ATLANTIC-WIDE RESEARCH PROGRAMME FOR BLUEFIN TUNA (ICCAT GBYP 02/2018– PHASE 8)

ELABORATION OF DATA FROM THE AERIAL SURVEYS ON BLUEFIN TUNA SPAWNING AGGREGATIONS

Report

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Background

The objectives of the comprehensive ICCAT Atlantic-Wide Research Programme for Bluefin Tuna (GBYP) are to improve basic data collection and our understanding of key biological and ecological processes in order to develop a robust scientific management framework.

An important element of this programme is to develop fisheries independent indices of population abundance. Therefore, in 2010 and 2011 aerial surveys were conducted in the Mediterranean on selected spawning grounds. Extended surveys were carried out in 2013 and 2015. In 2017 a new survey was carried out again on selected spawning grounds, specifically on the "overlap areas" defined in 2015. The same areas as in 2017 were surveyed in 2018, with the exception of an exclusion area around NW Cyprus (see Figure 1)

The purpose of this work is to elaborate the Aerial Survey data collected under GBYP Phase 8 and to provide a comprehensive analysis of the results of all aerial surveys conducted so far under the framework of the GBYP.

Objective

- To provide an analysis of all data collected during the 2018 ICCAT GBYP aerial survey, by overlap area, using the same methodology applied in previous surveys.

Deliverables

1. Map of the distribution of the Bluefin tuna spawners by overlap area (on and off effort)

2. Summary table with the same information as previous surveys, with the aim of comparing results by year and area.

3. Analysis of the data by overlap area, using the same methodology as in previous surveys, and showing the abundance estimates and uncertainty per area

4. A draft PowerPoint presentation of the main results for the SCRS

5. An executive summary of this report

Data

Survey design

The same survey design as in 2017, done using program DISTANCE http://www.ruwpa.st-and.ac.uk/distance/ and the "industry standard" software for line and point transect distance sampling, was used for the survey in 2018 (see Cañadas and Vazquez 2017 for the report on the survey design).

Survey coverage

Figure 1 shows the sub-areas. **Figure 2** and **3** show the realised transects and the sightings made on and off effort respectively. **Figures 4** to **7** show the realized effort and sightings in each sub-area.

In general, coverage of all sub-areas was comprehensive and all replicas could be completed. There were no problems of uneven coverage in portions of the blocks as in some of the previous years.

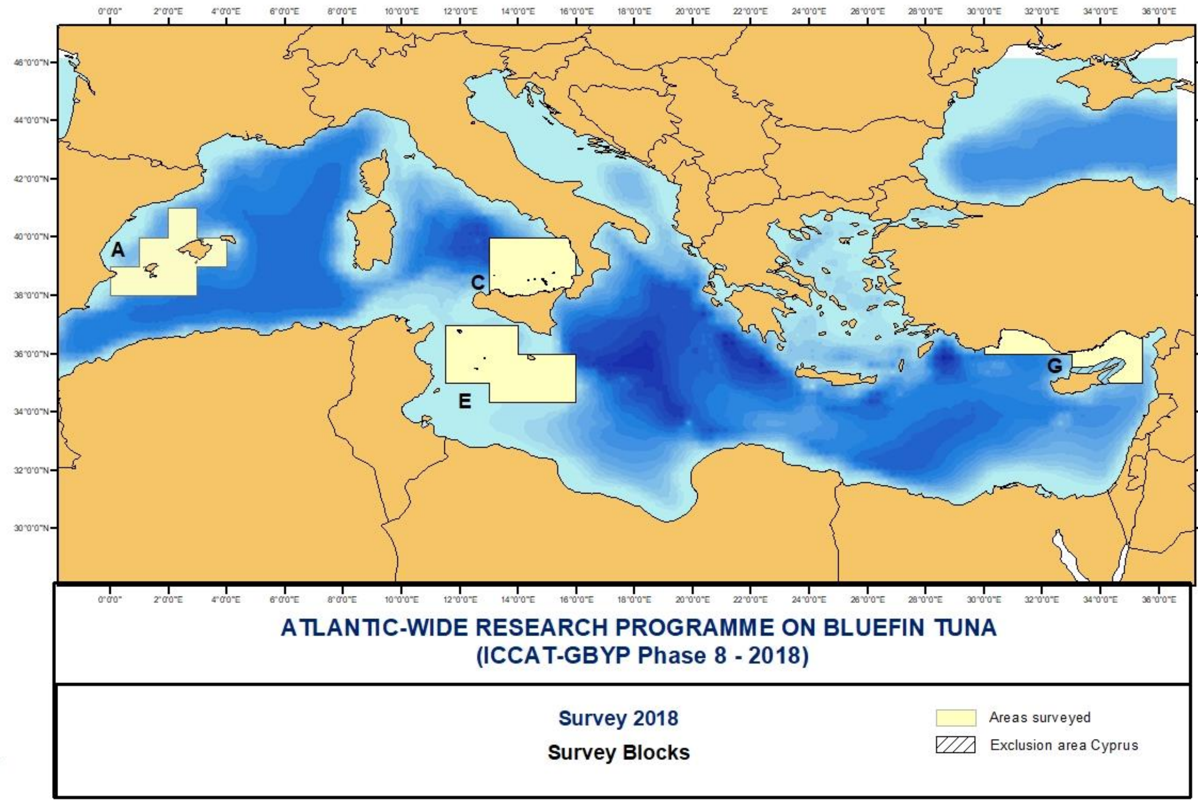

Figure 1. Survey areas in 2018.

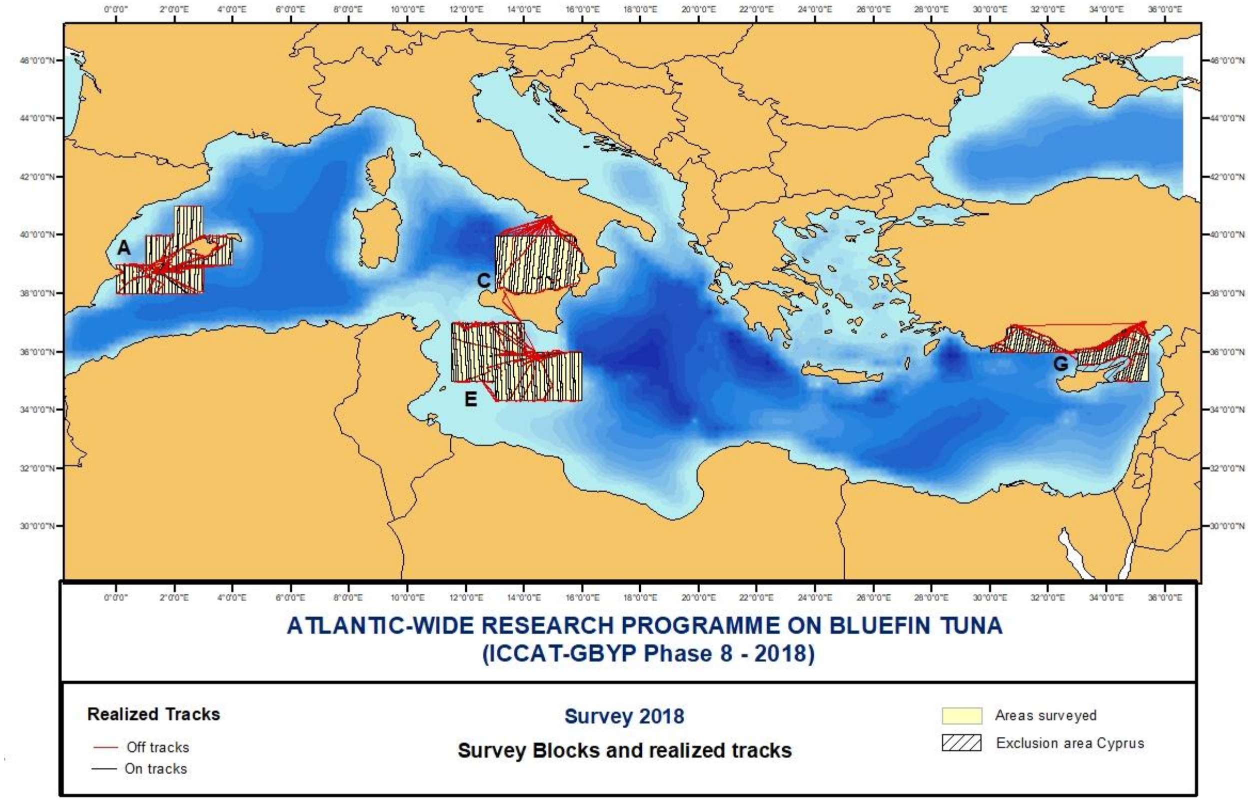

Figure 2. Tracks realized on and off track (on and off effort).

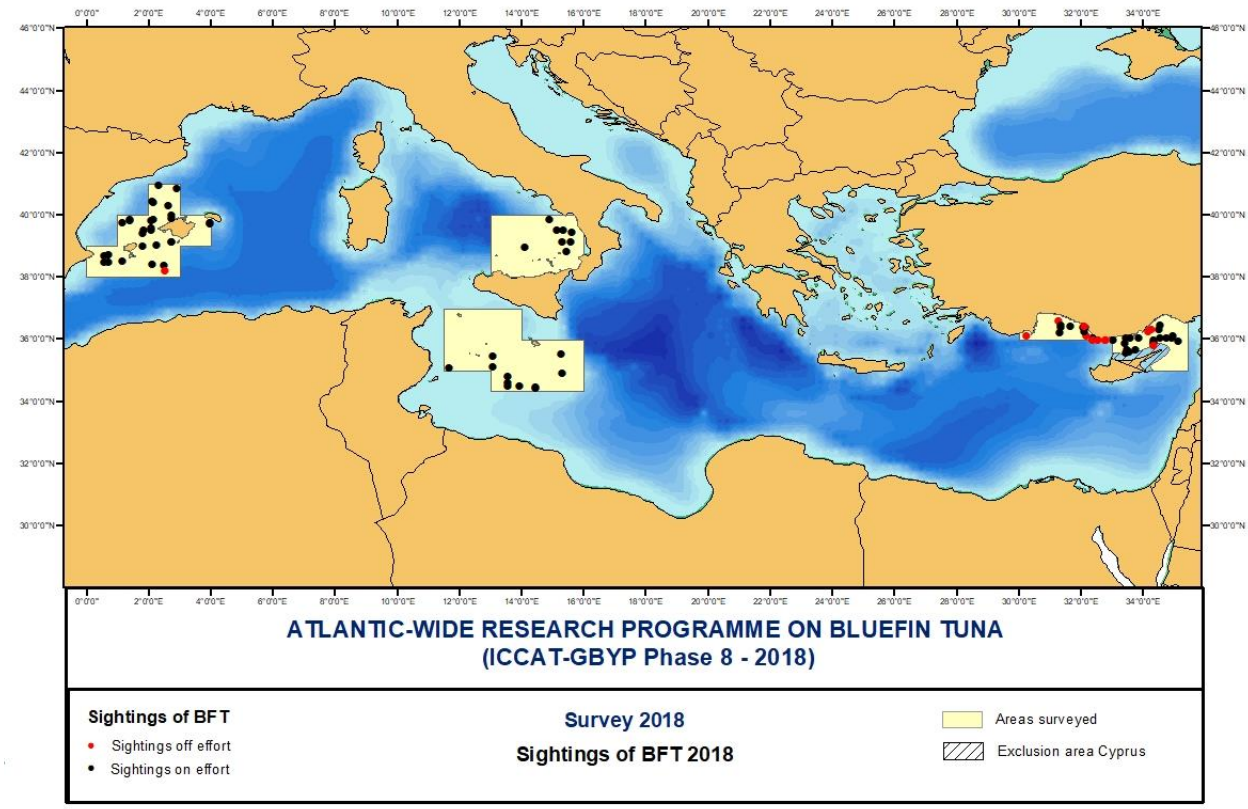

Figure 3. Sightings of Bluefin tuna on and off effort.

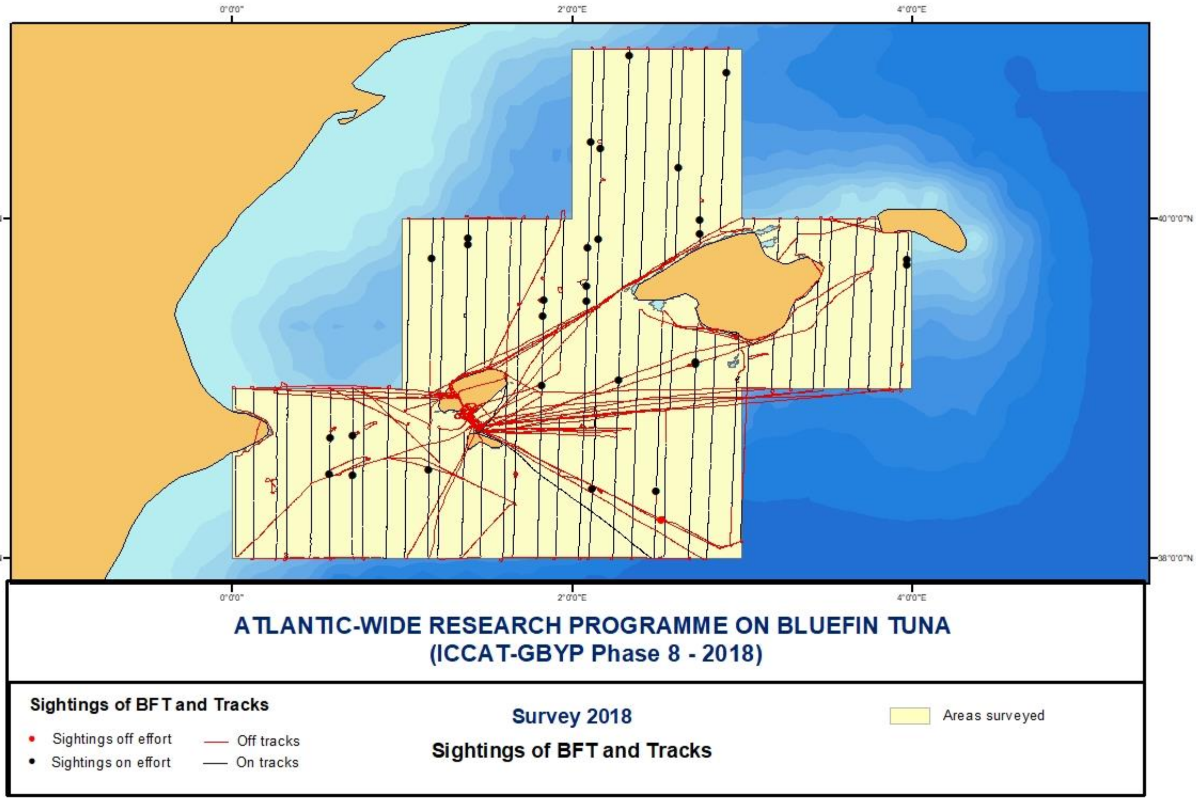

Figure 4. Tracks realized, and sightings of Bluefin tuna on and off effort in sub-area A.

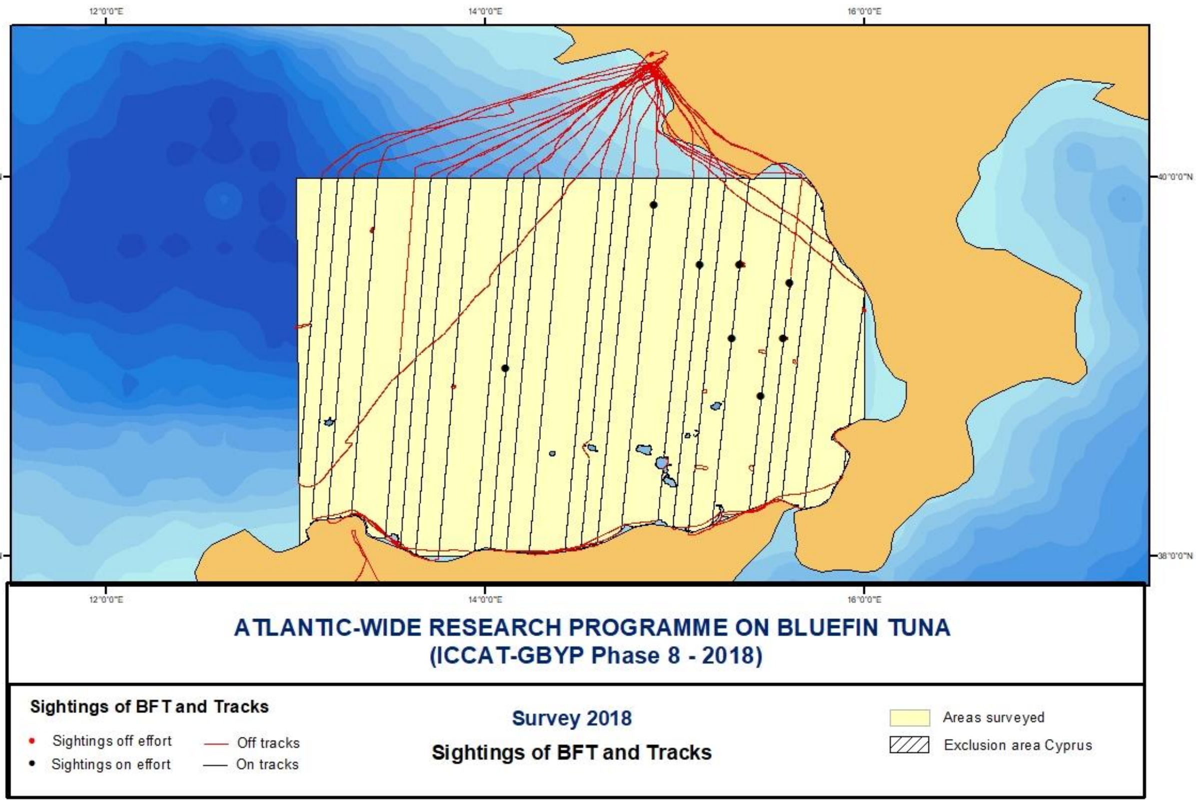

Figure 5. Tracks realized, and sightings of Bluefin tuna on and off effort in sub-area C.

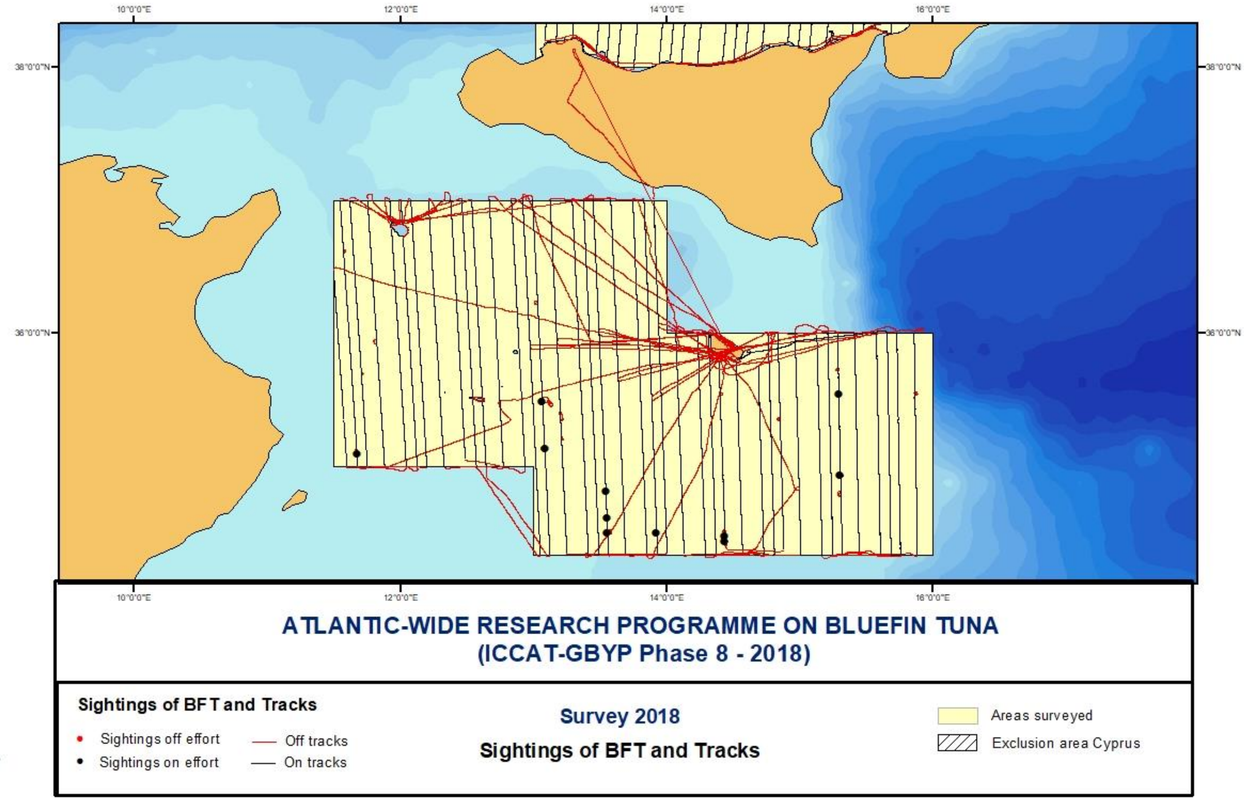

Figure 6. Tracks realized, and sightings of Bluefin tuna on and off effort in sub-area E.

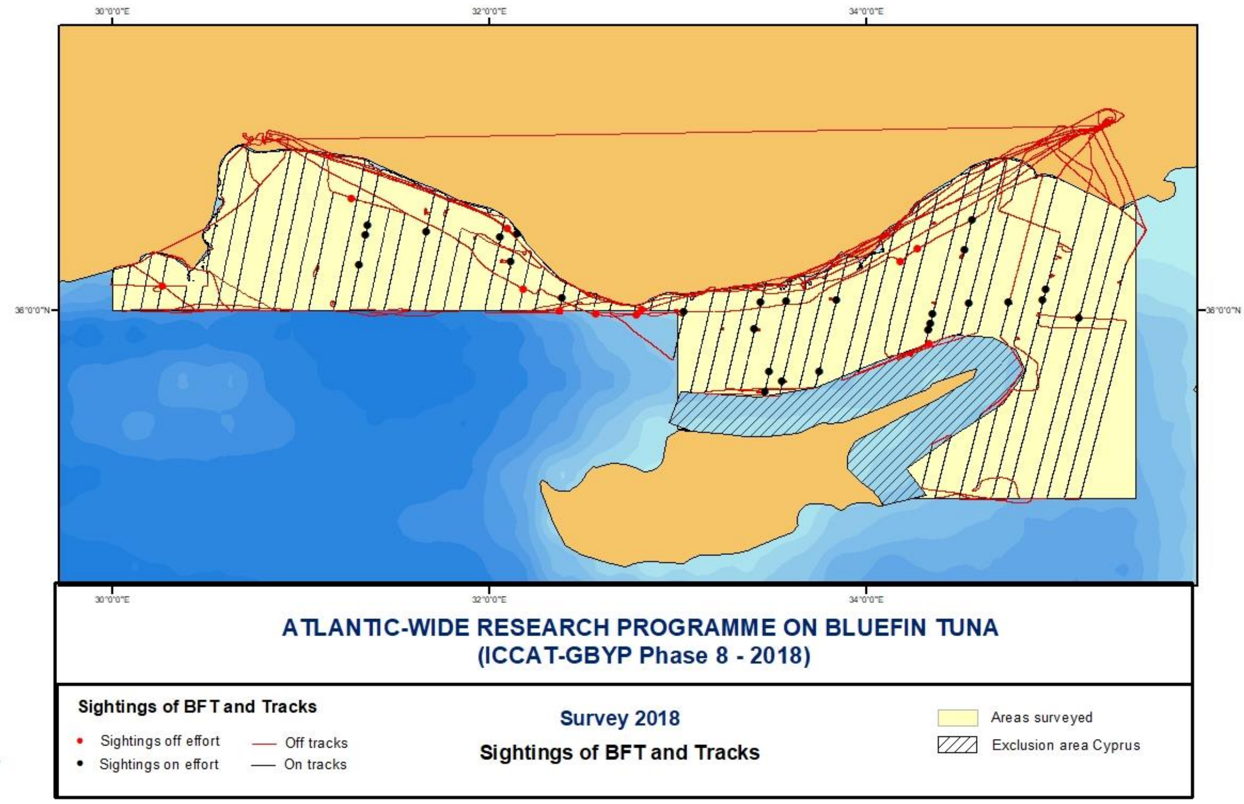

Figure 7. Tracks realized, and sightings of Bluefin tuna on and off effort in sub-area G.

Data processing

This year, as in 2017, data were delivered from each area on a weekly basis, and immediately processed and checked to find any potential problem in the data collection or data recording. Small issues arose in some areas some weeks, but they were all easily detected (as only one week of data had to be checked each time), consulted with the responsible teams, and solved. This proved to be a very useful approach to real-time process and check of the data, to solve problems quickly and avoid repeating them during the following weeks.

The data on school size were recorded in two ways: estimated number of animals in the school, and estimated total weight in tons of the school. Both were used as a measure of school size in analysis, performing two analyses for each sub-area to consider both measures of school size.

Sightings made while the aircraft was transiting to and from the survey area or between transects were labelled as “off effort”. They were used to estimate the detection function, but not to estimate abundance.

Perpendicular distances

Perpendicular distance was estimated in two ways: a) with the declination angles; and b) in Geographic Information System (GIS) using the circling over the schools.

The procedure followed to estimate perpendicular distances with GIS using GPS tracks was the same as explained in Cañadas & Vazquez (2016). ArcGIS software was used to estimate perpendicular distances based on spatial measurements. Each GPS data set was plotted on a map covering the study area together with the BFT sightings recorded in that area. Perpendicular distances were estimated measuring the length between the centre of the contiguous circles made by the airplane while flying over the BFT to obtain school size and weight estimates, and the direction of flight in a straight line.

Out of 87 sightings of BFT in 2018, 82 had distances estimated with the inclinometer and 46 had perpendicular distances estimated with GIS from the circling (including 4 of the 5 sightings with missing distance from the inclinometer). In 41 of the 87 BFT sightings it was not possible to estimate perpendicular distances with GIS, mainly because the circles were not concentric so it was not possible to identify a clear point to measure and in those cases where the group size was not big enough so there was risk of losing it once leaving the transect if a circle was attempted.

Unfortunately, as observed in the analysis done in previous years, the differences between the values obtained by GIS and using declination angle are very unequal and with no apparent tendency. Figure 8 shows a scatterplot with the perpendicular distances estimated from the angle in the X axis and the perpendicular distances estimated with GIS on the Y axis, for those sightings with both data. The red line represents the “perfect match” of equal distances from both methods. The blue line represents the actual trend line from the data.

The recommendation of the cruise leader of area A was to use the GIS values for the BFT sightings detected by the professional spotter because it was complicated to estimate precise angles before leaving the transect (mainly in the further distances), and to use the declination angle values for the BFT sightings detected by the scientific spotter. In the rest of the areas, although there is no clear recommendation from the cruise leader, it would be logic to use the same criteria. Therefore, the following steps or criteria were followed: 1- When the values of the column “Abeam” in the excel files were N (the angle was not taken when abeam), the GIS position was used; 2- For all the sightings by professional spotter, the GIS distances were used (unless there were none in which case the angle was used); 3- For all the sightings by scientific spotter, the angle was used; and 4- in case of doubt, the data were revised in detail and the expert criteria was used.

A combined dataset was created that was consistent across all data fields, with the selected perpendicular distance for each sighting. This dataset was entered into software DISTANCE for analysis.

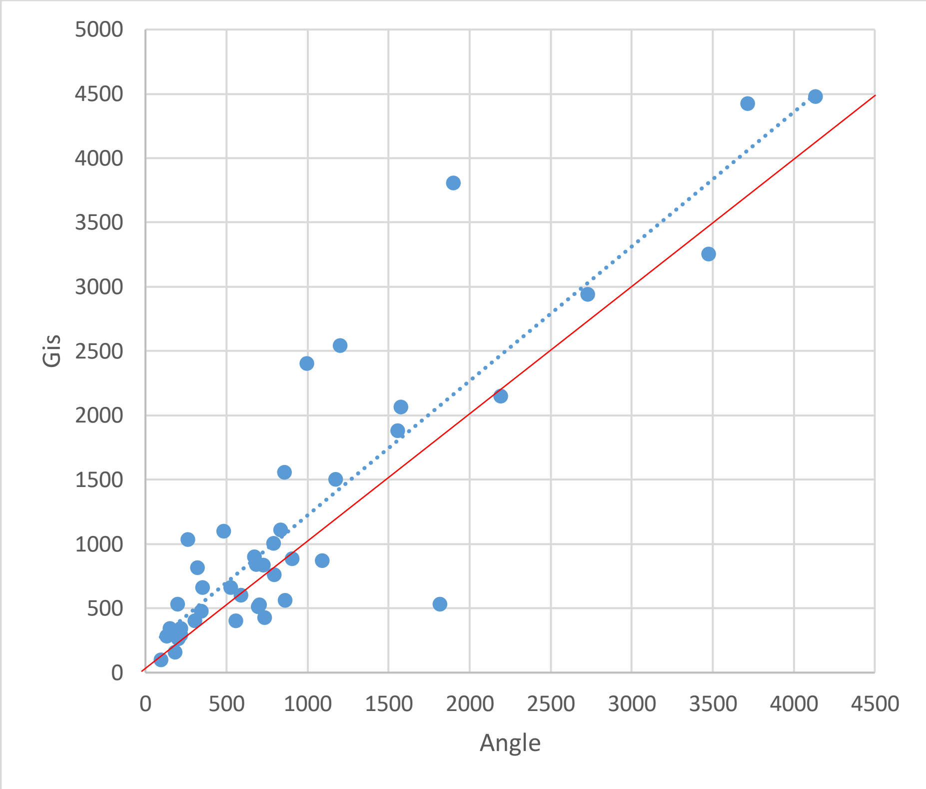

Figure 8. Scatterplot of pairs of distances from the angle and GIS for BFT tuna

Data analysis

Analysis of the data followed standard line transect methodology (Buckland *et al.* 2001).

Density of schools was estimated from the number of schools sighted, the length of transect searched and the estimated *esw* (reciprocal of the probability of detecting a school within a strip defined by the data). The equation that relates density to the collected data is:

$$\hat{D} = \frac{n\,\bar{s}}{2\,esw\,L}$$

where $\widehat{D}$ is density (the hat indicates an estimated quantity), n is the number of separate sightings of schools, $\bar{s}$ is mean school size (see below), L is the total length of transect searched, and *esw* is the estimated effective strip half-width. The quantity 2 *esw* L is thus the area of the strip that has been searched. The effective strip half-width is estimated from the perpendicular distance data for all the detected animals. It is effectively the width at which the number of animals detected outside the strip equals the number of animals missed inside the strip, assuming that everything is seen at a perpendicular distance of zero. To calculate the effective strip half-width, we fitted a detection function (see below and Buckland *et al.* 2001 for further details).

Abundance was estimated as:

$$\hat{N} = A\,\hat{D}$$

where A is the size of the survey area.

Because school size was measured in tonnes in one of the analysis, the final estimate of abundance is the total estimated weight of tunas in the surveyed areas in that case.

All analysis was undertaken in software DISTANCE http://www.ruwpa.st-and.ac.uk/distance/, which estimates all quantities and their uncertainties.

Fitting the detection function

Given the large amount of sightings "off effort", a two steps process was followed: (a) a detection function was fitted to all sightings, on and off effort; and (b) an estimate of abundance was obtained using the fitted detection function but applied only to data on effort. To do this, the MRDS (Mark-recapture distance sampling) engine in DISTANCE was used with the configuration of "single observer".

Detection functions were fitted to the perpendicular distance data to estimate the effective strip half-width, *esw*. Multi-Covariate Distance Sampling (MCDS) methods, within the MRDS engine, were used to allow detection probability to be modelled as a function of covariates additional to perpendicular distance from the transect line. These covariates were defined in the survey design phase and included sea state, air haziness, water turbidity, glare, subjective (a factor indicating whether the sighting conditions were good, moderate or poor), observers searching and cue. **Table 1** shows the covariates tested in the models.

Table 1. Covariates tested in the models and their ranges or factor levels

Covariate	Type	Levels
Sighting related		
Cue2	factor	jump ripples splash underwater other
School size class	factor	1-20 21-100 101-500 501-2000 2001-5000
Observer Type	factor	SS – Scientific spotter PS – Professional spotter
Effort related		
Beaufort sea state	factor	0 (calm) 1 (very light) 2 (light breeze) 2.5 (isolated whitecaps) 3 (gentle breeze) 4 (moderate breeze)
Air haziness	factor	0 (clear) 1 (slight) 2 (moderate) 3 (diffused) 4 (heavy)
Water turbidity	factor	0 (clear) 1 (moderately clear) 2 (moderately turbid) 3 (turbid)
Observer level	factor	17 levels

Team	factor	AirMed ActionAir Unimar
Block	factor	A C E G
Airplane	factor	Cessna Partenavia
Glare intensity	factor	0 (null) 1 (slight) 2 (moderate) 3 (strong)
Glare 30	factor	Same as Glare intensity but only considering 30º each side of abeam (60º-120º / 240º-300º)

A detection function could not be done for each area independently because of insufficient sample size in most of the areas to perform a robust independent analysis. Instead, a single detection function was estimated, post-stratified by areas in the analysis.

It is common practice to right truncate perpendicular distance data to eliminate sightings at large distances that have no influence on the fit of the detection function close to the transect line (the quantity of interest) but may adversely affect the fit. After initial exploration of the data, 3500m right truncation distance was chosen, removing the furthest four sightings, and therefore leaving 78 on/off sightings for the detection function, out of a total of 82 useful sightings (with both perpendicular distance and group size).

Model diagnostics and selection

The best functional form (Half Normal or Hazard Rate model) of the detection function and the covariates retained by the best fitting models were selected based on model fitting diagnostics: AIC, goodness of fit tests, Q-Q plots, and inspection of plots of fitted functions.

Q-Q plots (quantile-quantile plots) compare the distribution of two variables; if they follow the same distribution, a plot of the quantiles of the first variable against the quantiles of the second should follow a straight line. To compare the fit of a detection function model to the data, we used a Q-Q plot of the fitted cumulative distribution function (cdf) against the empirical distribution function (edf).

For goodness of fit tests, we used the Kolmogorov-Smirnov statistic (a goodness of fit test that focuses on the largest difference between the cdf and the edf), Cramer-von Mises statistics (that focus on the sum of squared differences between cdf and edf) and the Chi-square goodness of fit statistic (that compares observed with expected frequencies of observations in each selected range of perpendicular distances).

Data exploration and comparison of searching patterns

Comparison among areas and observer types

In order to explore the potential differences of searching patterns among the different areas and the observer type (Professional o Scientific spotter) within each area, separate detection functions were fitted for each area in 2018, using observer type as only covariate in each of them.

Results on searching patterns

Figures 9 to 11 show the detection functions for each area (same truncation distance of 3500m for each one), the factor level PS (professional spotter) in the detection function of each area, and the factor level SS (scientific spotter) in the detection function of each area, respectively. For areas E and G it was not possible to use the covariate Observer Type as it returned error (no convergence), so they were fitted (just to see the histogram, due to the small sample size) for each observer type independently. In area A there was one sighting made by the Pilot, which was put together with PS. In area G there were 4 sightings made by the National Observer, which were put together with the SS.

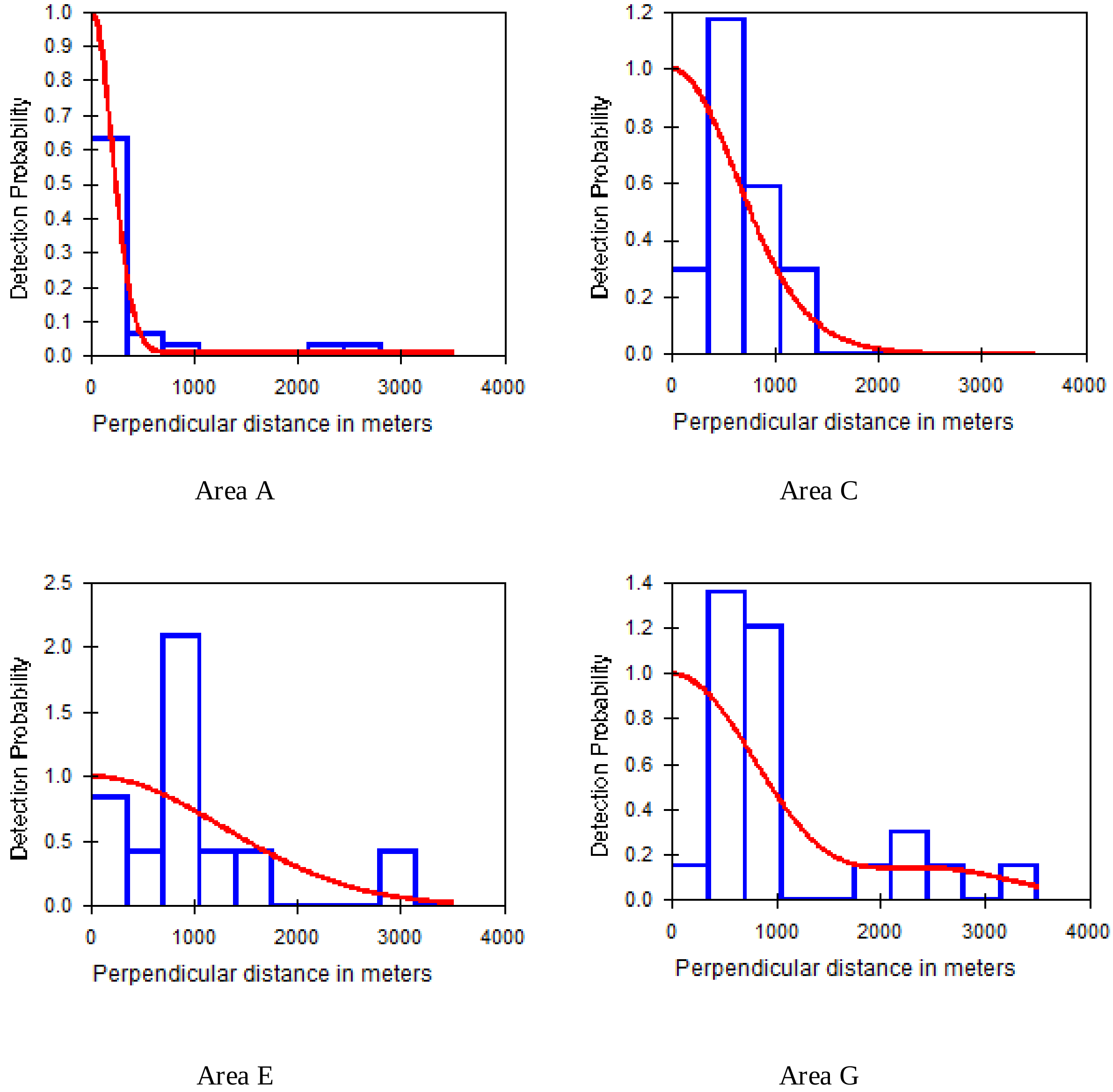

Figure 9. Detection functions for each area

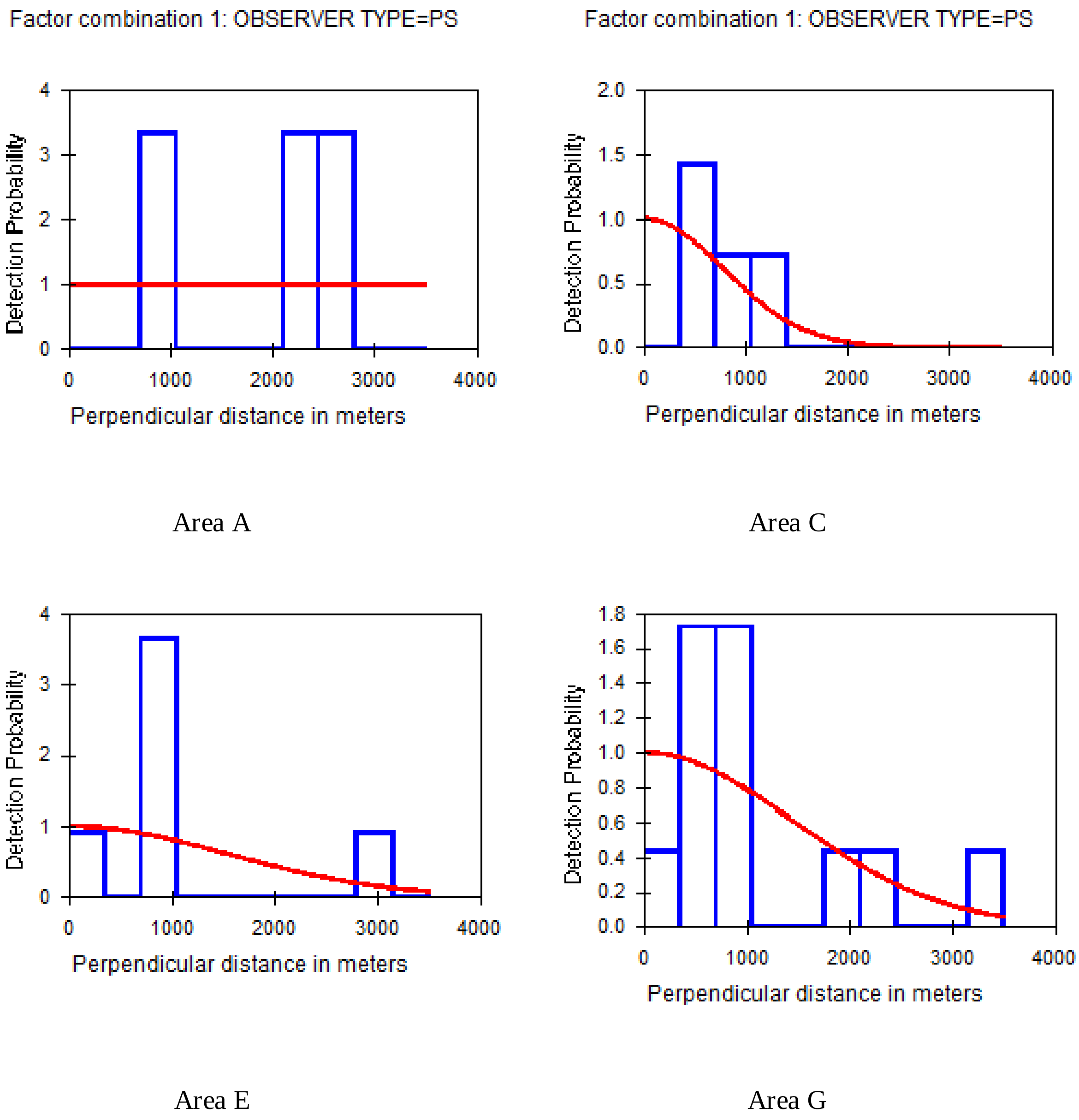

Figure 10. Detection functions for each area. Factor level: PS (Professional spotters).

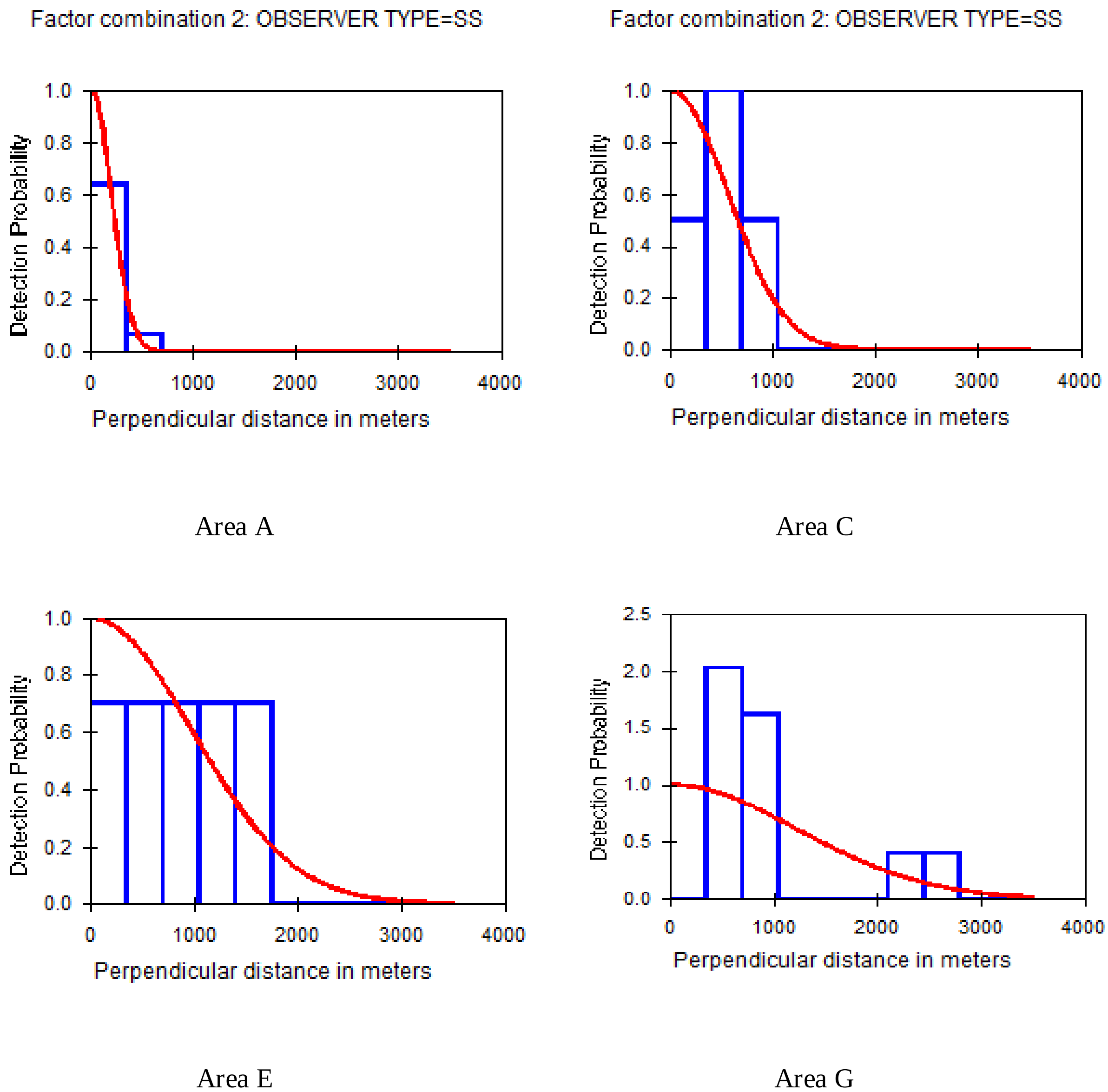

Figure 11. Detection functions for each area. Factor level: SS (Scientific spotters)

Table 2 shows the number of observations of BFT available for the detection function (with data on perpendicular distances and size), and their mean perpendicular distances for each area and observer type (in brackets the maximum distance registered within the truncation distance).

Table 2. Number of sightings used for fitting the detection function

	Number of sightings			Mean perpendicular distance (m)		
Area	**PS**	**SS**	**Total**	**PS**	**SS**	**Total**
A	5	21	26	1535 (2545)	159 (447)	424
C	4	4	8	753 (1102)	527 (789)	640
E	6	5	11	1156 (3016)	852 (1574)	1018
G	20	14	34	954 (3254)	930 (2728)	944
Total	**35**	**44**	**79**	**1049**	**517**	**752**

Results on data analysis

Table 3 shows the surface area of each survey sub-area, the number and length of searched transects and the number of sightings of Bluefin tuna schools used for analysis.

Table 3. Areas, total length of transects and number of sightings of Bluefin tuna for each surveyed sub-area.

Sub-area	Area (km^2)	Length of transects on effort (km)	Number of observations (after truncation) Detection Function	Number of observations (after truncation) Abundance estimate
A	61,849	5560	26	25
C	51,777	4832	8	8
E	90,097	8933	11	11
G	38,801	3983	34	23
Total	242,523	23,308	79	67

The detection functions either using weight or number of animals as school size are identical, and the only thing changing is the final estimate provided. Therefore, we refer to it here as "the detection function", even if it was performed twice.

The final model of detection function selected had two covariates (Team and Observer Type) with a Hazard-rate key function. There was a model with the lowest AIC which had also two covariates (cue2 and Block) with a Hazard-rate key function. However, all diagnostics were better for selected model and the CV of the estimate was lower. Therefore, the model with Team and Observer Type was chosen. The Cramer-von Mises test performed very well and overall there were no significant differences between the cdf and the edf. The Kolmogorov-Smirnov test, however, did not perform very well in any of the models, probably due to small sample size. The q-q plot showed a moderately good agreement between the cdf and the edf. **Table**

4 shows the main parameters for the detection function and the results of the diagnostics tests. **Figure 12** shows the fitted detection function and **Figure 13** shows the Q-Q plot.

Table 4. Parameters and diagnostics of the detection function.

Average probability of detection (p)	CV probability of detection	Effective strip width (esw) (m)	Chi-square test (p)	Cramer-von Mises test (unweighted) (p)
0.2045	17.32%	715	0.0033	0.167

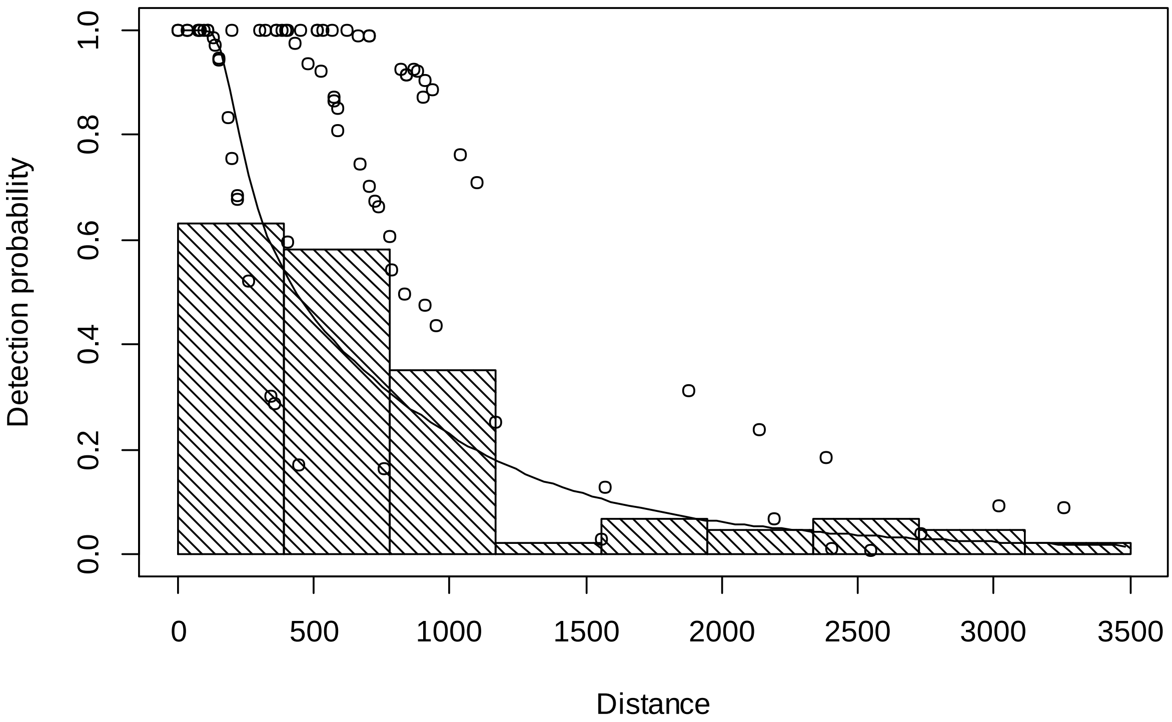

Figure 12. Detection function, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings.

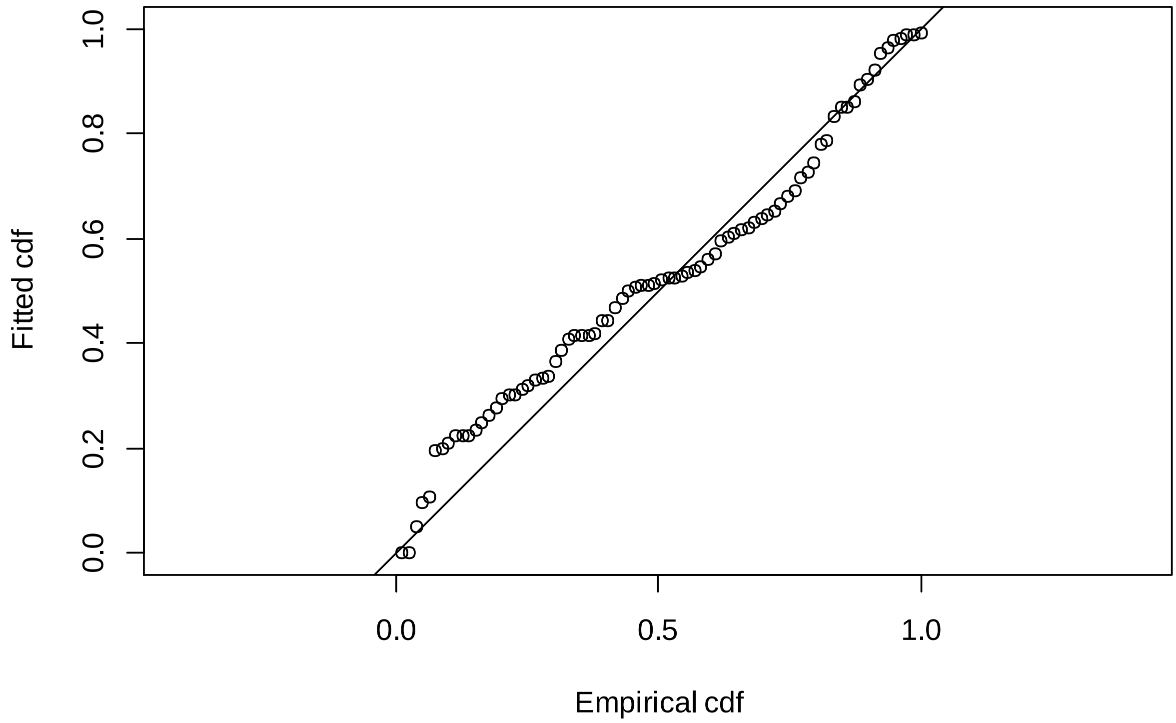

Figure 13. Q-Q plot.

Table 5 shows the estimates of density of schools, number of individuals and total weight of Bluefin tuna in each sub-area.

Table 5. Mean school size, density and total weight and abundance of Bluefin tuna for each subarea in 2018. All data is for on effort-observations.

Area	**A**	**C**	**E**	**G**	**Total (sum)**	**Total (mean)**
Survey area (km^2)	61,933	53,868	93,614	47,719	257,135	
Transect length (km)	5,560	4,832	8,933	3,984	23,308	
Effective strip width x2 (km)	1.43	1.43	1.43	1.43		1.43
Area searched (km^2)	7,959	6,917	12,788	5,702	33,365	
% coverage	12.9	12.8	13.7	11.9		13.0
Number of schools ON effort	25	8	11	23	67	
Abundance of schools	384	36	45	103	568	
%CV abundance of schools	30.6	45.6	41.2	30.7	22.5	
Encounter rate of schools	0.0045	0.0017	0.0012	0.0058		0.0029
%CV encounter rate	20.8	36.3	30.9	23.0		13.6
Density of schools (1000 km^{-2})	6.198	0.660	0.481	2.163		2.208
%CV density of schools	30.6	45.6	41.2	30.7		22.5
Mean weight (t)	98.6	140.8	97.0	6.9		84.5
%CV weight	28.4	58.8	26.1	46.6		24.4
Mean cluster size (animals)	663	1,222	1,013	208		643
%CV abundance	23.9	39.9	24.8	39.3		18.5
Density of animals (km^{-2})	4.110	0.807	0.487	0.450		**1.420**
%CV density of animals	37.2	62.8	46.1	48.5		28.4
Total weight (t)	**37,861**	**5,007**	**4,369**	**709**	**47,946**	
%CV total weight	40.3	74.9	47.3	53.1	33.4	
L 95% CI total weight	17,658	1,317	1,798	365	25,283	
U 95% CI total weight	81,183	19,040	10,613	1,897	90,921	
Total abundance (animals)	**254,552**	**43,466**	**45,600**	**21,474**	**365,091**	
%CV total abundance	37.2	62.8	46.1	48.5	28.4	
L 95% CI total abundance	125,322	13,998	19,214	8,092	211,128	
U 95% CI total abundance	517,039	140,079	107,869	51,779	631,334	

Overall, a total of 47,946 (CV = 33.4%) tonnes and 365,091 (CV = 28.4%) individuals of Bluefin tuna were estimated in all the spawning sub-areas together.

Comparison with previous estimates

Tables 6 to 9 show a comparison between the estimates in 2010, 2011, 2013, 2015, 2017 and 2018 for each area. Table 9 shows the same comparison for all areas combined.

Table 6. Results for all surveys in overlap area A

Year	**2010**	**2011**	**2013**	**2015**	**2017**	**2018**	**Total (sum)**	**Total (mean)**
Survey area (km^2)	61,933	61,933	61,933	61,933	61,933	61,933		61,933
Transect length (km)	6,118	7,838	6,807	4,109	4,981	5,560	35,412	5,902
Effective strip width x2 (km)	2.96	1.36	3.0	3.9	2.9	1.4		
Area searched (km^2)	18,130	10,660	20,398	15,961	14,369	7,959	87,477	14,580
% coverage	29.3	17.2	32.9	25.8	23.2	12.9		23.5
Number of schools ON effort	8	10	10	6	22	25	81	13.5
Abundance of schools	25	58	30	23	95	384		103
%CV abundance of schools	55.4	35.9	36.1	43.4	30.8	30.6		
Encounter rate of schools	0.0013	0.0013	0.0015	0.0014	0.0044	0.0045		0.0023
%CV encounter rate	54.5	33.8	35.1	41.1	25.9	20.8		
Density of schools (1000 km^{-2})	0.402	0.938	0.490	0.372	1.531	6.198		1.655
%CV density of schools	55.4	35.9	36.1	43.4	30.8	30.6		
Mean weight (t)	131.25	122.43	194.1	160.7	133.9	98.6		140.158
%CV weight	6.2	19.2	23.8	11.7	34.9	28.4		
Mean cluster size (animals)		678.1	611	825	754	663		706
%CV abundance		27.9	26.0	11.0	33.6	23.9		
Density of animals (km^{-2})		0.636	0.299	0.307	1.155	4.110		1.301
%CV density of animals		45.4	44.5	44.7	39.7	37.2		
Total weight (t)	**3,587**	**4,371**	**3,539**	**4,712**	**12,693**	**37,861**		**11,127**
%CV total weight	56.5	46.2	40.6	42.0	40.9	40.3		
L 95% CI total weight	1,251	1,807	1,624	2,132	5,848	17,658		
U 95% CI total weight	10,285	10,577	7,710	10,414	27,551	81,183		
Total abundance (animals)		**39,399**	**18,542**	**19,002**	**71,520**	**254,552**		**80,603**
%CV total abundance		45.4	44.5	44.7	39.7	37.2		
L 95% CI total abundance		16,540	7,913	8,195	33,620	125,322		
U 95% CI total abundance		93,850	43,445	44,060	152,141	517,039		

Table 7. Results for all surveys in overlap area C

Year	**2010**	**2011**	**2013**	**2015**	**2017**	**2018**	**Total (sum)**	**Total (mean)**
Survey area (km^2)	53,868	53,868	53,868	53,868	53,868	53,868		53,868
Transect length (km)	8,487	8,826	2,791	2,739	4,911	4,832	32,586	5,431
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	2.9	1.4		
Area searched (km^2)	25,150	12,004	8,364	10,640	14,242	6,917	77,316	12,886
% coverage	46.7	22.3	15.5	19.8	26.4	12.8		23.9
Number of schools ON effort	6	10	10	3	15	8	52	8.7
Abundance of schools	12	45	64	13	57	36		38
%CV abundance of schools	45.7	33.4	34.3	62.0	28.8	45.6		
Encounter rate of schools	0.0007	0.0011	0.0036	0.0009	0.0031	0.0017		0.0016
%CV encounter rate	44.6	31.2	33.1	60.5	23.6	36.3		
Density of schools (1000 km^{-2})	0.217	0.833	1.196	0.239	1.058	0.660		0.701
%CV density of schools	45.7	33.4	34.3	62.0	28.8	45.6		
Mean weight (t)	124.17	38.87	173.5	190.0	202.5	140.8		144.967
%CV weight	5.6	44.4	22.1	19.9	21.9	58.8		
Mean cluster size (animals)	733	291	1,285	1,533	1,453	1,222		1,086
%CV cluster size	36.5	30.7	17.0	19.0	17.2	39.9		
Density of animals (km^{-2})	0.182	0.242	1.536	0.366	1.539	0.807		0.779
%CV density of animals	59.2	45.3	38.3	64.9	33.3	62.8		
Total weight (t)	**1,596**	**1917**	**11,370**	**2,665**	**11,547**	**5,007**		**4,387**
%CV total weight	46.9	54.9	40.8	65.1	35.5	74.9		
L 95% CI total weight	652	661	5,161	802	5,829	1,317		
U 95% CI total weight	3,904	5,557	25,049	8,856	22,874	19,040		
Total abundance (animals)	**9,797**	**13,059**	**82,763**	**19,708**	**82,886**	**43,466**		**41,947**
%CV total abundance	59.2	45.3	38.3	64.9	33.3	62.8		
L 95% CI total abundance	3,187	5,446	39,399	5,958	43,597	13,998		
U 95% CI total abundance	30,016	31,317	173,860	65,192	157,580	140,079		

Table 8. Results for all surveys in overlap area E

Year	**2010**	**2011**	**2013**	**2015**	**2017**	**2018**	**Total (sum)**	**Total (mean)**
Survey area (km^2)	93,614	93,614	93,614	93,614	93,614	93,614		93,614
Transect length (km)	13,137	10,192	4,381	2,566	6,705	8,933	45,914	7,652
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	2.9	1.4		
Area searched (km^2)	38,930	13,862	13,129	9,969	19,445	12,788	108,121	18,020
% coverage	41.6	14.8	14.0	10.6	20.8	13.7		19.2
Number of schools ON effort	29	45	20	3	9	11	117	19.5
Abundance of schools	63	304	135	20	44	45		102
%CV abundance of schools	31.5	24.1	34.8	58.0	36.4	41.2		
Encounter rate of schools	0.0022	0.0044	0.0046	0.0008	0.0013	0.0012		0.0025
%CV encounter rate	29.9	21.0	33.6	56.3	32.4	30.9		
Density of schools (1000 km^{-2})	0.678	3.246	1.447	0.213	0.466	0.481		1.088
%CV density of schools	31.5	24.1	34.8	58.0	36.4	41.2		
Mean weight (t)	110.14	118.05	11.0	50.2	102.3	97.0		81.452
%CV weight	33.9	19.2	66.0	99.5	51.2	26.1		
Mean cluster size (animals)	1,015	1,715	361	507	848	1,013		910
%CV cluster size	19.0	21.5	67.3	97.9	33.2	24.8		
Density of animals (km^{-2})	0.787	5.566	0.522	0.108	0.395	0.487		1.311
%CV density of animals	37.8	32.3	75.7	113.8	49.9	46.1		
Total weight (t)	**7,681**	**37,851**	**1,517**	**1,093**	**4,457**	**4,369**		**9,495**
%CV total weight	47.1	32.2	74.6	115.2	63.4	47.3		
L 95% CI total weight	3,155	20,342	390	75	1,413	1,798		
U 95% CI total weight	18,698	70,432	5,899	15,857	14,062	10,613		
Total abundance (animals)	**73,676**	**521,085**	**48,884**	**10,126**	**36,927**	**45,600**		**122,716**
%CV total abundance	37.8	32.3	75.7	113.8	49.9	46.1		
L 95% CI total abundance	35,741	279,620	12,363	727	14,559	19,214		
U 95% CI total abundance	151,880	971,060	193,280	141,020	93,662	107,869		

Table 9. Results for all surveys in overlap area G

Year	**2010**	**2011**	**2013**	**2015**	**2017**	**2018**	**Total (sum)**	**Total (mean)**
Survey area (km^2)	56,211		56,211	56,211	56,211	47,719		56,211
Transect length (km)	3,790		2,081	859	4,581	3,983	15,295	3,059
Effective strip width x2 (km)	2.96		3.00	3.9	2.9	1.4		
Area searched (km^2)	11,231		6,236	3,335	13,215	5,702	39,789	7,958
% coverage	20.0		11.1	5.9	23.5	11.9		14.5
Number of schools ON effort	33		12	2	45	23	115	23
Abundance of schools	150		108	22	191	103		115
%CV abundance of schools	28.1		39.7	70.9	23.5	30.7		
Encounter rate of schools	0.0087		0.0058	0.0015	0.0098	0.0058		0.0075
%CV encounter rate	26.3		38.7	69.5	16.6	23.0		
Density of schools (1000 km^{-2})	2.674		1.924	0.399	3.398	2.163		2.111
%CV density of schools	28.1		39.7	70.9	23.5	30.7		
Mean weight (t)	63.621		4.0	9.0	16.5	6.9		19.996
%CV weight	12.7		40.2	66.7	31.5	46.6		
Mean cluster size (animals)			336	600	809	208		488
%CV cluster size			36.7	66.7	31.9	39.3		
Density of animals (km^{-2})			0.646	0.239	2.756	0.450		1.023
%CV density of animals			54.1	97.3	40.1	48.5		
Total weight (t)	**10,507**		**440**	**220**	**3,157**	**709**		**3,007**
%CV total weight	32.1		56.5	97.3	39.3	53.1		
L 95% CI total weight	5,643		151	25	1,495	365		
U 95% CI total weight	19,561		1,285	1,965	6,669	1,897		
Total abundance (animals)			**36,316**	**13,448**	**154,939**	**21,474**		**56,544**
%CV total abundance			54.1	97.3	40.1	48.5		
L 95% CI total abundance			12,995	1,506	72,366	8,092		
U 95% CI total abundance			101,490	120,070	331,731	51,779		

Table 10. Results for all surveys in all areas combined

Year	2010	2011	2013	2015	2017	2018	Total (sum)	Total (mean)
Survey area (km^2)	265,627	209,416	265,627	265,627	265,627	257,135		265,627
Transect length (km)	31,532	26,856	16,060	10,272	21,178	23,308	129,206	21,534
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	2.9	1.4		2.6
Area searched (km^2)	93,442	36,525	48,127	39,904	61,096	33,365	334,307	52.08
% coverage	35.2	17.4	18.1	15.0	23.0	13.0		20.3
Number of schools ON effort	76	65	52	14	91	67	365	60.8
Abundance of schools	250	388	338	78	387	568		335
%CV abundance of schools	22.8	19.9	21.5	38.9	20.2	22.5		
Encounter rate of schools	0.0024	0.0024	0.0032	0.0014	0.0043	0.0029		0.0028
%CV encounter rate				20.2	11.6	13.6		
Density of schools (1000 km^{-2})	0.942	1.852	1.274	0.295	1.457	2.208		1.261
%CV density of schools	22.8	19.9	21.5	38.9	23.4	22.5		
Mean weight (t)	87.9	101.1	22.6	272.2	82.3	84.5		**108.420**
%CV weight	16.8	27.5	51.0	41.4	19.2	24.4		
Mean cluster size (animals)	791	1,275	582	1,548	895	643		**956**
%CV cluster size	18.6	37.3	18.5	40.5	17.0	18.5		
Density of animals (km^{-2})		**2.7388**	**0.702**	**0.234**	**1.304**	1.420		**1.161**
%CV density of animals		29.9	29.4	39.1	25.9	28.4		
Total weight (t)	**23,371**	**44,139**	**16,866**	**8,690**	**31,855**	**47,946**		**28,811**
%CV total weight	25.6	28.7	30.3	35.3	26.7	33.4		
L 95% CI total weight	14,243	25,315	9,343	4,398	19,018	25,283		
U 95% CI total weight	38,347	76,964	30,447	17,169	53,355	90,921		
Total abundance (animals)		**573,543**	**186,505**	**62,284**	**346,272**	**365,091**		**269,528**
%CV total abundance		29.9	29.4	39.1	25.9	28.4		
L 95% CI total abundance		321,620	105,320	28,766	209,816	211,128		
U 95% CI total abundance		1,022,800	330,270	134,860	571,473	631,334		

Discussion

Survey logistics

The survey design generally worked very well, and homogeneous coverage was achieved in all areas despite some temporally disruptions or delays due to exclusion of areas due to military/political reasons.

Data collection worked much better than in previous surveys and it seems to be improving from year to year. The weekly review of the data collected helped in great deal to detect small issues at an early stage and correct them for the rest of the survey.

However, the problem of observers searching too far away and not that much close to the transect, especially PS (in all areas) and sometimes SS (especially in areas C and G and to lesser extent E), persist after making strong recommendations each year to do it properly, i.e. most of the searching effort closer to the transect and much less further away. This is a problem that prevents the fit of a good detection function and forces in some cases to truncate the furthest sightings, decreasing the sample size to estimate abundance and therefore increasing the CV.

Precision of estimates

The CV of abundance is determined by the CVs of estimated density of schools and mean school sizes in each sub-area. The CV of estimated density of schools is determined by the CVs of encounter rate (number of schools seen per survey km) and effective strip half width (*esw*). All of these quantities are functions of the number of schools seen, as well as the distribution of the data.

CVs for density of schools in all areas varied between 31 % and 46%. The precision of mean school size varied between 24 and 40%. CVs for estimates of mean weight were more variable: 29-59%. Summing over all areas surveyed, the CV of total abundance was 28.6%.

In Table 4 it is obvious that the largest CVs correspond to the area C. This is probably due to the very small number of observations of BFT this year, which has probably increased greatly the variance for the encounter rate (the largest of all areas: 36% compared to 21-31% in the other areas).

The number of schools seen in most of the areas was insufficient to estimate an independent *esw* per area so data from all sub-areas were pooled together. This is acceptable as long as differences in conditions in each area (such as sea state, air haziness, water turbidity, observers) or the differences in searching patterns (team, observer type) can be investigated as a covariate in fitting the detection function. Using the same *esw* for multiple areas generates correlation in the estimates which was taken into account (in software DISTANCE) in estimating the CV of total abundance by stratifying by area.

The main way to reduce the estimated CVs in future surveys is to increase the number of sightings. This can be achieved partly by more efficient searching and partly by increasing the amount of searching effort (transect length). But it is also a consequence of the study year real density of animals. The number of sightings was smaller this year in areas C and G with respect to 2017, which increased considerably the CV of the encounter rate and density of schools in those areas.

However, another component of the overall CV, the mean school size, varies considerably and is relatively independent of sample size. The CV of school size in 2018 was much larger, again, in areas C and G compared with 2017, and the same pattern occurred with the CV of the mean weight. Due to the lower number of sightings, the total CV for abundance of animals and for total weight increased considerably in areas C and G.

Relative estimates of abundance

Line transect sampling assumes that detection on the transect line itself is certain. In aerial surveys, in general, it is not possible to assume this because the speed of flight means that potentially some schools available to be sampled will inevitably not be detected (so-called perception bias), although we believe this bias to be very small for spawning BFT given their usual large group sizes and conspicuous behaviour when spawning. But this cannot be quantified without a double-platform configuration, which is usually difficult and expensive for aerial surveys if done with two airplanes or with airplanes that allow two sets of observers simultaneously. However, it could be potentially possible to quantify with a continuous recording video system installed on the airplane to cover the area closer to the transect line. In addition, tuna spend some of the time beneath the surface and unavailable to be detected (so-called availability bias) when at depth of more than just a few meters, and depending on the distance from the track line (due to the angle of observation and therefore ability to see underwater). The analysis done in 2016 in this regard (Cañadas and Vazquez 2016) showed that the time spent during day time between 10m depth and surface and therefore available for detection can be around 50% average (between 40% and 62%) depending on year and area. Estimates of abundance from these surveys are thus underestimates (minimum estimates). If mini-PATs for Bluefin tuna passing through the areas sampled by the aerial survey in the same period of time were available for 2018, a correction for availability bias could be attempted as in 2016.

The appropriateness of these estimates as indices of abundance for the future depends on a number of factors including: timing of surveys; areas surveyed; stability of availability and perception biases. Perception bias can reasonably be assumed to be stable over time but availability bias may be affected by the sea surface temperature at the time of the survey, and fluctuation of the distribution in time and space of Bluefin tuna throughout the Mediterranean Sea is influenced by environmental factors and the knowledge on the subject is incomplete. To minimise natural variation in using survey estimates as indices of abundance over time, surveys should ideally occur in the same areas at the same time of year.

Comparison with previous estimates

Table 11 shows a comparison of track effort, sightings on effort (after truncation), encounter rate of schools, total estimated weight and total estimated number of animals, between 2018 and the mean of 2010 to 2017, as well as percentage differences with each of the previous five surveys.

Table 11. Comparison between 2018 and the previous surveys. In red those percentages in which the values are smaller in 2018. In black the percentages in which the values are larger in 2018.

	Values		Percentage difference					
Area A	2018	Mean 2010-2017	2010	2011	2013	2015	2017	Mean 2010-2017
Effort	5,560	5,970	9.1	29.1	18.3	26.1	10.4	6.9
Sightings	25	11	68.0	60.0	60.0	76.0	12.0	55.2
ER schools	0.0045	0.0020	70.9	71.6	67.3	67.9	1.8	55.9
Total weight	37,861	5,780	90.5	88.5	90.7	87.6	66.5	84.7
Total animals	254,552	37,116	0.0	84.5	92.7	92.5	71.9	85.4
Area C								
Effort	4,832	5,551	43.1	45.3	42.2	43.3	1.6	12.9
Sightings	8	9	25.0	20.0	20.0	62.5	46.7	9.1
ER schools	0.0017	0.0019	57.3	31.6	53.8	44.0	45.8	12.0
Total weight	5,007	5,819	68.7	62.4	55.2	47.7	55.8	14.0
Total animals	43,466	41,643	77.9	70.5	46.5	55.5	46.6	4.2
Area E								
Effort	8,933	7,396	32.0	12.4	51.0	71.3	24.9	17.2
Sightings	11	21	62.1	75.6	45.0	72.7	18.2	48.1
ER schools	0.0012	0.0027	44.2	72.1	73.0	32.7	8.3	53.9
Total weight	4,369	10,520	43.1	88.5	65.3	75.0	2.0	58.5
Total animals	45,600	138,140	38.2	91.3	6.9	77.8	18.9	67.0
Area G								
Effort	3,983	2,828	4.9		47.8	78.5	13.0	29.0
Sightings	23	23	33.3		45.5	90.9	51.1	0.0
ER schools	0.0058	0.0065	36.6		4.2	72.0	43.8	10.6
Total weight	709	3,581	93.8		32.7	66.4	79.3	80.2
Total animals	21,474	68,234			43.7	34.3	86.8	68.5
All areas								
Effort	23,308	21,180	26.1	13.2	31.1	55.9	9.1	9.1
Sightings	67	60	11.8	3.0	22.4	79.1	26.4	11.0
ER schools	0.0029	0.0027	16.2	15.8	11.2	52.6	33.1	4.5
Total weight	47,946	24,984	51.3	7.9	64.8	81.9	33.6	47.9
Total animals	365,091	250,415	77.1	36.3	48.9	82.9	5.2	31.4

Area A

In Area A there was a bit more effort than in 2015 and 2017 but less than in 2010, 2011 and 2013, although the inter-annual differences are small. Overall, there was 7% less effort in 2018 than the mean effort of 2010 to 2017. However, there was 55% more sightings on effort this year than the mean of the previous 5 years and this was the year with most sightings in Area A so far, even if the effort was lower. All encounter rate, total weight and total number of animals were much higher in 2018 than in the mean and each of the previous years (except encounter rate in 2017), up to 85% increase.

The fact that the encounter rates and final estimates are much higher than the previous years when at the same time there was similar effort in 2018 than the rest of the years, indicates that there was a real increase of BFT in area A in 2018 in respect to the previous 5 years. There was already an important increase in 2017 in comparison to the previous years, but the increment is much larger in 2018 even with respect to 2017.

Area C

In area C, there was approximately half the amount of effort than in 2010 and 2011, but double than in 2013 and 2015 and similar than in 2017. However, the amount of sightings of BFT was similar to the mean of the previous years but much less than in 2017 (for similar amount of effort). The encounter rate of groups, total abundance and total weight are similar to the mean of 2010-2017, but much lower than in 2017 and 2013 taken individually.

Area E

This area had a much smaller number of sightings of BFT in 2015, 2017 and 2018 with respect to 2010, 2011 and 2013, not corresponding exactly to the variations of effort. For example, in 2011 there was only 125 km more of effort than in 2018 but there were 75% more sightings; or in 2018 there was 51% more effort than in 2013 but there were 45% more sightings in 2013. Overall, 2015 was the year with the lowest encounter rate, total weight and total abundance, and 2011 the year with much larger abundance and total weight. 2018 is similar to 2013 in terms of final total abundance but also similar to 2017 in terms of total weight.

Area G

Area G was not surveyed in 2011, and mean school size was not recorded in 2010, so comparisons are more limited than for the other areas. There was 13% less effort and 51% less sightings than in 2017. Overall, there was 29% more effort in 2018 than the mean for 2010-2017, but the same amount of sightings, and much smaller mean weight and school size, resulting in 80% smaller total weight and 68.5% lower abundance than the mean for 2010-2017.

All areas together

Overall, there has been similar amount of effort in 2018 as in the five previous surveys (only 9% more than the mean), and 10% more sightings. The mean weight is 25% smaller than the mean for 2010-2017 (113) and the mean school size is 73% smaller than the mean (1018). The total weight in 2018 is 47% larger than the mean 2010-2017, and the total abundance is 31% larger than the mean for the 5 previous years. However, the total abundance estimate for 2018 (361,995) is very similar to 2017 (346,272), so total abundance has not really changed overall from last year to this one, although distribution has. This year abundance in area A is much higher and in E is much lower than in 2017. Therefore, the distribution pattern may have changed due to environmental conditions that may have affected the timing of the migration.

Given the strong inter-annual and spatial variability in the different components (encounter rate of groups, mean weight and mean school size), there is no clear pattern discerned in weight and/or abundance among years and areas. An understanding of the variability of the environmental conditions that affect the distribution and abundance of BFT, across years and areas, might help understand much better the variability in distribution and abundance observed.

Comparison among areas and observer types

Looking at the detection functions by area, only Block A has the expected and desirable pattern of more detections at closest distances. The peak at shortest distances is very high for Block A; this could be due to the large amount of sightings done by the SS, typically at shorter distances than the PS (see below and Table 10).

In Blocks A, E and G there is a gap between closer and longer distances, maybe partly due to a random effect because of the small sample size, and partly to the different search patterns by SS and PS in those areas. In Table 10 the difference between PS and SS is more obvious, in Blocks A, C and E (especially A). In block G there is no difference in the mean perpendicular distance by PS and SS. To check if this is due to assigning the national observer to the SS, additional analysis was made treating the national observer as a special category, but no significant difference was noted (mean perpendicular distances: NS=1400, PS=1122, SS=1012).

In Blocks C and G, and to a lesser extent in E there is an undesirable lower detection at small distances. Again, this could be potentially due to a random effect because of the very small sample size in all areas, or the true effect of different searching patterns.

More emphasis should be put in future surveys, as has been highlighted in previous reports, to search closer to the track line, not looking that far away.

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