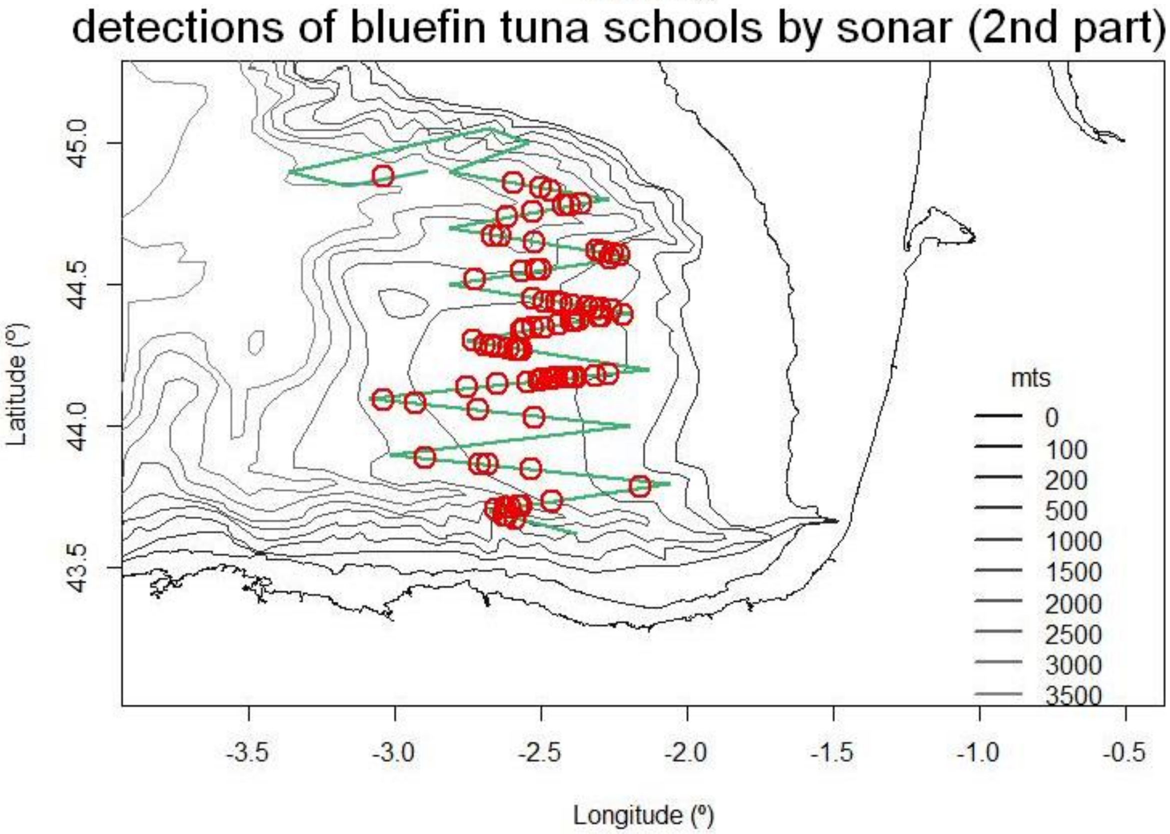


Figure 8. Spatial distribution of the bluefin tuna schools detected by sonar during the first and second half of the 2015 survey.

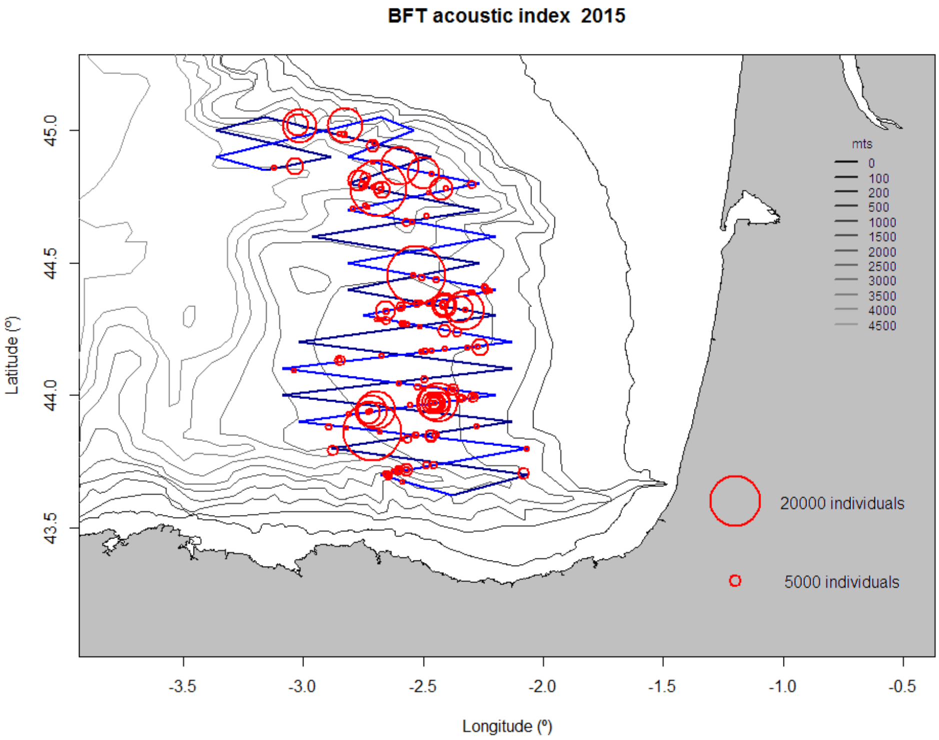


Figure 9. Estimations of the number of individuals in the bluefin tuna schools sampled during the 2015 survey.

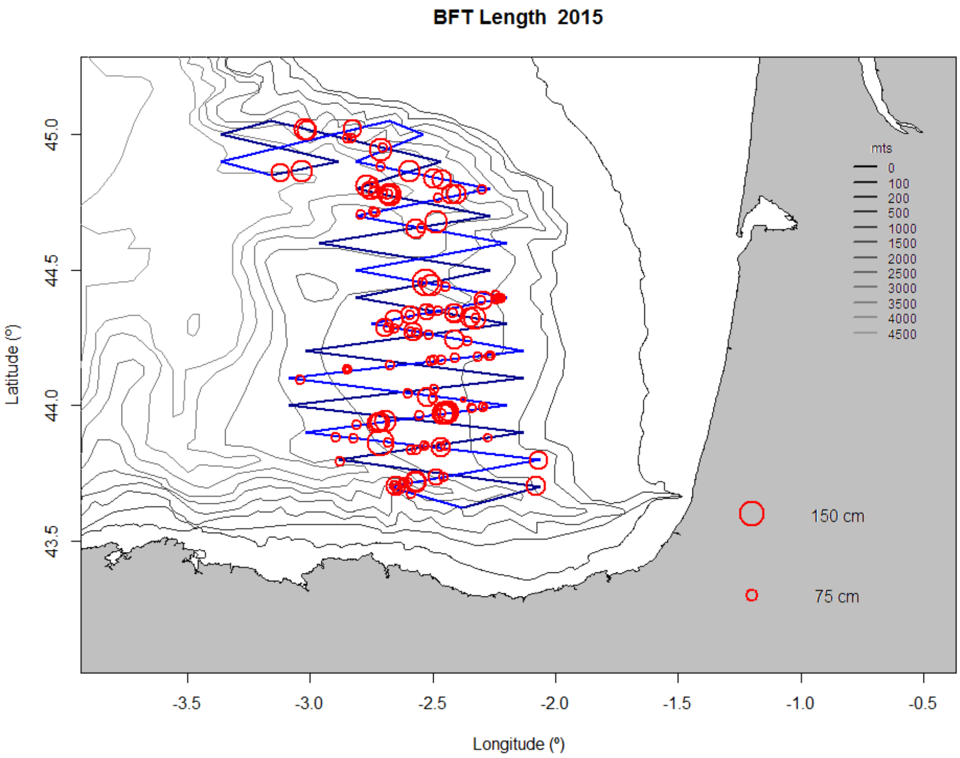


Figure 10. Sizes of individuals in the bluefin tuna schools sampled during the 2015 survey.