ACOUSTIC-BASED FISHERY-INDEPENDENT ABUNDANCE INDEX OF BLUEFIN TUNA IN THE BAY OF BISCAY: RESULTS FROM THE FIRST SEVEN SURVEYS

I. Onandia[1], N. Goñi[2], J. Uranga[3], I. Arregui[3], U. Martinez3, G. Boyra[3], G.D. Melvin[4], I. Godard[5], H. Arrizabalaga[3]

SUMMARY

The main objective of this survey is to develop an acoustics-based, fishery independent abundance index in the Bay of Biscay that continues the historical one, based on catch rates, used in the EBFT stock assessment, that stopped in 2015.An acoustic survey covering summer feeding area for bluefin tunas was conducted in the Bay of Biscay from July 2015 to 2021 on-board a baitboat fishing vessel, using a medium-range 90kHz sonar and a SIMRAD EK60 scientific echosounder working at three frequencies, of which 38 kHz was used for echointegration. The survey followed systematic transects defined according to historical baitboat catch locations. All bluefin detections by sonar and echosounder were recorded. In each aggregation, species identification and 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/age of individuals in the detected schools.

RÉSUMÉ

L'objectif principal de cette prospection est de développer un indice d'abondance indépendant des pêcheries, dans le Golfe de Gascogne, basé sur l'acoustique, dans la continuité de l'indice historique, basé sur les taux de capture, utilisé dans l'évaluation du stock de thon rouge de l'Est, qui s'est arrêté en 2015. Une prospection acoustique couvrant la zone trophique estivale du thon rouge a été menée dans le Golfe de Gascogne de juillet 2015 à 2021 à bord d'un canneur, à l'aide d'un sonar de moyenne portée de 90 kHz et d'un échosondeur scientifique SIMRAD EK60 travaillant à trois fréquences, dont 38 kHz ont été utilisées pour l'écho intégration. La prospection a suivi des transects systématiques définis en fonction des lieux historiques de capture des canneurs. Toutes les détections de thon rouge par sonar et échosondeur ont été enregistrées. Dans chaque agrégation, l'identification des espèces et l'échantillonnage des tailles ont été effectués par le biais d'événements de pêche sans mortalité, d'une caméra stéréoscopique et/ou d'un sonar multifaisceaux. La distribution spatiale des bancs de thons rouges détectés est indiquée, ainsi que le nombre estimé et la taille/âge des spécimens dans les bancs détectés.

RESUMEN

El objetivo principal de esta prospección es desarrollar un índice de abundancia basado en la acústica independiente de la pesquería en el golfo de Vizcaya que continúe el índice histórico, basado en tasas de captura, utilizado en la evaluación del stock de atún rojo del este, que llegaba hasta 2015. Se llevó a cabo una prospección acústica en el golfo de Vizcaya desde julio de 2015 hasta 2021 que cubría la zona de alimentación del atún rojo en verano a bordo de un buque de pesca de cebo vivo, utilizando un sonar de 90 kHz de medio alcance y una ecosonda científico SIMRAD EK60 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 históricas de la captura del cebo vivo. Se consignaron todas las detecciones de atún rojo mediante el sonar y la ecosonda. En cada agregación, se llevó a cabo la 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, así como el número y talla/edad estimados de los ejemplares de los bancos detectados.

KEYWORDS

Abundance index, Acoustics, Atlantic, Bay of Biscay, Bluefin tuna

---

[1] AZTI, Marine Research division; Txatxarramendi ugartea z/g, 48395 Sukarrieta (Bizkaia), Spain
Corresponding author: E-mail ionandia@azti.es; Tel.: +34 667174386; Fax: +34 94657255

[2] Luonnonvarakeskus (Luke) / Natural Resources Institute Finland. Itäinen Pitkäkatu 4 A, FI-20520 Turku, Finland

[3] AZTI, Marine Research division; Herrera kaia, portualdea z/g; 20110 Pasaia (Gipuzkoa), Spain

[4] Fisheries and Oceans Canada, 531 Brandy Cove Road, St. Andrews, New Brunswick, Canada

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 residency in the Bay of Biscay, with the 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.,* 2018). Their continued occurrence in this area in summer months enabled the development of a baitboat fishery since the late 1940s. This 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 one of longest abundance indices for juvenile bluefin tunas (Santiago *et al.*, 2015) and is the only index of juveniles in the northeast Atlantic. However, in recent years, the local Spanish baitboat fleet transferred its quotas, jeopardizing the continuity of the catch per unit of effort (CPUE) series used to build the abundance index. This, together with uncertainties related to the reliability of fishery-dependent abundance indices, raises the need to develop fishery-independent abundance indices for this species. In the Bay of Biscay, among other approaches, 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 seem to be concentrated in a relatively 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 historical catch occurs. Out of this area, most of the catch of the baitboat fleet is comprised of albacore, and bluefin catch is 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 developing a BFT abundance index in this region. This document presents the first results and perspectives of the 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 over approximately 10 consecutive days, following the defined transects (**Figure 3b**). The total distance covered 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 conducted using the F/V Nuevo Horizonte Abierto in 2015 and 2019, the F/V Txingudi in 2016, 2017, 2018 and 2021, the F/V Tuku-Tuku in 2020, all bait boat vessels were based in Hondarribia (Basque Country). They all are equipped with a MAQ or Furuno medium-range commercial sonars, 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**), so our acoustic swept area was 640 m diameter along 960 nm.

Throughout these years, acoustic equipment has been updated and different acoustic configurations have been used to obtain the best possible information for school size estimation. Initially, acoustic data were collected with a SIMRAD EK60 echo-sounder connected to 38 kHz and 120 kHz split-beam transducers oriented vertically and the 200 kHz transducer was oriented laterally 7º off the sea surface, to allow observing the vertical and horizontal dimensions of the tuna schools detected. Since 2018 the SIMRAD EK80 was incorporated, comprising a set of five transducers (frequencies 38, 70, 120, and two transducers of 200 kHz). In 2021, six frequencies were connected to the SIMRAD EK80: 38, 120 and 200 kHz echosounder oriented vertically and 70, 120 and 200 echosounders oriented laterally.

The high frequency (200kHz) M3 sonar (after 2016) and the AM100 stereoscopic camera (in 2017) where installed to estimate fish size as a complement to size sampling of fish caught (**Table 1**).

During all surveys, two trolling lines were also fishing at the stern of the boat to allow determine the specie and size of the detected schools.

2.3 Data registered on board

Along the transects, all tuna detections (species, size, location, and time) by sonar or echosounder, as well as visual detections were registered. The schools were attracted to the vessel using live bait 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 (fish jumping at the surface), through a stereoscopic camera or the M3 sonar. In the case of small tuna aggregations for which the vessel was not stopping, size/age was assigned according to nearby catches, the acoustic signal and surrounding tuna sightings. If needed, the skipper's knowledge as well as a Wesmar 165 sonar (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; or

- after fishing events, when the vessel stayed enough time at reduced speed to allow a tuna school to be detected a second time.

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 Acoustic data processing

The echosounder recordings (**Figure 5**) were 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 provided us with the vertical dimension and one of the horizontal dimensions of the tuna schools.

The software used to process echosounder data was 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 to keep only pings containing acoustic backscattering corresponding to tuna aggregations, by keeping only non-zero echointegration pings. This produced 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.

Once the acoustic backscattering is converted into number of individuals, we divided by the acoustic swept area to calculate the average spatial density.

MAQ sonar screenshots are recorded every second during the survey. The images are processed according to Uranga *et al.*, (2017) to calculate school dimensions, which, if necessary, are used to check the diameter of the school.

Length to weight and length to age conversions are conducted according to Rodriguez Marín *et al.*, (2015) and Cort (1990) respectively.

2.5 Coefficient of variation (CV) of the abundance estimation

The precision of the abundance estimate for BFT was calculated as an estimation of variance, taking into account only the variability in acoustic backscatter that converts into numbers of individuals, derived based on classic random sampling theory. The method was based on the estimate precision used in the small pelagic surveys in SW Europe (Doray *et al.*, 2021) but assuming that no error was committed when assigning acoustic backscattering energy to BFT and simplified accordingly based on this assumption. This assumption was taken given that the catches are usually monospecific, yielding percentages of BFT of 100%. Under this assumption, the uncertainty each year was calculated as follows.

First, all the EDSUs with zero abundance were filtered from the abundance dataset. Then, the mean abundance was calculated as the average over the non-zero EDSUs:

$$\langle Ab \rangle_y = \frac{1}{N_y} \sum_{j=1}^{N_y} Ab_{j,y} \qquad (1)$$

Where y represents the year, j each non-zero ESDU, $Ab_{j,y}$ is the abundance of BFT in each EDSU and year, and N_y is the number of non-zero EDSUs sampled per year.

The variance of each year abundance estimate s_y^2 was estimated as the sum of the squares of the residuals of the mean abundance:

$$s_y^2 = \frac{1}{N_y - 1} \sum_{j=1}^{N_y} \left(\langle Ab \rangle_y - Ab_{j,y} \right)^2 \qquad (2)$$

The standard deviation per ping interval and transect, s_y, was obtained as the squared root of the variance:

$$s_y = \sqrt{s_y^2} = \sqrt{\frac{1}{N_y - 1} \sum_{j=1}^{N_y} \left(\langle Ab \rangle_y - Ab_{j,y} \right)^2} \qquad (3)$$

The annual standard error was defined as:

$$se_y = \frac{s_y}{\sqrt{N_y}} \tag{4}$$

Finally, the coefficient of variation of the abundance estimation per year was defined as:

$$CV_y = \frac{se_y}{\langle Ab \rangle_y} \tag{5}$$

3. Results

After removing the possible double counts, a total of 417 bluefin tuna schools were detected during the seven years of surveying (**Table 1**). Estimated bluefin abundance also showed relatively lower values in the last four years (2018-2021) compared to the first three (2015-2017), and specially the first two years where the largest abundance was observed (**Table 2, Table 3, Figure 9**). The spatial distribution of tuna detections was heterogeneous in all the years (**Figure 6**), 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 distances (**Table 2**).

Size measurements where positively correlated with M3 size estimates obtained in 2016 (**Figure 8b**). We found that bluefin schools are composed of the same age class individuals specially in age classes 1, 2, 3 and 4. Age 5 and above could be found sometimes mixed. In the following years when the detected schools were attracted to the boat, we could observe fish jumping around the boat or recorded with the M3 sonar, thus age classes were easily estimated, and fishing was avoided. We also found that schools of the same age class share a common area (**figure 7**) and we could confirm it with catches from the trolling lines, thus when small schools were detected, not big enough to start a fishing event, we assigned the nearest known age class. In the sampled detections, an abundance of up to 32582 individuals by school was estimated (namely in 2015). The number of individuals by school was highly variable and the estimated abundance was below 40 individuals for 50% of the schools (**Figure 6**).

During the last 7 years in which this cruise has been conducted, BFT from ages 1 to 5+ have been detected. Although not all age classes are found every year, in particular ages 1 and 2, the largest specimens (ages 5+) have been observed during all the years and in greater proportion than the rest of the ages (**Figure 9**). This suggests that the larger fish selectivity of the SP_BB2 index (ages 3-6, 2007-2014), compared to SP_BB1 (ages 2-3, 1952-2006), could be due to implementation of regulations, but potentially also due to an increased availability of large fish.

The average spatial density of tunas (all age groups) ranged from 7.36 tunas / km^2 (in 2018) to 48.50 tunas / km^2 (in 2015). The coefficient of variation of the abundance estimation ranged from 22% to 44% (**Table 3**).

4. Discussion

Determining fish size is an important step for biomass estimation. Using a live bait boat able to attract the bluefin tuna schools close to the boat, eased the size sampling for every method we used; fishing events, visual estimations (including Am100 stereo camera) or M3 sonar sizing. Our abundance estimates are up to 1000 times higher than the ones found in the gulf of St Lawrence with similar equipment onboard (Minch 2020), which shows the importance of the Bay of Biscay in the trophic migration of this species.

Among the main features of the distribution of bluefin tuna we can confirm the high aggregative behavior, as high biomasses are observed in very concentrated small areas of the survey during the first years of this survey. In other areas we observed a scarcity or an absence of bluefin tuna. The heterogeneity of the spatial distribution is a typical feature of this species (Tenningen, 2019). Bluefin tuna prey species and competing predators might affect bluefin spatial distribution. Our preliminarily analyzed the first four years of data provided some insight into these relations. Anchovies seem to be affected by bluefin tuna local abundance, due to foraging, and albacore tunas may be affecting the spatial distribution of bluefin tunas in the Bay of Biscay, due to competition. At a coarser scale, bluefin use a more coastal habitat than albacore (**Figure 1**). In fact, albacores were not always detected in the survey area. However, the decrease in bluefin abundance during the last four years coincides with a relatively high abundance of albacore tuna in the Northeast Atlantic. In such circumstances, it is likely that albacore tended to co-occupy the inner Bay of Biscay with bluefin. During our surveys we noted that albacore and bluefin are rarely observed together but tended to split the space (**Figure 10**). Further investigation, using the whole database, is required, is required to explore the effects of prey and other predators on bluefin spatial distribution and abundance within the Bay of Biscay.

In addition, the potential impact of environmental variables affecting interannual variability of bluefin tuna migration into the Bay of Biscay would also be worth studying i.e., using habitat models.

The observed age composition and the absence of some age groups during the years is also worth further investigation. It would have been ideal to have a complete overlap between the baitboat fishery and the acoustic survey, to compare size structure. Unfortunately, this is not possible as the fleet had no activity for most of the survey years. However, in 2018 the fleet was active during the survey period and did catch a wider age range (ages 2 to 5+, **Figure 11**) than observed in the acoustic survey (ages 4 to 5+). This suggests that the 10-day survey with a single boat might not be enough to properly represent the available population. Additional acoustic surveys (i.e., at different times during the season) would improve the quality of the index but cost would be a serious concern.
The last three years the survey started slightly earlier (2-3 weeks before the previous 3 years), in the second half of June. This could affect the abundance found in the Bay of Biscay. In fact, the largest abundance was observed in 2015, when the survey started latest (13th of July, **Table 1**). However, this would not explain the abundance drop observed in 2018, when the survey started the 3rd of July. Moreover, Arregui et al (2018) showed, using multiyear archival tagging data, that most of the entries to the Bay of Biscay occur before mid-June so this might not fully explain the observed drop in the last three years.

The index provided in this document is available for consideration by the BFT WG as candidate for future assessments and/or MSE efforts as a potential abundance index of bluefin tuna available in the surveyed area. Previous baitboat fishery indices of abundance in this region indexed abundance of ages 2-3 for the historical period 1952-2006) and ages 3-6 during the 2007-2014 period. This change in the indexed ages reflect a change in targeting larger ages after management recommendations were implemented. The acoustic index, if considered useful, could be considered to index ages 2 to 6 as there is no targeting effect the index is available for consideration by the group, given the limitations that we have.

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, F/V Txingudi and F/V Tuku-Tuku for their collaboration and help in this project, and especially to Aitor Olaskoaga, Jose Antonio Agirre and Norberto Emazabel 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.; Lam, C.H.; Fraile, I.; Santiago, J.; Lutcavage, M.; Arrizabalaga, H. Movements and geographic distribution of juvenile bluefin tuna in the Northeast Atlantic, described through internal and satellite archival tags. ICES J Mar Sci. 75:1560–1572; 2018

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

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., Boyra, G., and van der Kooij, J. (Eds). 2021. ICES Survey Protocols – Manual for Acoustic Surveys Coordinated under the ICES Working Group on Acoustic and Egg Surveys for Small Pelagic Fish (WGACEGG). ICES Techniques in Marine Environmental Sciences Vol. 64. 100 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 Collective Volume of Scientific Papers 65(3): 755-769

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.

Melvin, G.D. Observations of in situ Atlantic bluefin tuna (*Thunnus thynnus*) with 500-kHz multibeam sonar. ICES Journal of Marine Science. 73:1975-1986; 2016

Minch, T., Turcotte, F., McDermid, J.L. 2019 Update to the Gulf of Saint Lawrence acoustic index of abundance for Atlantic bluefin tuna SCRS/2020/158 collect. Vol. Sci. Pap. ICCAT, 77(2): 944-951 (2021) 944

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.

Tenningen, M.; Pena, H.; Korneliussen, R.; Ona, E.; Pons, V.P. Feasibility study on the use of scientific multibeam sonar to characterize the Atlantic Bluefin Tuna spawning stock. Rapport fra Havforskningen: Institute of Marine Research (IMR) and the Polytechnic University of Valencia (UPV); 2019

Uranga J, Arrizabalaga H, Boyra G, Hernandez MC, Goñi N, Arregui I, *et al.*, (2017) Detecting the presence-absence of bluefin tuna by automated analysis of medium-range sonars on fishing vessels. PLoS ONE 12(2): e0171382. https://doi.org/10.1371/journal.pone.0171382

Table 1. Summary of acoustic equipment used during survey (beyond the vertical 28 KHz, vertical 120 KHz and lateral 200 KHz transducers), dates of the survey, number of detected schools and measured individuals by method.

Year	*Dates*	*Sonar 360m range*	*Sonar M3*	*AM100 stereo camera*	*N schools detected*	*N schools with catches*	*N bio-measured BFT*	*N BFT sized M3*	*N BFT sized AM100*
2015	13-22 July	MAQ	N/A	N/A	106	5	67	-	-
2016	4-13 July	MAQ	onboard	N/A	83	11	71	220	-
2017	4-13 July	MAQ	N/A	onboard	77	3	3	-	7
2018	3-10 July	MAQ	onboard	onboard	34	7	8	200	-
2019	15-22 June	MAQ	onboard	onboard	61	6	7	60	-
2020	16-23 June	FURUNO	N/A	onboard	20	8	10	-	-
2021	14-27 June	MAQ	onboard	onboard	36	3	3	40	-

Table 2. Summary of bluefin tuna detections per nautical mile.

Transect start point	Longitude	Latitude	Distance to next point (n.m.)*	Detections per n.m. 2015	Detections per n.m. 2016	Detections per n.m. 2017	Detections per n.m. 2018	Detections per n.m. 2019	Detections per n.m. 2020	Detections per n.m. 2021
1	-1.917	43.500	24.7	0	0	0	0	0	0.081	0.04
2	-2.470	43.600	18.72	0.053	0.053	0	0.267	0.107	0	0.053
3	-2.063	43.700	35.98	0	0.139	0	0	0.056	0	0
4	-2.879	43.800	33.01	0.121	0.182	0	0	0.061	0	0
5	-2.131	43.900	41.75	0	0.024	0	0.024	0.048	0	0.096
6	-3.085	44.000	41.69	0	0	0	0.024	0.048	0	0.024
7	-2.131	44.100	38.78	0	0	0	0	0	0.026	0.052
8	-3.018	44.200	35.77	0	0.028	0	0	0.028	0.056	0.056
9	-2.200	44.300	27.12	0.074	0.074	0	0	0.111	0	0
10	-2.815	44.400	24.23	0	0.041	0	0	0.041	0	0.041
11	-2.268	44.500	30.32	0	0.033	0.066	0	0.066	0	0.033
12	-2.962	44.600	30.29	0	0.033	0.297	0	0	0.033	0.132
13	-2.268	44.700	24.13	0.124	0.041	0.29	0.041	0.083	0.041	0.124
14	-2.815	44.800	15.97	0.125	0	0.376	0	0	0	0.063
15	-2.468	44.900	30.75	0.163	0	0.065	0.066	0	0.098	0.098
16	-3.158	45.050	9.3	0	0	0.215	0	0.108	0	0
17	-3.363	45.000	21.27	0	0	0.047	0	0	0.047	0
18	-2.884	44.900	12.16	0.164	0	0	0.082	0	0	0
19	-3.158	44.850	9.39	0.106	0	0	0	0.319	0	0
20	-3.363	44.900	30.58	0	0.098	0	0.066	0.065	0.033	0
21	-2.676	45.050	6.47	0	0	0.464	0.155	0.155	0	0
22	-2.541	45.000	13.11	0	0	0.534	0	0.076	0.229	0
23	-2.815	44.900	24.08	0	0	0.623	0.042	0	0	0
24	-2.268	44.800	24.12	0.124	0.083	0.332	0.166	0	0.041	0.083
25	-2.815	44.700	27	0.185	0	0	0	0.074	0	0
26	-2.200	44.600	27.04	0.259	0	0.259	0.037	0	0	0
27	-2.815	44.500	27.08	0.332	0	0	0	0.185	0	0
28	-2.200	44.400	24.31	0.535	0	0	0.082	0	0	0
29	-2.750	44.300	27.24	0.22	0.11	0	0.037	0.184	0	0
30	-2.131	44.200	41.62	0.336	0.048	0	0	0.12	0	0
31	-3.085	44.100	38.74	0.103	0.026	0	0.077	0.103	0.052	0
32	-2.200	44.000	35.93	0	0	0	0	0.223	0	0
33	-3.018	43.900	41.83	0.12	0.024	0.024	0.024	0.072	0	0.096
34	-2.063	43.800	27.37	0.292	0	0.183	0.073	0.073	0	0.11
35	-2.678	43.700	35.25	0.085	0.057	0.057	0.142	0.085	0.057	0.085

*n.m. nautical mile (1852 m).

Table 3. BFT index: Yearly summary of estimated ABFT in the survey area (1105.92 km^2).

Year	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*
N BFT estimated	57197	57133	29137	10391	18479	16280	12625
N BFT/km^2	48.5	48.44	23.83	7.36	14.47	14.31	9.32
CV	26%	41%	32%	22%	22%	44%	22%

Table 4. Estimated total number of individuals by age-group in the schools detected during the surveys 2015 to 2021.

	2015	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*
Age 1	2808	3033	0	64	3549	14312	3
Age 2	5848	0	0	4	78	25	25
Age 3	0	18450	2765	0	44	1943	227
Age 4	13944	7869	0	1632	3345	0	4
Age 5+	32582	25765	24355	6673	9444	*0*	10345

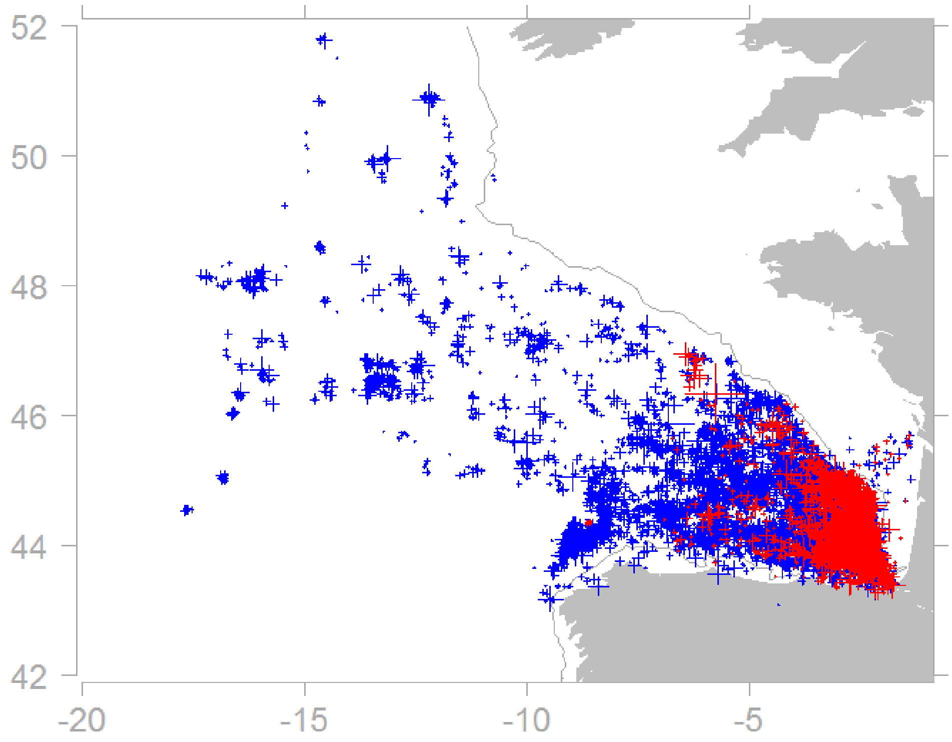


Figure 1. Spatial distribution of BFT (in red) and ALB (in blue) catches by the baitboat fleet of Gipuzkoa and Bizkaia in the Bay of Biscay in the period 2000-2014.

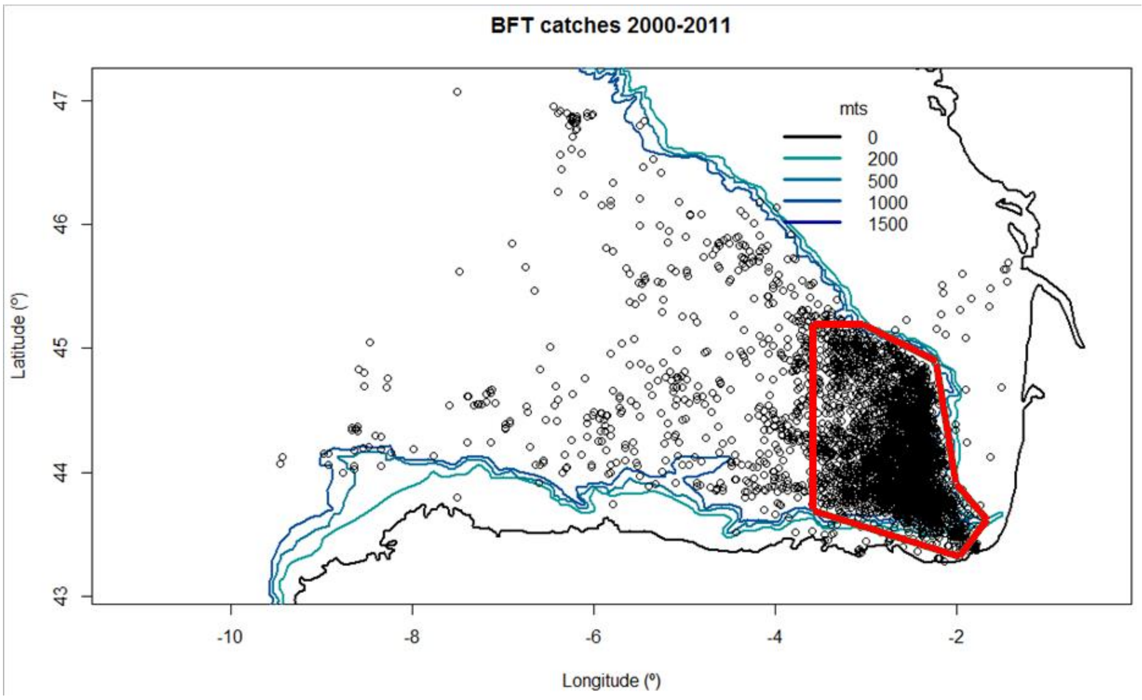


Figure 2. Spatial distribution of bluefin tuna catches by the baitboat fleet in the Bay of Biscay in the years 2000-2011 and spatial definition of the zone of highest catches (84.5% of fishing events and 85.5% of catch weight), delimited by red line.

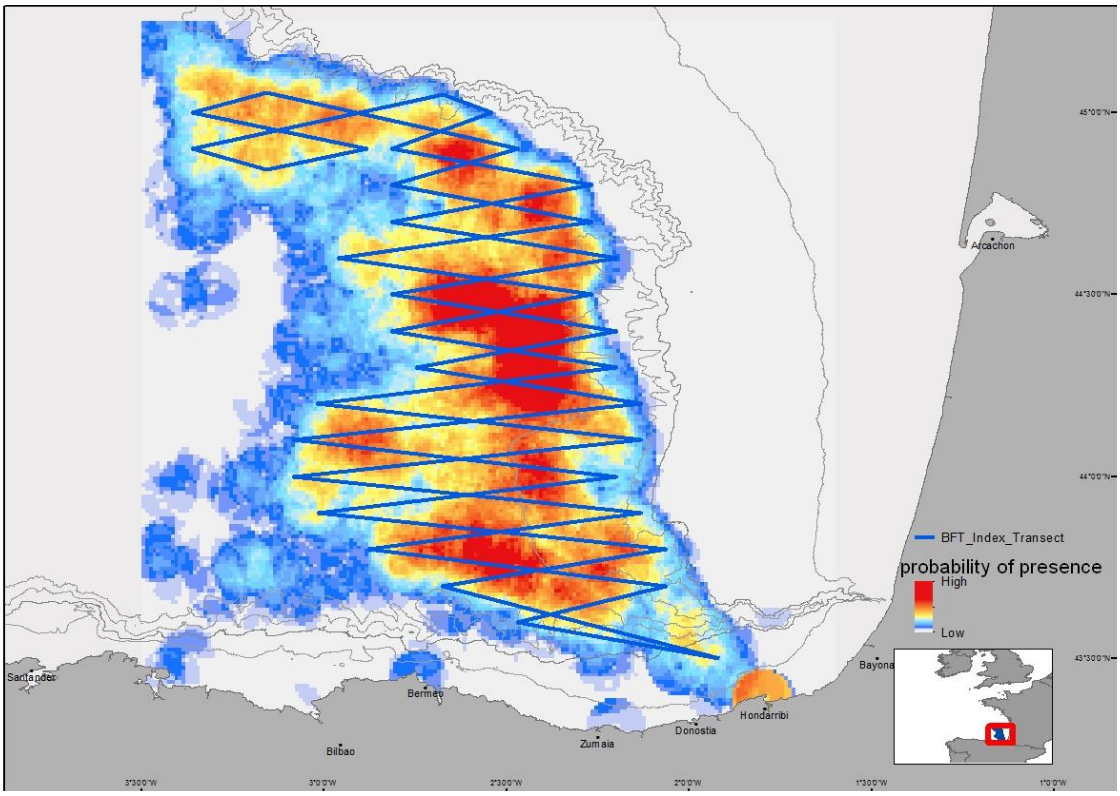


Figure 3a. Probability of bluefin tuna presence according to the Basque baitboat CPUE data for the period 2000-2011, and spatial definition of the transects followed during the survey.

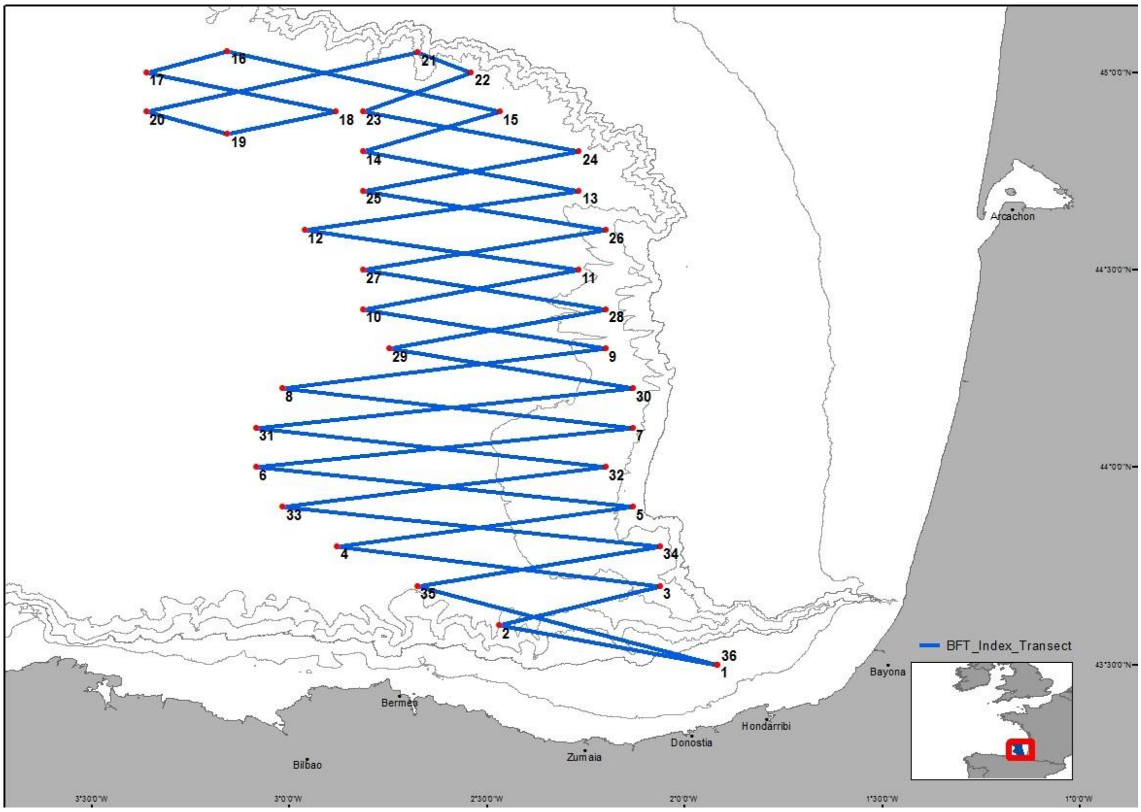


Figure 3b. Spatial definition of the transects followed during the survey, with identification of the 36 waypoints.

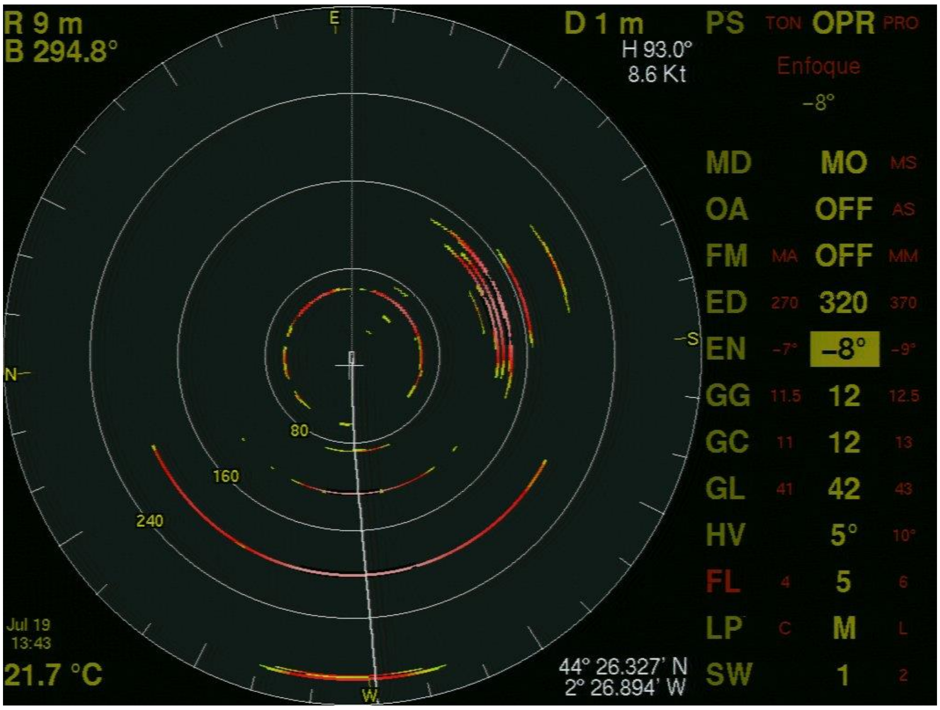


Figure 4. Example of detection of a bluefin tuna school by MAQ sonar (right part of the screenshot).

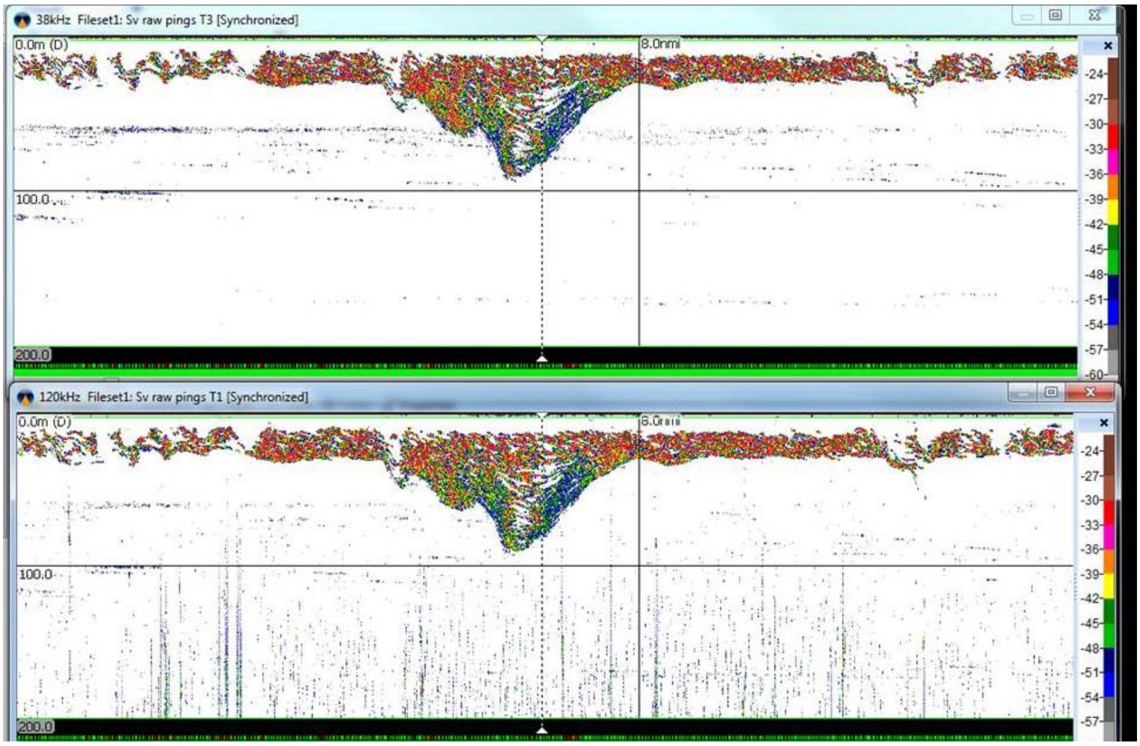


Figure 5. Simrad EK 60 BFT school detection with 38 and 120 KHz frequencies.

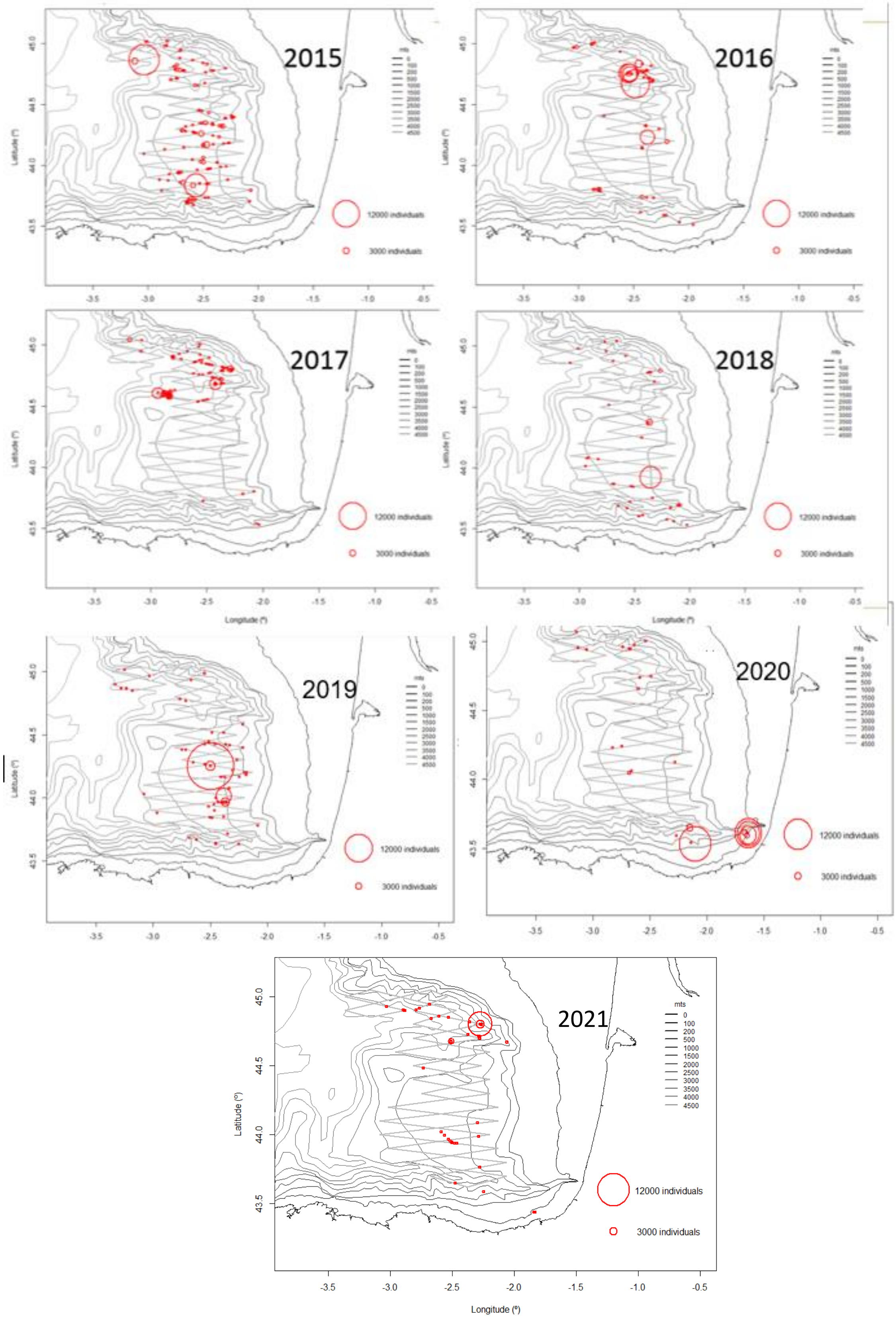


Figure 6. Estimations of the number of individuals in the bluefin tuna schools sampled during the 2015-2021 survey.

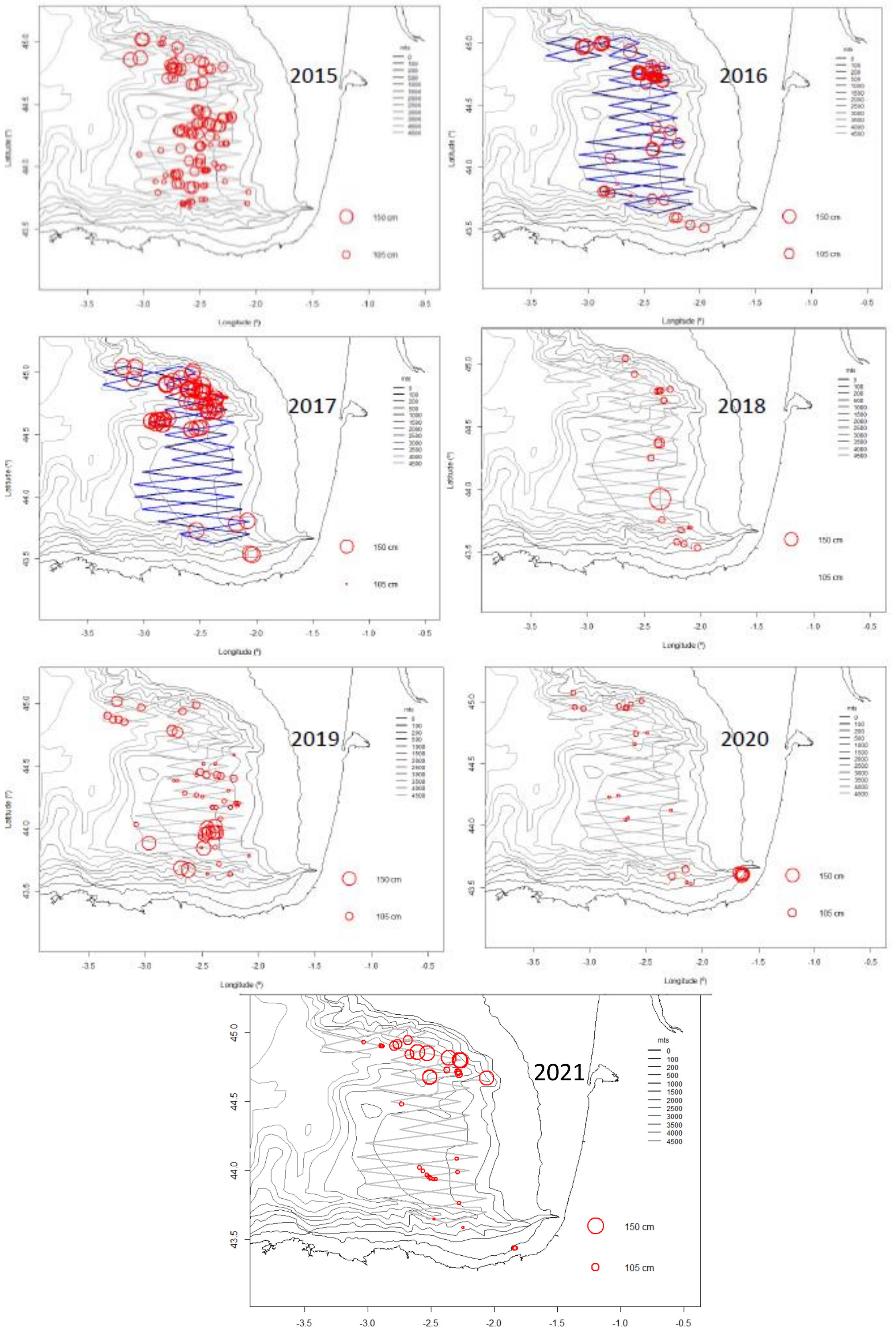
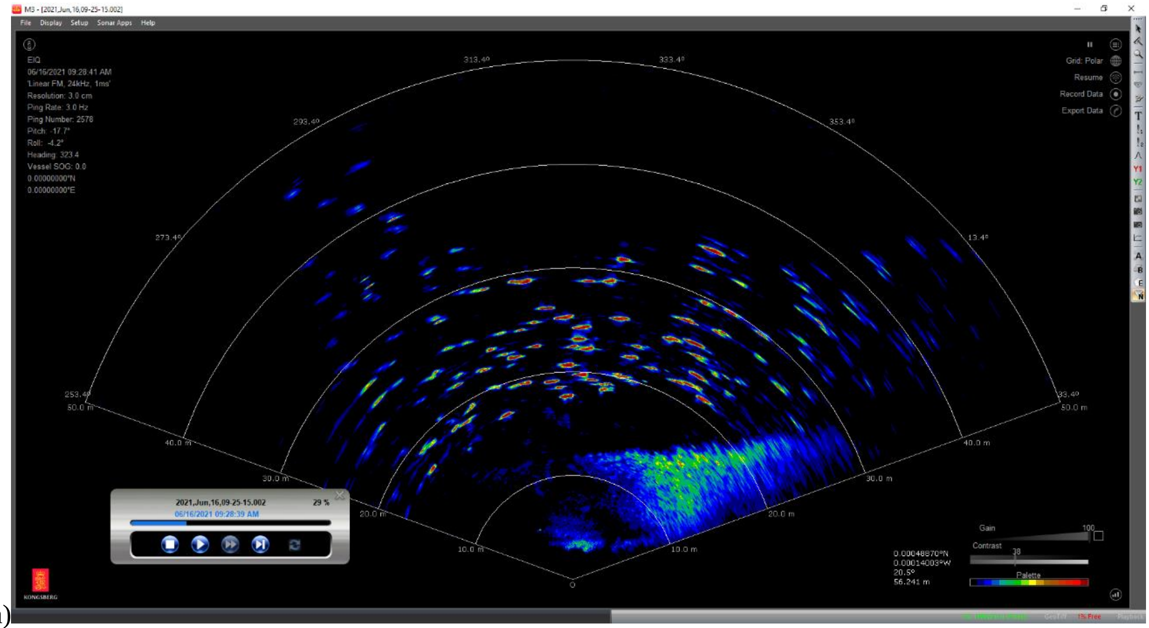


Figure 7. Average length estimations of individuals in the bluefin tuna schools sampled during the 2015-2021 survey.



a)

b)

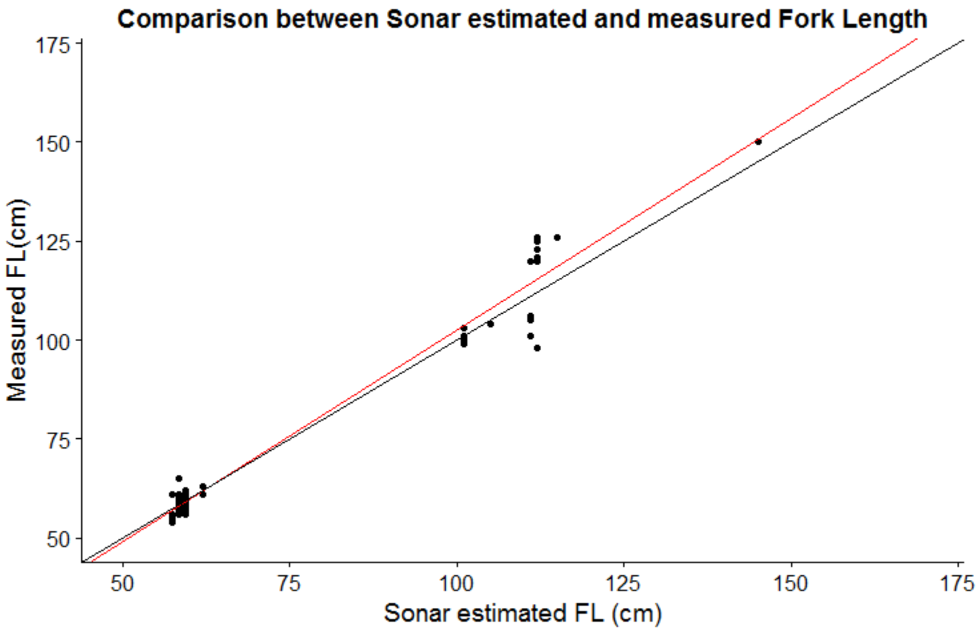


Figure 8. a) Interface of the Kongsberg Simrad M3 sonar used for sizing, and b) correlation between measured fork length and M3 size estimates.

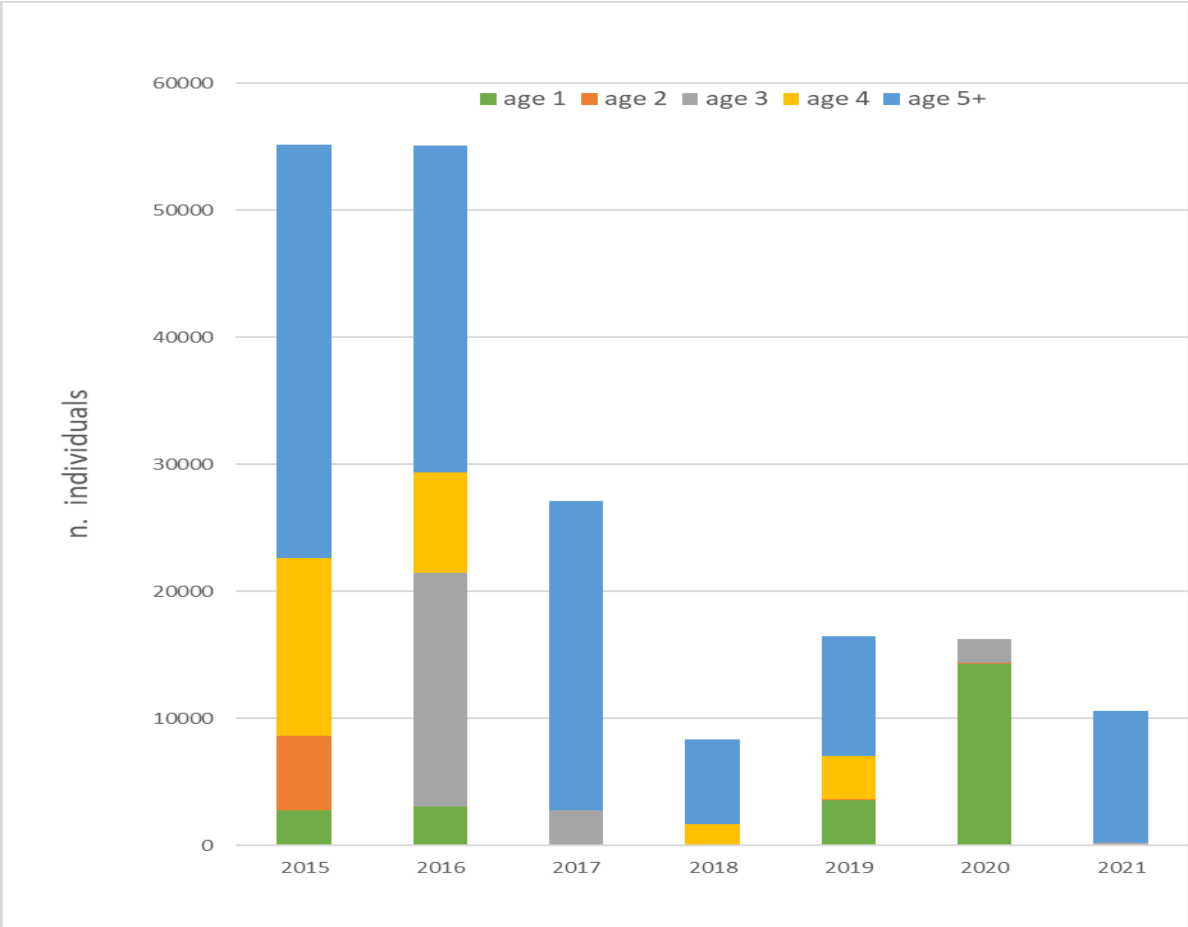


Figure 9. Estimated total number of individuals by age-group in the schools detected during the surveys.

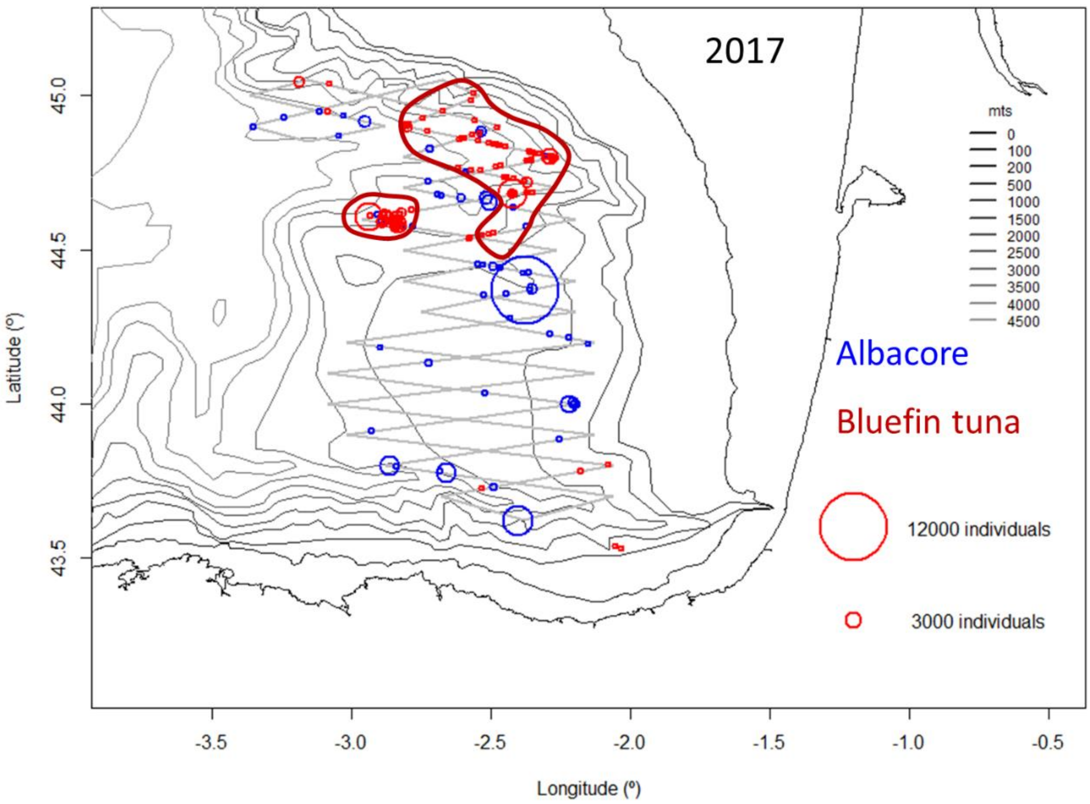


Figure 10. Albacore and bluefin distributions during 2017 survey.

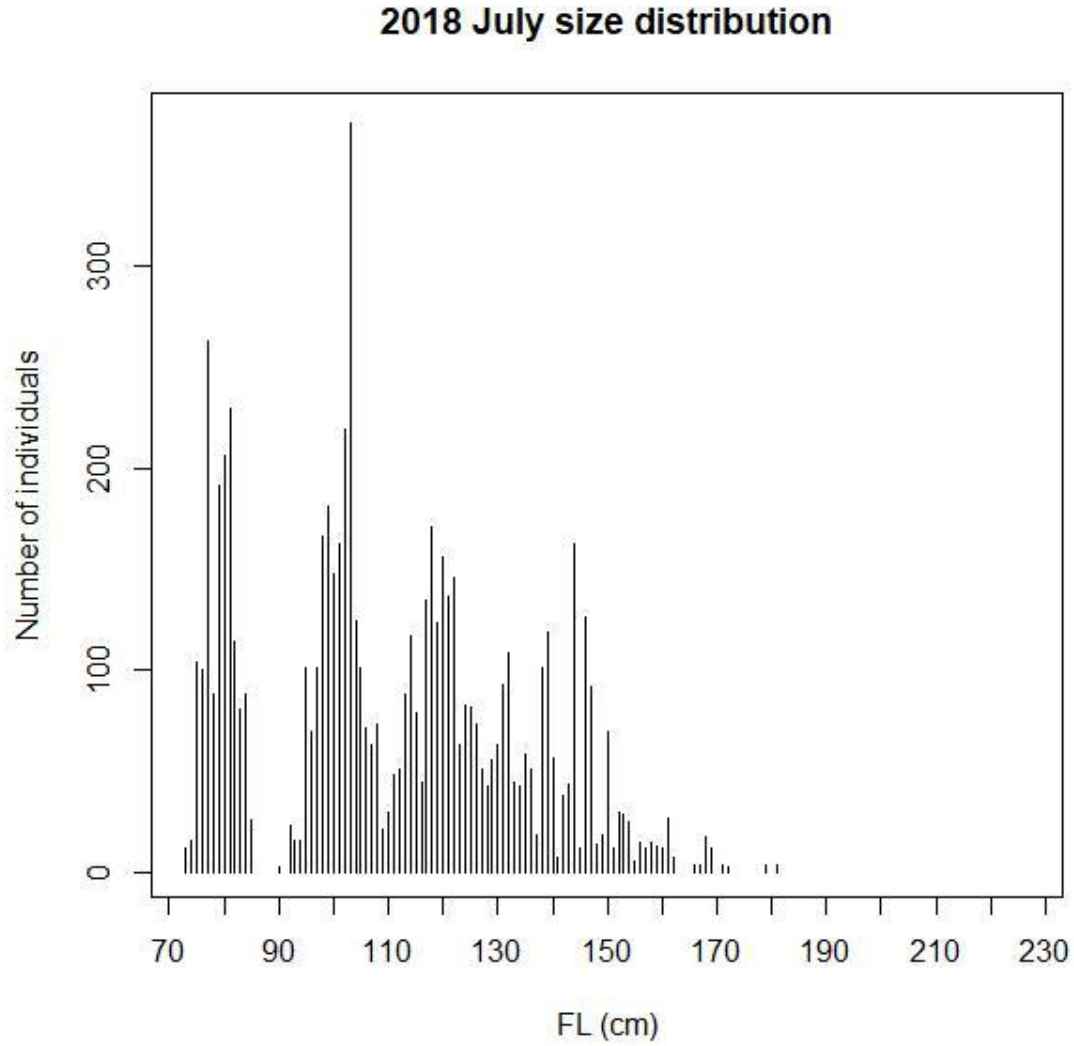


Figure 11. Bluefin tuna size distribution of the Bay of Biscay baitboat fleet in July 2018.