ATLANTIC-WIDE RESEARCH PROGRAMME ON BLUEFIN TUNA (ICCAT GBYP – PHASE 7 - 2017)

ELABORATION OF DATA FROM THE AERIAL SURVEYS ON SPAWNING AGGREGATIONS

Report

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Background

The objectives of the comprehensive ICCAT Atlantic-Wide Research Programme on Bluefin Tuna (GBYP) are to improve basic data collection and our understanding of key biological and ecological processes and 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 have been conducted in the Mediterranean on the selected spawning grounds. An extended survey was carried out in 2013 and 2015. In 2017 a new survey was carried out on the selected spawning grounds using the “overlap areas” defined in 2015.

The purpose of this work is to elaborate the Aerial Survey data, collected under Phase 7 of the GBYP 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 aerial survey of ICCAT GBYP of 2017, 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

Aerial surveys for Bluefin tuna in the Mediterranean Sea were designed using program DISTANCE http://www.ruwpa.st-and.ac.uk/distance/, the "industry standard" software for line and point transect distance sampling (see Cañadas and Vazquez 2017 for the report on the survey design).

Survey coverage

Figure 1 shows the original designed survey transects for the sub-areas. **Figures 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. There were no problems of uneven coverage in portions of the blocks as in previous years. Unfortunately, in areas A and E only 3 replicas could be realized, instead of four, due to weather conditions. However, as the realized replicas were completed, this do not cause any bias for failing the assumption of even coverage probability. It just means smaller sample size.

Data processing

This year data was delivered from each area in a weekly basis, and immediately processed and checked to find any potential problems 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 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.

In 40 of the 128 BFT sightings was not possible to estimate perpendicular distances, 28 of them because the aircraft did not leave the transect and no circles were available, and 12 of them because even if the aircraft leaved the transect the circles were not concentric so it was not possible to identify a clear point to measure. Most of the sightings with no circles were recorded in area A, where unusual small groups of BFT, between 1 and 10 animals, were detected.

Unfortunately, as observed in the analysis done in 2016 with all data collecting in 2010, 2011, 2013 and 2015, the differences between the values obtained by GIS and angle are very unequal and with no apparent tendency. In the case of area A, the recommendation of the CL was to use the GIS values for the BFT sightings detected by the PS because it was complicated to estimate precise angles before leaving the transect, and to use the angle values for the BFT sightings detected by the SS. In the rest of the areas although there is no clear recommendation from de CL it would be logic to use the same criteria. Therefore, the following steps or criteria were followed: 1- When the column "Abeam" in the excel files were N (the angle was not taken when abeam), the GIS position was used; 2- All the sightings by PS use the GIS distances (unless there is none in which case the angle-derived is taken); 3- All the sightings by SS use the angle –derived distance; and 4- in case of doubt, it is revised and the expert criteria is 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.

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 $\hat{D}$ 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	1-5 6-50 51-200 201-1000 1001-3000 3001-12000
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
Airplae	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)

Analysis could not be done for each sub-area independently because of insufficient sample size for most of them to perform a robust independent analysis. Instead, they were post-stratified by sub-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, 8000m right truncation distance was chosen in the dataset using perpendicular distances from the declination angle, removing the furthest sighting, and therefore leaving 127 on/off sightings for the detection function, out of a total of 128.

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).

Results

Table 2 shows the 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 2. Surface, number and total length of transects and number of sightings of Bluefin tuna for each surveyed area.

Area	Surface (km^2)	Number of transects	Length of transects on effort (km)	Number of observations (after truncation) Detection Function	Number of observations (after truncation) Abundance estimate
A	61,933	26	4,981	40	22
C	53,868	25	4,911	16	15
E	93,614	30	6,705	10	9
G	56,211	55	4,581	61	45
Total	265,626	136	21,178	127	91

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

The final model selected was the null model with a Hazard-rate key function. There was a model with the lowest AIC which had two covariates (subarea and glare30) with a Hazard-rate key function. However, all diagnostics were better for the null model, the CV of the estimate was lower and the point estimate was very similar. Therefore, the simplest model was chosen. The Kolmogorov-Smirnov and the Cramer-von Mises tests performed very well and overall there were no significant differences between the cdf and the edf. The q-q plot shows a good agreement between the cdf and the edf. **Table 3** shows the main parameters for the detection function and the results of the diagnostics tests. **Figure 8** shows the fitted detection function and **Figure 9** shows the Q-Q plot.

Table 3. Parameters and diagnostics of the detection function.

Average probability of detection (p)	Effective strip width (esw) (km)	Chi-square test	K-S test (p)	Cramer-von Mises test (unweighted) (p)
0.1803	0.704	0.7252	0.8689	0.8721

In order to investigate the effect of Subarea (AirMed in A, AirMed in E, ActionAir in G and Unimar in C) on the probability of detection, an MCDS model was run in DISTANCE to visualize the curves of the detection function for each team (**Figures 10** to **13**). The original angle-derived perpendicular distances were used here to test for rounding of angles.

Table 4 shows the estimates of density of schools, number of individuals and total weight of Bluefin tuna in each sub-area.

Table 4. Mean school size, density and total weight and abundance of Bluefin tuna for each subarea. All data are only for on effort-observations.

Year	**A**	**C**	**E**	**G**	**Total (sum)**	**Total (mean)**
Survey area (km^2)	61,933	53,868	93,614	56,211	265,627	
Transect length (km)	4,981	4,911	6,705	4,581	21,178	
Effective strip width x2 (km)	1.4	1.4	1.4	1.4		1.4
Area searched (km^2)	7,017	6,918	9,446	6,453	29,834	
% coverage	11.3	12.8	10.1	11.5		11.2
Number of schools ON effort	22	15	9	45	91	
Abundance of schools	95	57	44	191	387	
%CV abundance of schools	30.8	28.8	36.4	23.5	20.2	
Encounter rate of schools	0.0044	0.0031	0.0013	0.0098		0.0043
%CV encounter rate	25.9	23.6	32.4	16.6		11.6
Density of schools (1000 km^{-2})	1.531	1.058	0.466	3.398		1.457
%CV density of schools	30.8	28.8	36.4	23.5		23.4
Mean weight (t)	133.9	202.5	102.3	16.5		82.3
%CV weight	34.9	21.9	51.2	31.5		19.2
Mean cluster size (animals)	754	1,453	848	809		895
%CV abundance	33.6	17.2	33.2	31.9		17.0
Density of animals (km^{-2})	1.155	1.539	0.395	2.756		**1.304**
%CV density of animals	39.7	33.3	49.9	40.1		25.9
Total weight (t)	**12,693**	**11,547**	**4,457**	**3,157**		**31,855**
%CV total weight	40.9	35.5	63.4	39.3		26.7
L 95% CI total weight	5,848	5,829	1,413	1,495		19,018
U 95% CI total weight	27,551	22,874	14,062	6,669		53,355
Total abundance (animals)	**71,520**	**82,886**	**36,927**	**154,939**		**346,272**
%CV total abundance	39.7	33.3	49.9	40.1		25.9
L 95% CI total abundance	33,620	43,597	14,559	72,366		209,816
U 95% CI total abundance	152,141	157,580	93,662	331,731		571,473

Overall, a total of 31,855 (CV = 26.7%) tonnes and 346,272 (CV = 25.9%) individuals of Bluefin tuna werre estimated in all the spawning sub-areas together.

Comparison with previous estimates

Tables 5 to 8 show a comparison between the estimates in 2010, 2011, 2013, 2015 and 2017 for each area. Table 9 shows the same comparison for all areas combined.

Table 5. Results for all surveys in overlap area A

Year	**2010**	**2011**	**2013**	**2015**	**2017**	**Total (sum)**	**Total (mean)**
Survey area (km^2)	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	29,852	
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	1.4		
Area searched (km^2)	18,130	10,660	20,398	15,961	7,017	72,166	
% coverage	29.3	17.2	32.9	25.8	11.3		
Number of schools ON effort	8	10	10	6	22	56	
Abundance of schools	25	58	30	23	95		46
%CV abundance of schools	55.4	35.9	36.1	43.4	30.8		
Encounter rate of schools	0.0013	0.0013	0.0015	0.0014	0.0044		0.0019
%CV encounter rate	54.5	33.8	35.1	41.1	25.9		
Density of schools (1000 km^{-2})	0.402	0.938	0.490	0.372	1.531		0.747
%CV density of schools	55.4	35.9	36.1	43.4	30.8		
Mean weight (t)	131.25	122.43	194.1	160.7	133.9		148.462
%CV weight	6.2	19.2	23.8	11.7	34.9		
Mean cluster size (animals)		678.1	611	825	754		717
%CV abundance		27.9	26.0	11.0	33.6		
Density of animals (km^{-2})		0.636	0.299	0.307	1.155		0.599
%CV density of animals		45.4	44.5	44.7	39.7		
Total weight (t)	**3,587**	**4,371**	**3,539**	**4,712**	**12,693**		**5,780**
%CV total weight	56.5	46.2	40.6	42.0	40.9		
L 95% CI total weight	1,251	1,807	1,624	2,132	5,848		
U 95% CI total weight	10,285	10,577	7,710	10,414	27,551		
Total abundance (animals)		**39,399**	**18,542**	**19,002**	**71,520**		**37,116**
%CV total abundance		45.4	44.5	44.7	39.7		
L 95% CI total abundance		16,540	7,913	8,195	33,620		
U 95% CI total abundance		93,850	43,445	44,060	152,141		

Table 6. Results for all surveys in overlap area C

Year	2010	2011	2013	2015	2017	Total (sum)	Total (mean)
Survey area (km^2)	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	27,754	
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	1.4		
Area searched (km^2)	25,150	12,004	8,364	10,640	6,918	63,076	
% coverage	46.7	22.3	15.5	19.8	12.8		
Number of schools ON effort	6	10	10	3	15	44	
Abundance of schools	12	45	64	13	57		38
%CV abundance of schools	45.7	33.4	34.3	62.0	28.8		
Encounter rate of schools	0.0007	0.0011	0.0036	0.0009	0.0031		0.0016
%CV encounter rate	44.6	31.2	33.1	60.5	23.6		
Density of schools (1000 km^{-2})	0.217	0.833	1.196	0.239	1.058		0.709
%CV density of schools	45.7	33.4	34.3	62.0	28.8		
Mean weight (t)	124.17	38.87	173.5	190.0	202.5		145.808
%CV weight	5.6	44.4	22.1	19.9	21.9		
Mean cluster size (animals)	733	291	1,285	1,533	1,453		1,059
%CV abundance	36.5	30.7	17.0	19.0	17.2		
Density of animals (km^{-2})	0.182	0.242	1.536	0.366	1.539		0.773
%CV density of animals	59.2	45.3	38.3	64.9	33.3		
Total weight (t)	**1,596**	**1,917**	**11,370**	**2,665**	**11,547**		**4,387**
%CV total weight	46.9	54.9	40.8	65.1	35.5		
L 95% CI total weight	652	661	5,161	802	5,829		
U 95% CI total weight	3,904	5,557	25,049	8,856	22,874		
Total abundance (animals)	**9,797**	**13,059**	**82,763**	**19,708**	**82,886**		**41,643**
%CV total abundance	59.2	45.3	38.3	64.9	33.3		
L 95% CI total abundance	3,187	5,446	39,399	5,958	43,597		
U 95% CI total abundance	30,016	31,317	173,860	65,192	157,580		

Table 7. Results for all surveys in overlap area E

Year	2010	2011	2013	2015	2017	Total (sum)	Total (mean)
Survey area (km^2)	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	36,981	
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	1.4		
Area searched (km^2)	38,930	13,862	13,129	9,969	9,446	85,335	
% coverage	41.6	14.8	14.0	10.6	10.1		
Number of schools ON effort	29	45	20	3	9	106	
Abundance of schools	63	304	135	20	44		113
%CV abundance of schools	31.5	24.1	34.8	58.0	36.4		
Encounter rate of schools	0.0022	0.0044	0.0046	0.0008	0.0013		0.0029
%CV encounter rate	29.9	21.0	33.6	56.3	32.4		
Density of schools (1000 km^{-2})	0.678	3.246	1.447	0.213	0.466		1.210
%CV density of schools	31.5	24.1	34.8	58.0	36.4		
Mean weight (t)	110.14	118.05	11.0	50.2	102.3		78.338
%CV weight	33.9	19.2	66.0	99.5	51.2		
Mean cluster size (animals)	1,015	1,715	361	507	848		889
%CV abundance	19.0	21.5	67.3	97.9	33.2		
Density of animals (km^{-2})	0.787	5.566	0.522	0.108	0.395		1.476
%CV density of animals	37.8	32.3	75.7	113.8	49.9		
Total weight (t)	**7,681**	**37,851**	**1,517**	**1,093**	**4,457**		**10,520**
%CV total weight	47.1	32.2	74.6	115.2	63.4		
L 95% CI total weight	3,155	20,342	390	75	1,413		
U 95% CI total weight	18,698	70,432	5,899	15,857	14,062		
Total abundance (animals)	**73,676**	**521,085**	**48,884**	**10,126**	**36,927**		**138,140**
%CV total abundance	37.8	32.3	75.7	113.8	49.9		
L 95% CI total abundance	35,741	279,620	12,363	727	14,559		
U 95% CI total abundance	151,880	971,060	193,280	141,020	93,662		

Table 8. Results for all surveys in overlap area G

Year	**2010**	**2011**	**2013**	**2015**	**2017**	**Total (sum)**	**Total (mean)**
Survey area (km^2)	56,211		56,211	56,211	56,211		56,211
Transect length (km)	3,790		2,081	859	4,581	11,311	
Effective strip width x2 (km)	2.96		3.00	3.9	1.4		
Area searched (km^2)	11,231		6,236	3,335	6,453	27,256	
% coverage	20.0		11.1	5.9	11.5		
Number of schools ON effort	33		12	2	45	92	
Abundance of schools	150		108	22	191		118
%CV abundance of schools	28.1		39.7	70.9	23.5		
Encounter rate of schools	0.0087		0.0058	0.0015	0.0098		0.0081
%CV encounter rate	26.3		38.7	69.5	16.6		
Density of schools (1000 km^{-2})	2.674		1.924	0.399	3.398		2.099
%CV density of schools	28.1		39.7	70.9	23.5		
Mean weight (t)	63.621		4.0	9.0	16.5		23.280
%CV weight	12.7		40.2	66.7	31.5		
Mean cluster size (animals)			336	600	809		582
%CV abundance			36.7	66.7	31.9		
Density of animals (km^{-2})			0.646	0.239	2.756		1.214
%CV density of animals			54.1	97.3	40.1		
Total weight (t)	**10,507**		**440**	**220**	**3,157**		**3,581**
%CV total weight	32.1		56.5	97.3	39.3		
L 95% CI total weight	5,643		151	25	1,495		
U 95% CI total weight	19,561		1,285	1,965	6,669		
Total abundance (animals)			**36,316**	**13,448**	**154,939**		**68,234**
%CV total abundance			54.1	97.3	40.1		
L 95% CI total abundance			12,995	1,506	72,366		
U 95% CI total abundance			101,490	120,070	331,731		

Table 9. Results for all surveys in all areas combined

Year	2010	2011	2013	2015	2017	Total (sum)	Total (mean)
Survey area (km^2)	265,627	209,416	265,627	265,627	265,627		265,627
Transect length (km)	31,532	26,856	16,060	10,272	21,178	105,898	
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	1.4		2.52
Area searched (km^2)	93,442	36,525	48,127	39,904	29,834	166,041	
% coverage	35.2	17.4	18.1	15.0	11.2	62.5	
Number of schools ON effort	76	65	52	14	91	298	
Abundance of schools	250	388	338	78	387		288
%CV abundance of schools	22.8	19.9	21.5	38.9	20.2		
Encounter rate of schools	0.0024	0.0024	0.0032	0.0014	0.0043		0.0028
%CV encounter rate				20.2	11.6		
Density of schools (1000 km^{-2})	0.942	1.852	1.274	0.295	1.457		1.086
%CV density of schools	22.8	19.9	21.5	38.9	23.4		
Mean weight (t)	87.9	101.1	22.6	272.2	82.3		113.212
%CV weight	16.8	27.5	51.0	41.4	19.2		
Mean cluster size (animals)	791	1,275	582	1,548	895		1018
%CV abundance	18.6	37.3	18.5	40.5	17.0		
Density of animals (km^{-2})		**2.7388**	**0.702**	**0.234**	**1.304**		**1.245**
%CV density of animals		29.9	29.4	39.1	25.9		
Total weight (t)	**23,371**	**44,139**	**16,866**	**8,690**	**31,855**		**24,984**
%CV total weight	25.6	28.7	30.3	35.3	26.7		
L 95% CI total weight	14,243	25,315	9,343	4,398	19,018		
U 95% CI total weight	38,347	76,964	30,447	17,169	53,355		
Total abundance (animals)		**573,543**	**186,505**	**62,284**	**346,272**		**292,151**
%CV total abundance		29.9	29.4	39.1	25.9		
L 95% CI total abundance		321,620	105,320	28,766	209,816		
U 95% CI total abundance		1,022,800	330,270	134,860	571,473		

Discussion

Survey logistics

The survey design generally seemed to work very well, and homogeneous coverage was achieved in all areas.

Data collection worked much better than in previous surveys. The weekly review of the data collected so far helped in a great deal to detect small issues at an early stage and correct them for the rest of the survey.

Looking at the detection functions by team, Blocks A and C have 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 with very small school size, only detectable at short distances. In Block C there is a gap between approximately 1000 and 2000 m, but this could be due to a random effect because of the small sample size, and being the first bins of the detection function the most important ones, this is reasonable. In Block E there is an undesirable lower detection at small distances, obvious both truncating at 8000 and at 4000m. Again, this could be potentially due to a random effect because of the very small sample size in this area (10 observations). In Block G, there is a pattern of histogram bars going up and down alternatively (obvious when truncating at 4000m). There is also a strong drop of detections in the first 300 meters from the line transect, and the detections extend very far from the track line. Sample size does not seem to be an issue in this area, so more emphasis should be put in future surveys in this company to search closer to the track line, not looking that far away, and to not round angles (a visual inspection of the declination angles recorded shows some degree of rounding at convenient angles: 5, 10, 15, 20, 35, 45, 55, 65). Furthermore, this is the only area where the aircraft type was different.

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 24 % and 36%. The precision of mean school size varied between 17 and 34%. CVs for estimates of total weight were more variable: 22-51%. Summing over all areas surveyed, the CV of total abundance was 26%.

In Table 4 it is obvious that the largest CVs correspond to the area E. This might be 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: 32% compared to 17-26% in the other areas).

The number of schools seen in most of the areas was insufficient to estimate an independent *esw* so data from all sub-areas were pooled. This is acceptable as long as differences in conditions in each area (such as sea state, air haziness, water turbidity, observers) 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 considerably increased in all areas except E, which reduced considerably the CV of the encounter rate and density of schools in areas A, C and G. In E these CVs were larger than in 2010 and 2011, similar to 2013 and smaller than in 2015 when the number of observations was even smaller.

However, another component of the overall CV, the mean school size, varies considerably and is independent of sample size. The CV of school size in 2017 was larger in area A, smaller in C (except compared with 2013) and G and intermediate in E. Equally variable is the CV of the mean weight. Thanks to the increased number of sightings, the total CV for abundance of animals was reduced in areas A, C and G and intermediate in E (larger than in 2010 and 2011 but smaller than 2013 and 2015). Similar pattern was obtained also for the CVs of total weight.

Relative estimates of abundance

Line transect sampling assumes that detection on the transect line itself is certain. On aerial surveys, in general, it is not possible to assume this because the speed of flight means that some schools available to be sampled will inevitably not be detected (so-called perception bias). In addition, tuna spend much of their time beneath the surface and unavailable to be detected (so-called availability bias). Estimates of abundance from these surveys are thus underestimates (minimum estimates) even though a detection function has been fitted to correct for animals missed within the survey strip.

The appropriateness of these estimates as indices of abundance for the future depends on a number of factors including: timing of surveys; areas surveyed; and stability of availability and perception biases. Availability and perception bias can reasonably be assumed to be stable over time but knowledge of the distribution in time and space of Bluefin tuna throughout the Mediterranean Sea 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 10 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 2017 and the mean of 2010 to 2015, as well with each of the previous four surveys.

Table 10. Comparison between the results in 2017 and the mean in previous surveys (2010-2015). In red those percentages in which the values are smaller in 2017. In black the percentages in which the values are larger in 2017.

	Values		Percentage difference				
Area A	**2017**	**Mean 2010-2015**	**2010**	**2011**	**2013**	**2015**	**Mean 2010-2015**
Effort	4981	6,218	18.6	36.4	26.8	17.5	19.9
Sightings	22	9	63.6	54.5	54.5	72.7	61.4
ER schools	0.00442	0.0014	70.4	71.1	66.7	67.3	68.9
Total weight	12693	4,052	71.7	65.6	72.1	62.9	68.1
Total animals	71520	25,647		44.9	74.1	73.4	64.1
Area C							
Effort	4,911	5,711	42.1	44.4	43.2	44.2	14.0
Sightings	15	7	60.0	33.3	33.3	80.0	51.7
ER schools	0.0031	0.0016	76.9	62.9	14.8	69.7	48.0
Total weight	11,547	4,387	86.2	83.4	1.5	76.9	62.0
Total animals	82,886	31,332	88.2	84.2	0.1	76.2	62.2
Area E							
Effort	6,705	7,569	49.0	34.2	34.7	61.7	11.4
Sightings	9	24	69.0	80.0	55.0	66.7	62.9
ER schools	0.0013	0.0030	39.2	69.6	70.6	38.3	55.3
Total weight	4,457	12,036	42.0	88.2	66.0	75.5	63.0
Total animals	36,927	163,443	49.9	92.9	24.5	72.6	77.4
Area G							
Effort	4,581	2,243	17.3		54.6	81.3	51.0
Sightings	45	16	26.7		73.3	95.6	65.2
ER schools	0.0098	0.0053	11.4		41.3	84.2	45.6
Total weight	3,157	3,722	70.0		86.1	93.0	15.2
Total animals	154,939	24,882			76.6	91.3	83.9
All areas							
Effort	21,178	21,180	32.8	21.1	24.2	51.5	0.0
Sightings	91	52	16.5	28.6	42.9	84.6	43.1
ER schools	0.0043	0.0024	43.9	43.7	24.6	68.3	45.1
Total weight	31,855	23,267	26.6	27.8	47.1	72.7	27.0
Total animals	346,272	274,111		39.6	46.1	82.0	20.8

Area A

In Area A there was a bit more effort than in 2015 but less than in 2010, 2011 and 2013. Overall, there was 20% less effort in 2017 than the mean effort of 2010 to 2015. However, there was 61% more sightings on effort this year than the mean of the previous 4 years, even the years with more effort. All encounter rate, total weight and total number of animals was much higher in 2017 than in the mean and each of the previous years, up to 65-75% increase.

The fact that the encounter rates and final estimates are much higher than the previous years when at the same time there was less effort in 2017 than most years, indicates that there was a real increase of BFT in area A in 2017 respect the previous 4 years.

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. However, the amount of sightings of BFT was larger than any previous years. However, the encounter rate is slightly larger in 2013, and the total estimated weight and abundance of animals are almost identical in 2013 and 2017. In those two years the estimates are much larger than in 2010, 2011 and 2015. In 2017 the increase is of around 62% compared with the mean of the four previous years, but it increases to 82% when considering the mean of 2010, 2011 and 2015 (given that 2013 is very similar).

As in area A, the increase of BFT in area C in 2017 seem to be real, only comparable to 2013.

Area E

This area had a surprisingly low number of sightings of BFT in 2017. As for area C, effort this year was higher than in 2013 and 2015 but lower than in 2010 and 2011. 2015 was the year with the lowest encounter rate, total weight and total abundance. 2017 has been better than 2015, but still much poorer in terms of encounter rates of BFT than the first 3 years. However, the mean weight was similar to 2010 and 2011 (and much higher than 2013 and 2015), which yielded a total estimated weight much larger than the last two years, and only 42% smaller than in 2010. 2011 was a case of high density, larger mean weight and larger school sizes than the other years.

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. However, this year seems to have been much better in this area than the previous ones. There was more effort and more sightings. The mean weight was much larger than in 2013 and 2015, but much smaller than in 2010. Therefore, the total estimated weight was much larger than in the previous two years but much smaller than in 2010. The estimated abundance of animals shows a very strong increase with respect to 2013 and 2015, not only because the encounter rate was much larger, but also the mean school size was larger, yielding an increase of 84% compared to the mean of the last two years. A similar increase is observed in terms of total weight when comparing with these two previous years only.

All areas together

Overall, there has been the same amount of effort than the mean of the four previous surveys together, but with 43% more sightings. This has resulted on a 45% increase in the encounter rate respect the 2010-2015 mean, but also with respect to each year independently when combining all areas. The total estimated weight is also larger, by 27%, compared to the mean and to each particular year, except 2011 (due to the large weights recorded in area E that year). The abundance of animals is more variable due to the extremely high abundance recorded in 2011 in area E, so the abundance in 2017 is smaller than that of 2011, but much larger than 2013 and especially 2015.

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Buckland, ST, Anderson, DR, Burnham, KP, Laake, JL, Borchers, DL & Thomas, L (2001). *Introduction to distance sampling: estimating abundance of biological populations.* Oxford University Press, Oxford.

Gerrodette, T (1987). A power analysis for detecting trends. Ecology 68: 1364-72. Software TRENDS available from http://swfsc.noaa.gov/textblock.aspx?Division=PRD&ParentMenuId=228&id=4740.

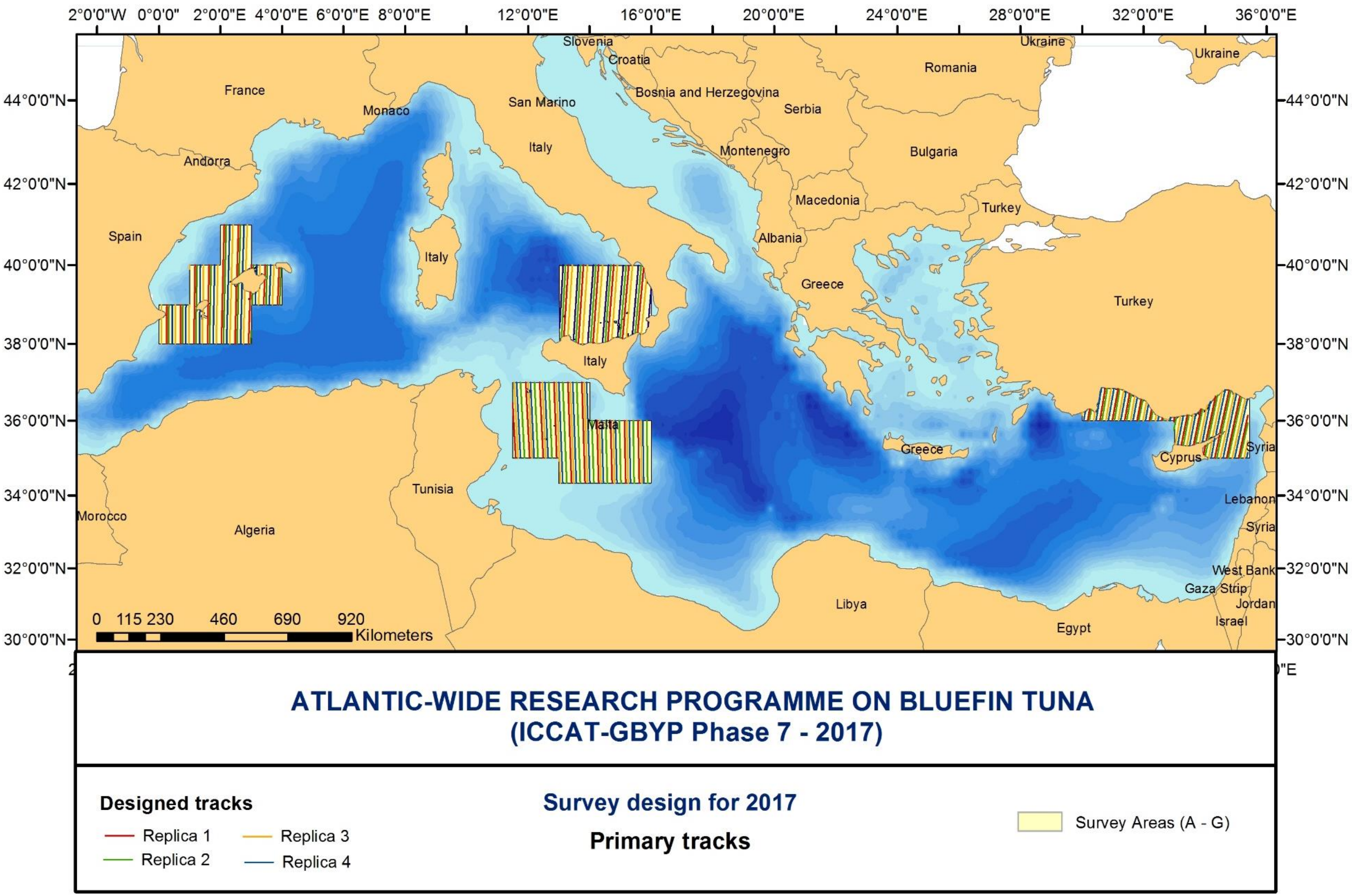

Figure 1. Originally designed transects for the aerial survey in 2017.

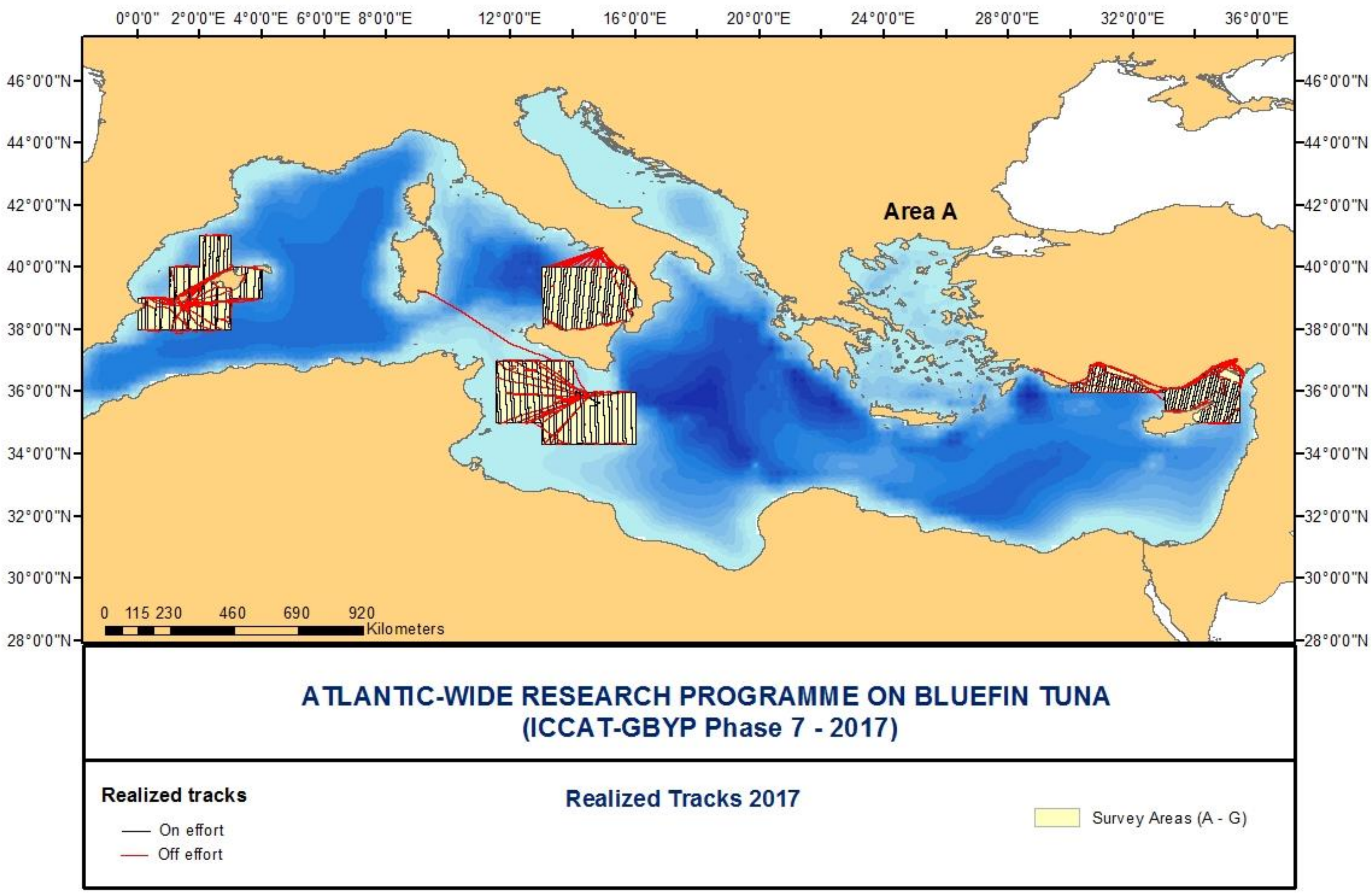

Figure 2. Transects flown on effort and off efforts, including logistics.

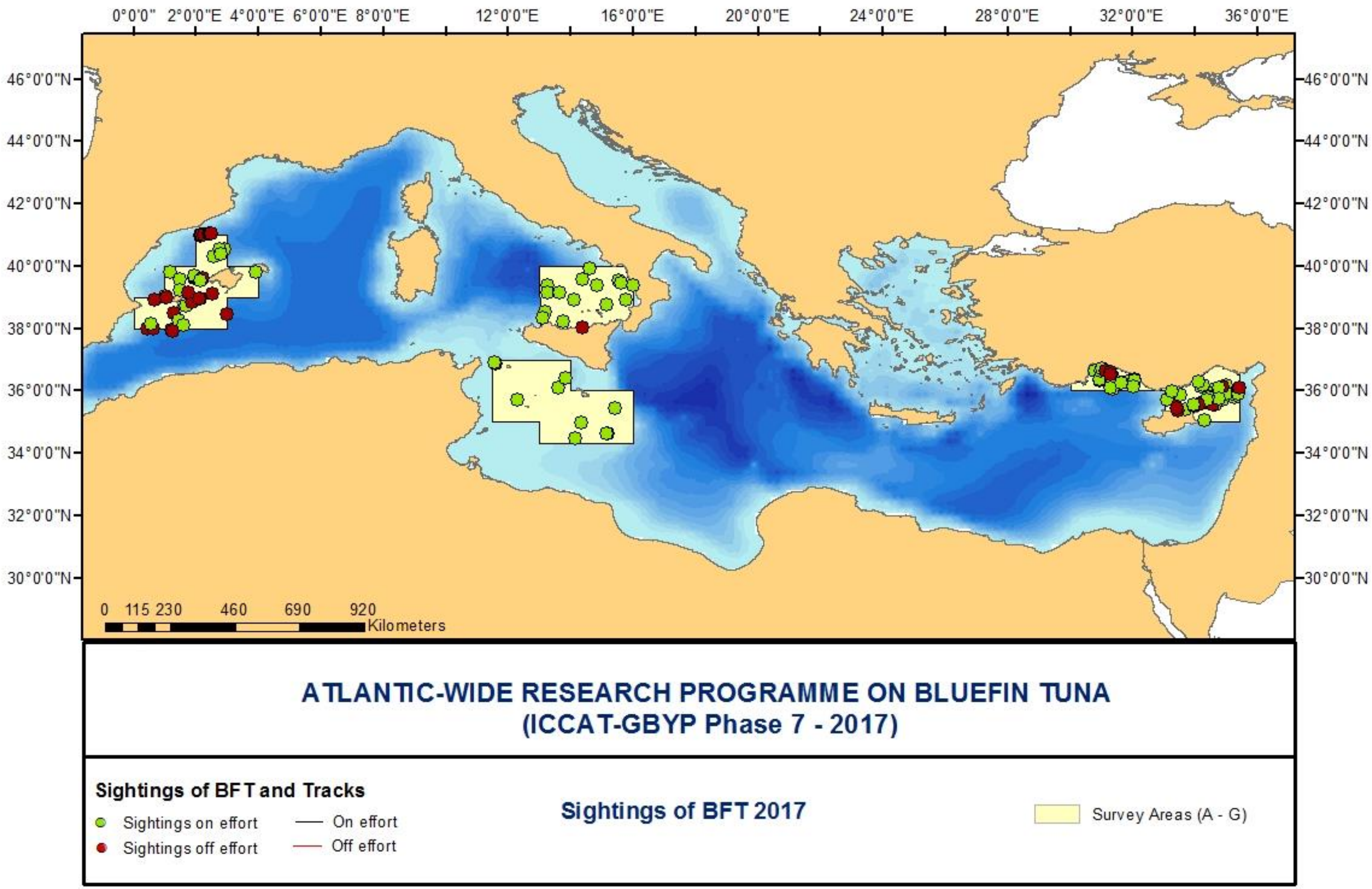

Figure 3. Sightings of Bluefin tuna on and off effort.

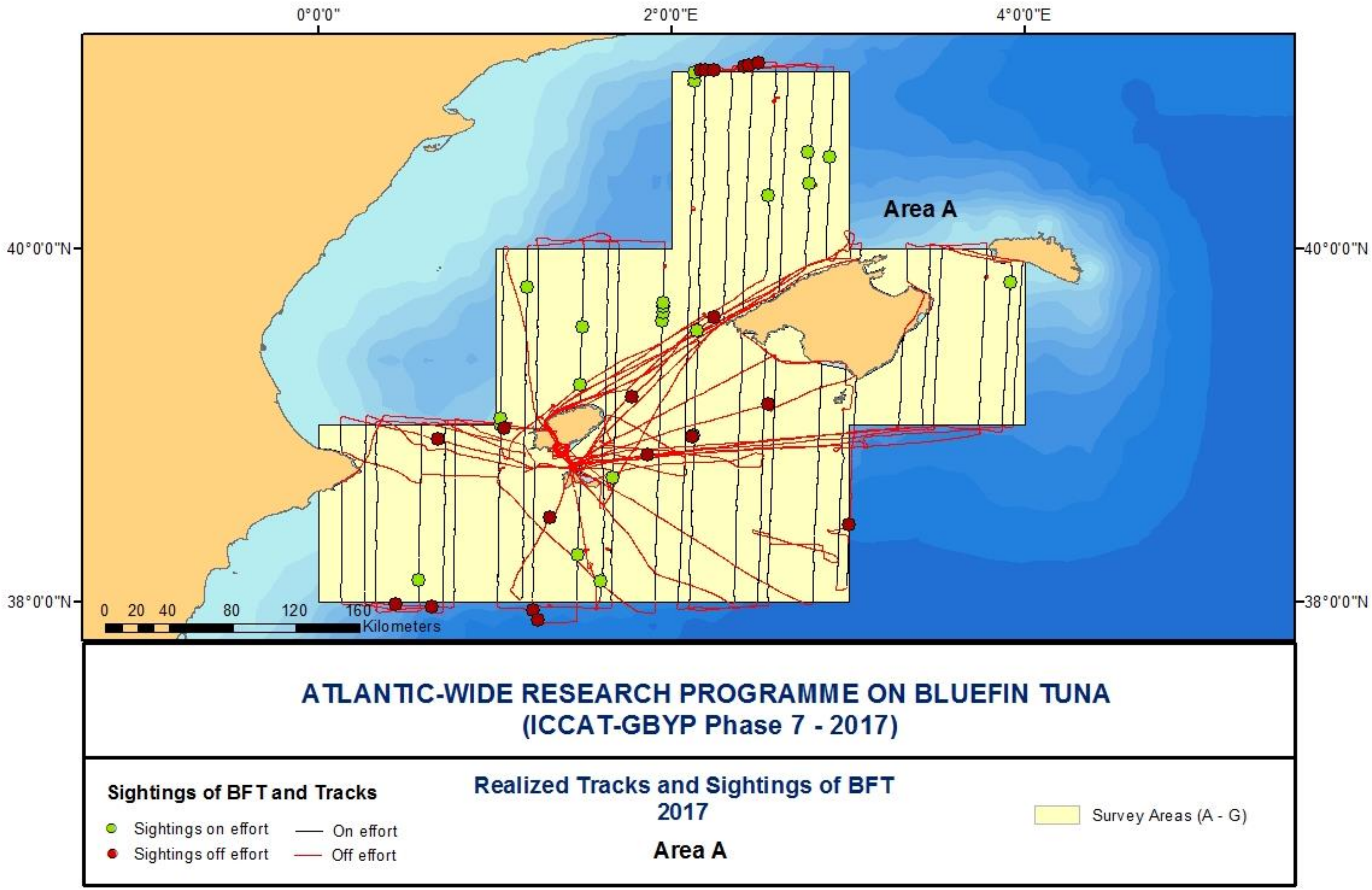

Figure 4. Transects realized, and sightings of Bluefin tuna on and off effort in sub-area A.

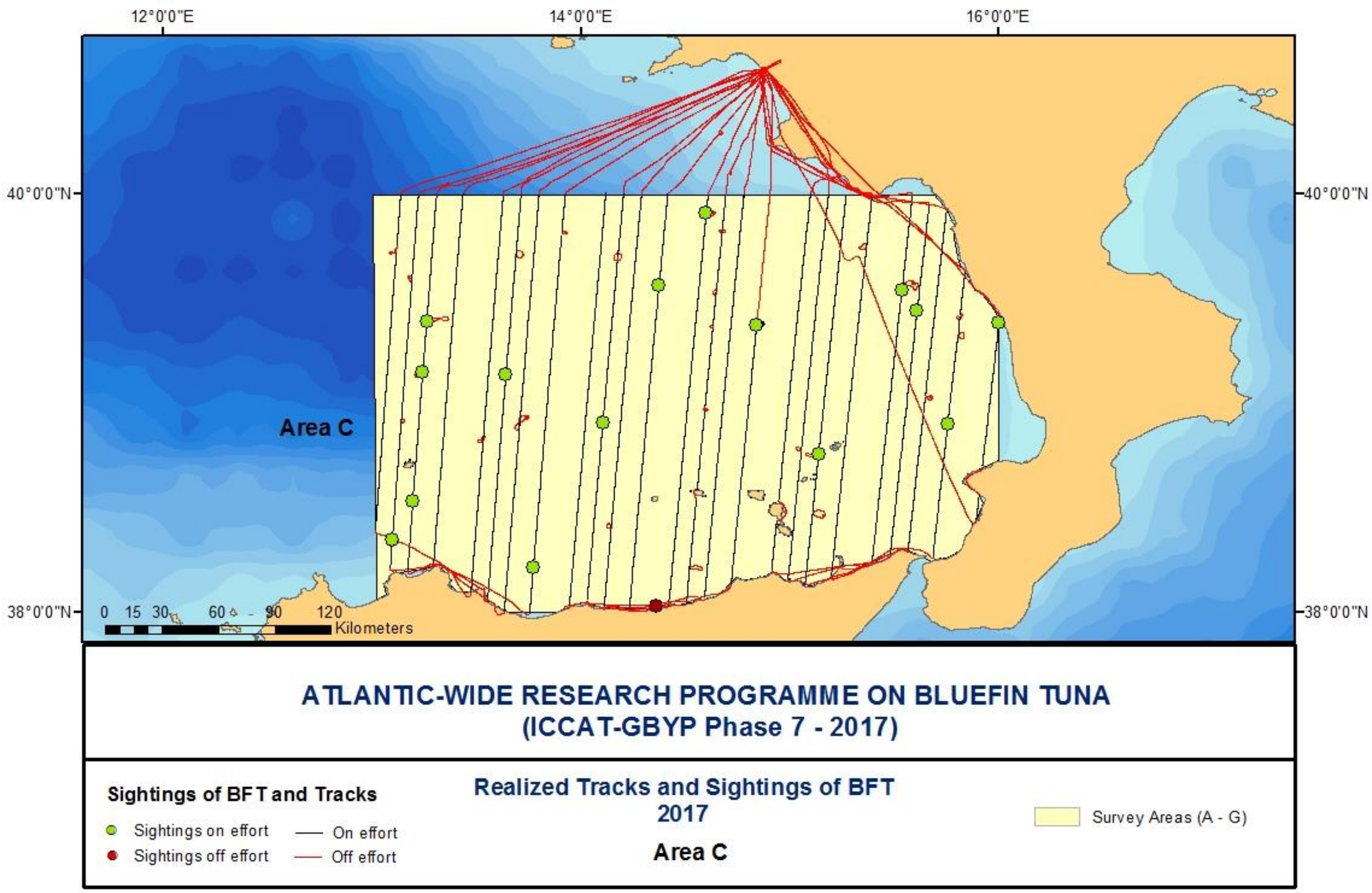

Figure 5. Transects realized, and sightings of Bluefin tuna on and off effort in sub-area C.

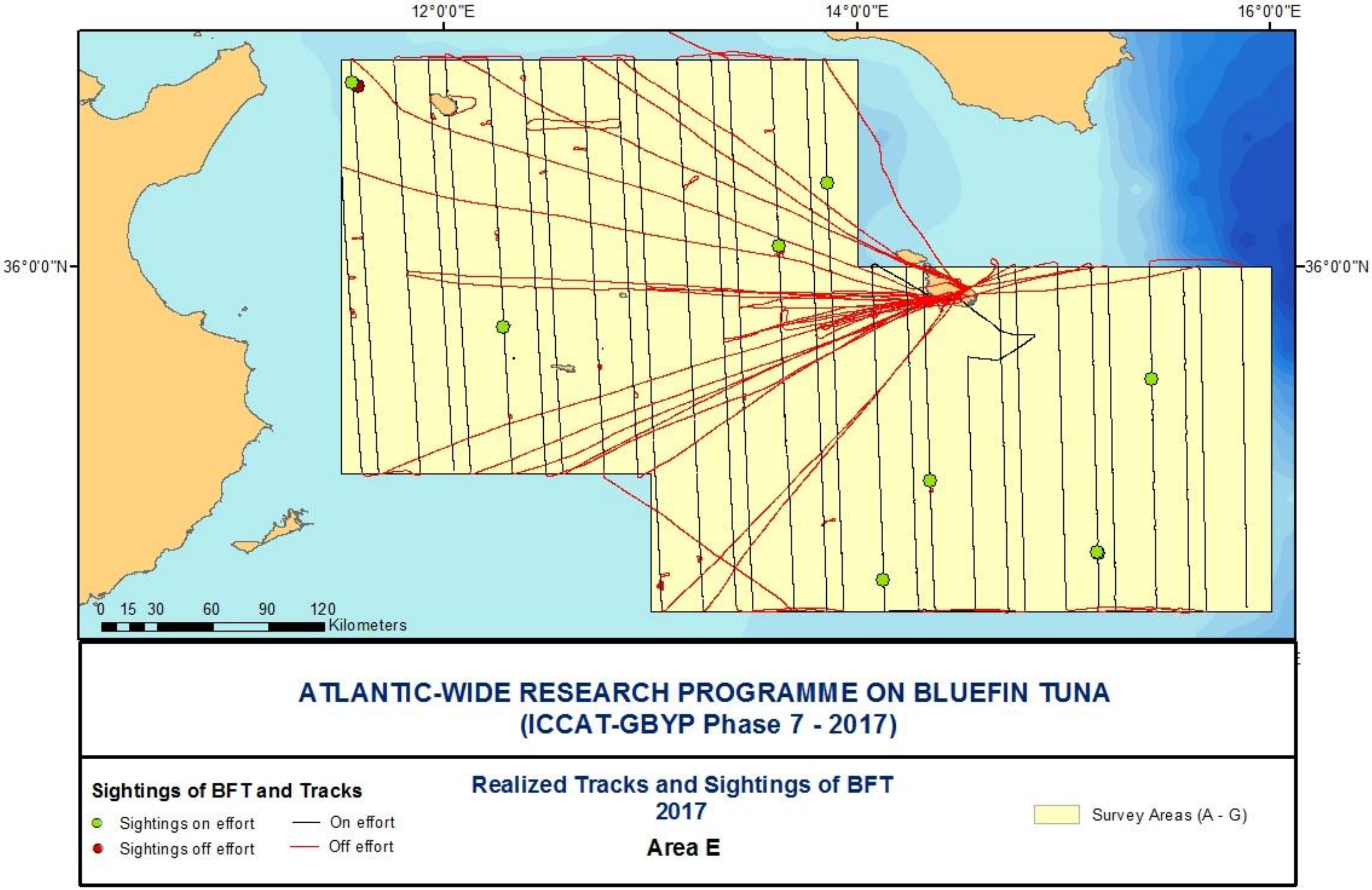

Figure 6. Transects realized, and sightings of Bluefin tuna on and off effort in sub-area E.

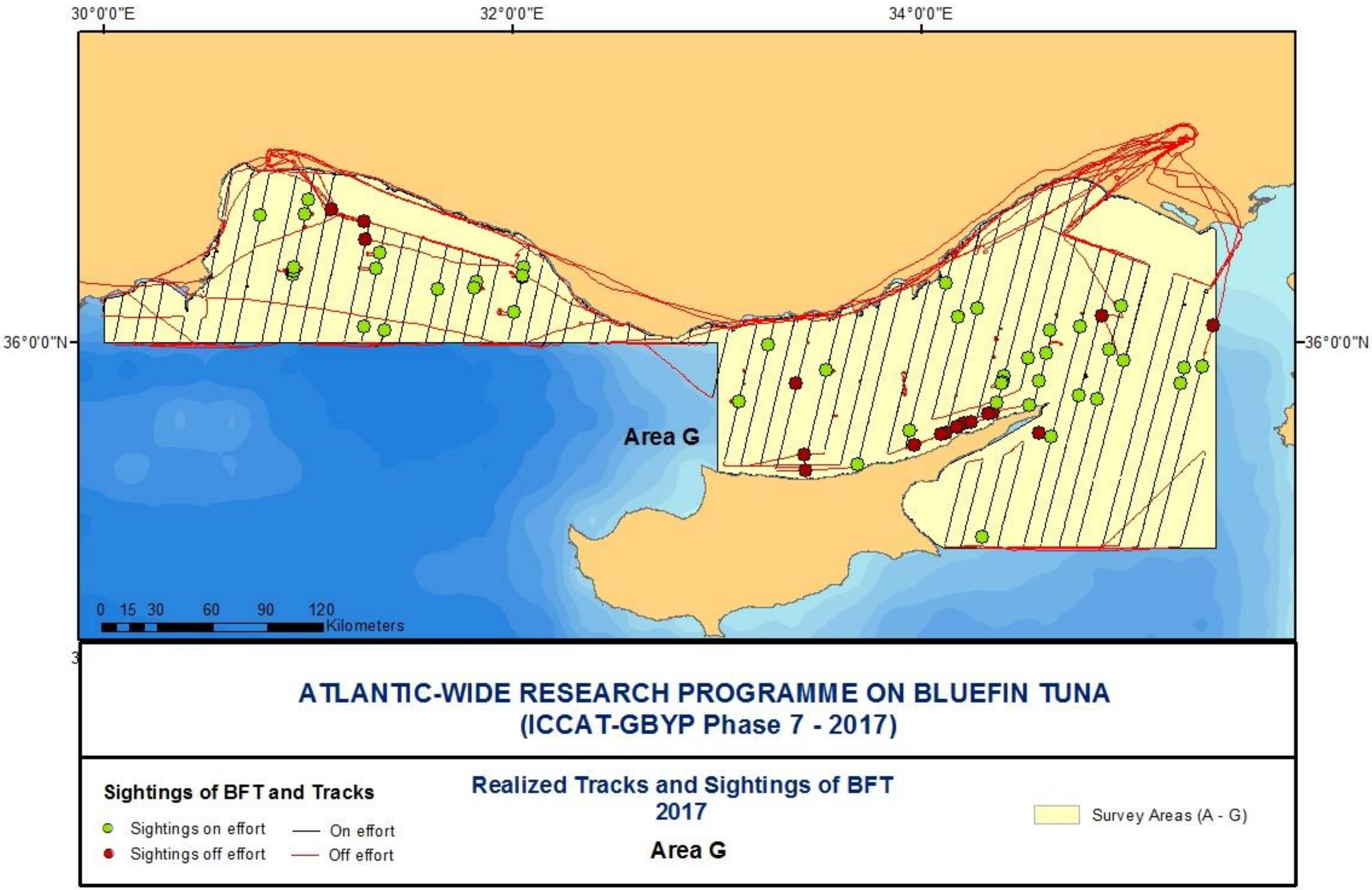

Figure 7. Transects realized, and sightings of Bluefin tuna on and off effort in sub-area G.

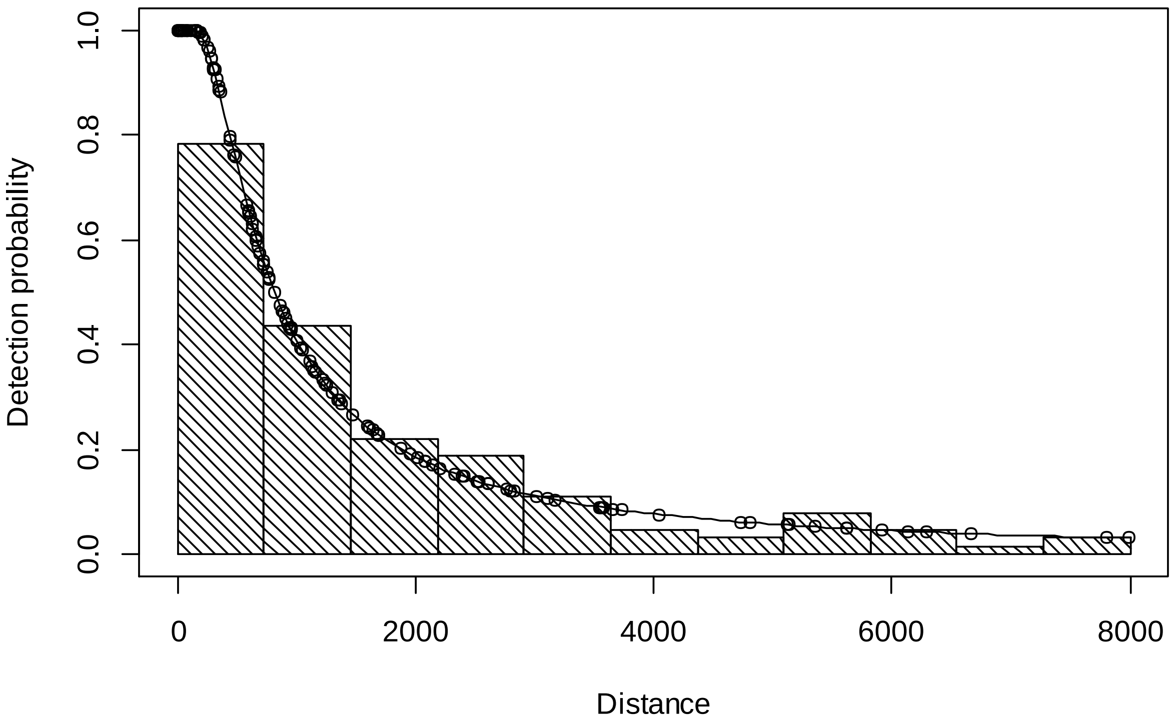

Figure 8. Detection function, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings.

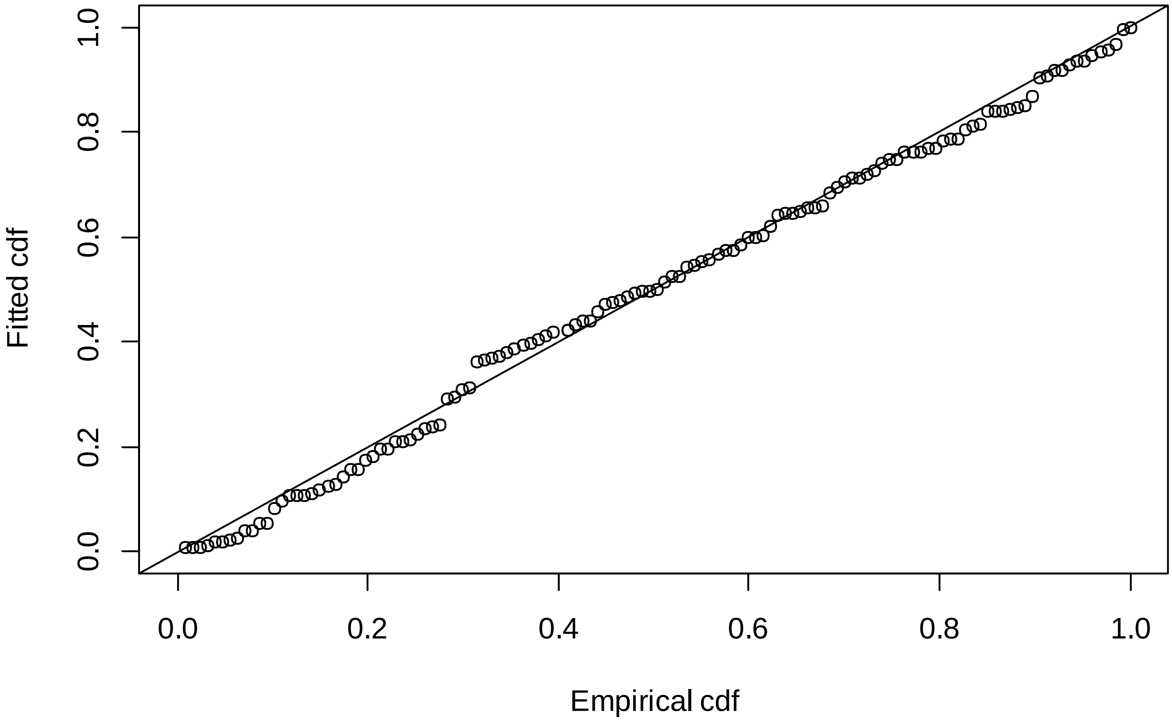

Figure 9. Q-Q plot.

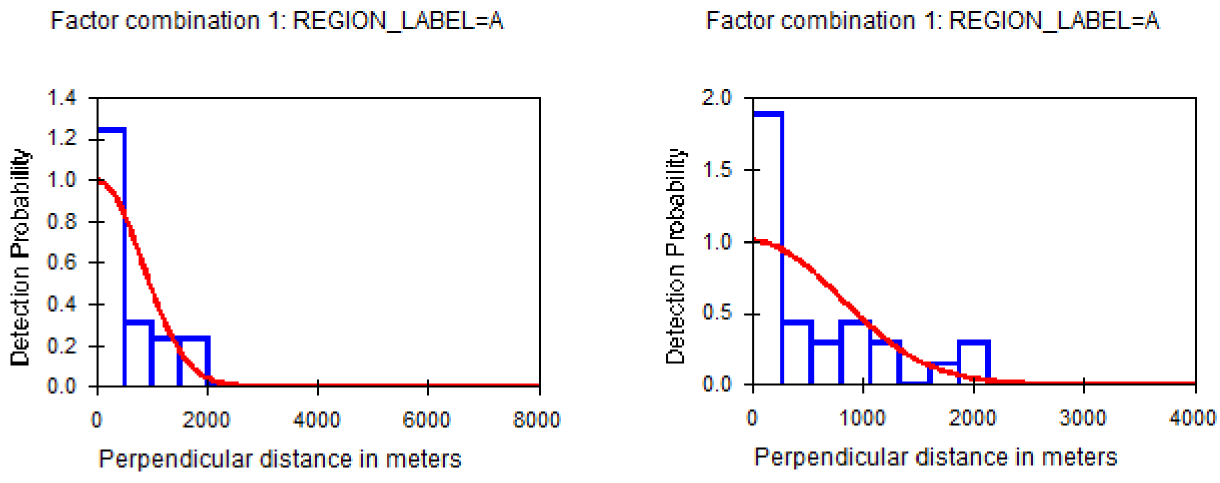

Figure 10. Detection function for AirMed – Area A. Used truncation of 8km on the left. Truncation of 4km on the right to see more details.

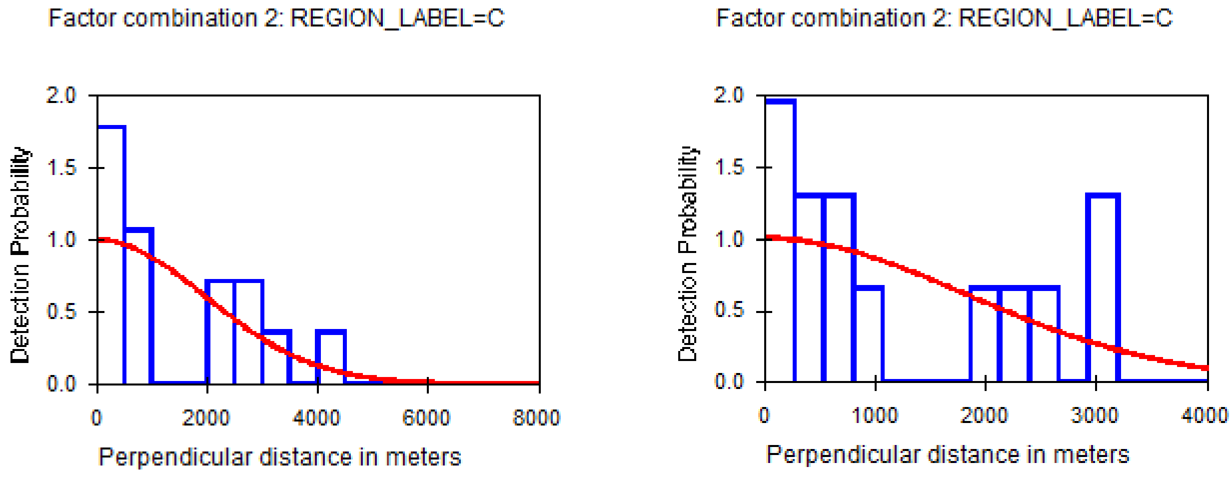

Figure 11. Detection function for Unimar – Area C. Used truncation of 8km on the left. Truncation of 4km on the right to see more details.

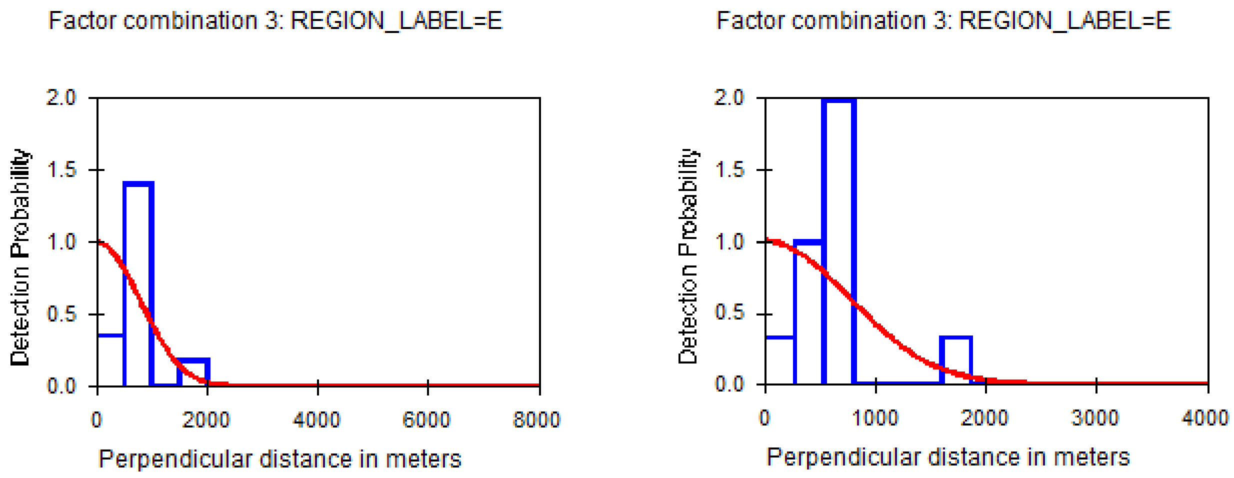

Figure 12. Detection function for AirMed – Area E. Used truncation of 8km on the left. Truncation of 4km on the right to see more details.

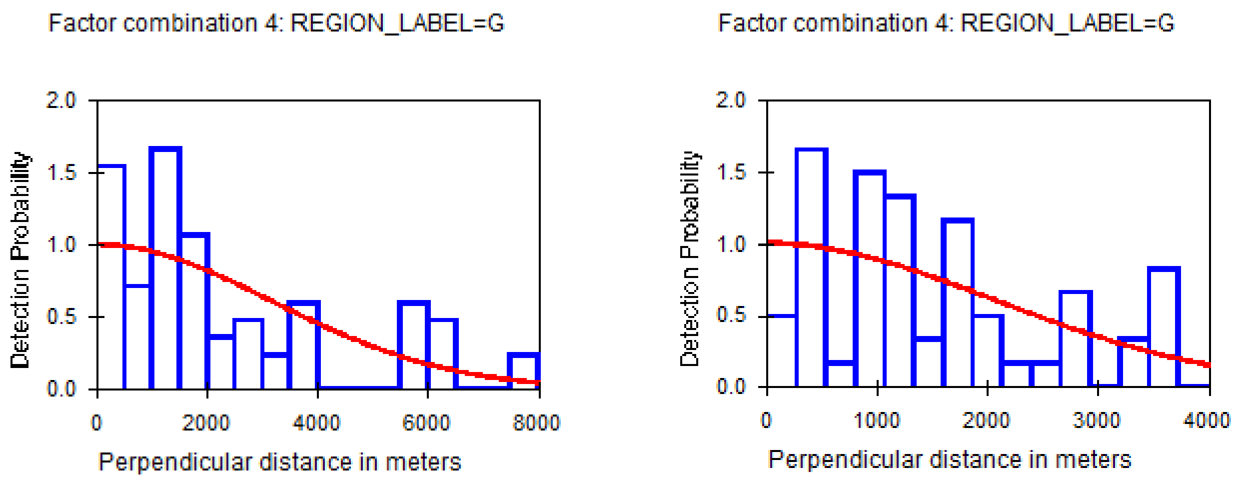

Figure 13. Detection function for ActionAir – Area G. Used truncation of 8km on the left. Truncation of 4km on the right to see more details.