ATLANTIC-WIDE RESEARCH PROGRAMME ON BLUEFIN TUNA (ICCAT-GBYP – PHASE 5 - 2015)

ELABORATION OF 2015 DATA FROM THE AERIAL SURVEY ON SPAWNING AGGREGATIONS

Final Report

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Ana Cañadas & José Antonio Vázquez

Alnilam Research and Conservation Ltd

Pradillos 29, 28491 Navacerrada, Madrid, Spain

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 indexes 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.

The purpose of this work is to elaborate the Aerial Survey data, collected under Phase 5 of the GBYP.

In 2010 an analysis of the aerial survey was conducted and this included a power analysis that evaluated the ability of the survey to detect population trends in the East Atlantic and Mediterranean bluefin recovery plan. This original analysis was based on data from a single year and then it was repeated using 2011 data and then reassessed with a further analysis in GBYP Phase 3. However, inter-annual variation (e.g. due to environmental variation and changes in population distribution) in abundance levels within areas will result in uncertainty in abundance estimates to be underestimated and the power of the survey to detect recovery to be overestimated. Despite many operational difficulties and problems, data have been collected in 2013 and 2015 in much more extended areas.

Objectives for September 2015

Analyses of 2015 aerial survey data:

- Map the distribution of Bluefin tuna spawners by area (internal and external areas).
- Provide a summary table following the same approach of previous surveys, see http://www.iccat.int/GBYP/en/asurvey.htm, with the objective of comparing the aerial survey results by area and year.
- Analyse the data by area, showing the distribution of sightings according to distance categories and following the same methodology used in previous analyses (http://www.iccat.int/GBYP/en/asurvey.htm). Provide estimates of abundance by area with appropriate estimates of uncertainty including sources of additional variance.
- Provide a detailed report concerning the aerial survey carried out in 2015.

Compare only comparable areas/time among years (for all surveys conducted so far)

- Identify overlapping internal areas among years and dates.
- Re-analyse the data for only these areas and assess the CVs

I. Analyses of 2015 aerial survey data

I.1 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 Aerial survey design report by Cañadas & Vázquez 2015) based on: the eleven defined survey areas (survey areas A to G; and sub-areas surveyed in 2010, 2011 and 2013 within blocks A, C, E and G, see Figure I.1), target survey time available (equivalent to 42,000 km), time for circling over detected schools to estimate their size (set at 10%), and time for flying in between lines (set between 10 and 15% depending on the line separation in each block). Surveys are designed as equal spaced parallel lines. Transect lines were placed in a north-south direction to be approximately perpendicular to the coast in most blocks.

The total effort available (42,000 km) according to Scenario 2 of the Feasibility study carried out at the beginning of 2013, in which the density of fish outside spawning areas (previously surveyed areas) is assumed to be half of that inside the spawning areas. Therefore, 50% of coverage (21,000 km) was allocated to the areas outside (called from now on "outside areas") and 50% (21,000 km) was allocated to the spawning areas previously surveyed (called from now on as A inside, C inside, E inside and G inside, or generically "inside areas").

The proportion of the total trackline effort (21,000km) for the inside areas was calculated for each block according to the proportion of the surface area of each block, and the same was done for the outside areas. Additionally, extra replicas were designed both for the inside and the outside areas in the event that more resources could be used and therefore more effort could be allocated.

See report of the Survey Design for more details.

Survey coverage

Figure I.2 shows the original designed survey transects for the sub-areas. Figures I.3, I.4 and I.5 show the realised transects, the sightings made on and off effort and the effort and sightings together for all sub-areas together. Figures I.6 to I.12 show the realized effort in each sub-area.

Coverage was not comprehensive in all sub-areas. Areas A, C and E inside were well covered, as were A, C, D, F and G outside, although D and F did not reach completely the southern border of the area. In the last moment, Tunisia did not provide permission to fly over its waters, and therefore sub-areas B, C and E had to be truncated after the survey design was done.

Sub-area E outside was barely surveyed, because the Tunisian air space was not accessible, limiting the interpretation of the few data available.. Sub-area G inside was not homogeneously covered either, missing a part of the south-eastern section, due to the problems with the air-space in the northern part of Cyprus.

Data provided

Draft data collection forms were proposed by Hammond, Cañadas & Vázquez (2010) and modified in 2013 and 2015. They were then generated by ICCAT. The completed data forms were provided electronically to ICCAT and passed on for analysis.

Data processing

There were a number of issues with the data forms that needed to be clarified and/or resolved prior to organising the data into an appropriate form for analysis. These included errors/inconsistencies and missing data. Details and comments will be given in the Discussion section. Missing data were checked with the survey teams, noted and corrected in most cases (correction was not always possible). A total of 85 sightings of BFT were recorded in 2015. Eight sightings had to be discarded due to lack of information on cluster size and 10 due to lack of information on weight (8 of them being coincident in not having cluster size neither). Other two sightings did not have declination angles, so perpendicular distances could not be calculated (estimation of distances using positions of animals with respect to the tracks will be investigated and compared during the second phase, for the February report). Therefore, a total of 10 sightings had to be discarded due to lack of vital information for the analysis with cluster size (8 lacking cluster size data and 2 different ones lacking perpendicular distance), and 12 sightings had to be discarded due to lack of vital information for the analysis with weight (10 lacking weight data and 2 different ones lacking perpendicular distance), leaving only 75 sightings to be used in the analysis with cluster size and 73 with weight for 2015. Of those, only 34 with cluster size and 33 with weight were on effort.

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.

A combined dataset was created that was consistent across all data fields. This dataset was entered into software DISTANCE for analysis.

I.2 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 analyses were undertaken in software DISTANCE 6.2 http://www.ruwpa.st-and.ac.uk/distance/, which estimates all quantities and their uncertainties.

Fitting the detection function

Given the small amount of sightings “on effort”, the following process was followed: (a) all off effort tracks and corresponding sightings were associated to an artificial area “OFF” with surface area = 0; (b) a detection function was fitted to all sightings, on and off effort; and (c) an estimate of abundance was obtained using the fitted detection function. As the off effort tracks and sightings were associated to the artificial OFF area, and only the on effort ones to the actual survey blocks, the estimates of abundance only applied to the on effort tracks/sightings within the survey areas.

Detection functions were fitted to the perpendicular distance data to estimate the effective strip half-width, *esw*. Multi-Covariate Distance Sampling (MCDS) methods 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. Table I.1 shows the covariates tested in the models.

Analysis could not be done for each sub-area independently because of insufficient sample size. 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, 5,000 m right truncation distance was chosen.

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).

I.3 Results

Table I.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.

The detection functions either using school size as weight or as number of animals are not identical, as there was one sighting were cluster size was available, but not weight. Hence, with one sighting less, given the already small sample size, the detection functions varied slightly, but enough to yielding a different selection of model.

The final model selected both for cluster size and weight, had two covariates (team, with three factors; Air-Med, Unimar and Action-Air; and observer type, with two factors: Professional spotter and Scientific spotter) with a Half-normal key function. 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 plots show a good agreement between the cdf and the edf. Table I.3 shows the main parameters for the detection function and the results of the diagnostics tests. Figure I.I.13 shows the fitted detection function and Figure I.I.14 shows the Q-Q plot for cluster size. Figure I.I.18 shows the fitted detection function and Figure I.I.19 shows the Q-Q plot for weight. The individual effect of each factor in the detection function are shown in Figures I.15 to I.20 for cluster size (basically identical for weight).

Tables I.4 and I.5 show the estimates of density of schools, number of individuals and total weight of bluefin tuna in each sub-area, inside and outside respectively.

Overall, a total of 203,943 (94.1% CV) tonnes and 1,156,428 (75.8% CV) individuals of bluefin tuna were estimated in all the sub-areas pooled together. Most of the CV is due to the large CVs in the “outside” areas.

Table I.6 shows the results for 2015, divided as ‘inside’ sub-areas, ‘outside’ sub-areas, and total.

Comparison with previous estimates

A comparison between the estimates in 2010, 2011, 2013 and 2015 in each of the sub-areas is given in the second section of this report, after reanalysing all years only for the overlapped ‘inside’ areas. But a table with the pre-overlapping results for all years is given in Table I.7 for all inside sub-areas, in Table I.8 for all outside sub-areas and Table I.9 for the total of inside and outside sub-areas. It is important to highlight that some outside areas have changed considerably, mainly due to more restricted air space and extended areas where not spawning was considered, according to the updated map adopted in 2015. So, for example, Sub-areas E outside and D actually correspond to sub-area E outside of 2013 (plus a bit of the southern portion of D 2013). But given that no observations were made in E outside and D in 2015, there is no need to get deeper in this comparison.

For purpose of comparison, the surface areas of 2010 and 2011 prior to the overlapping process were recalculated again using the Transverse Mercator projection (in WGS 1984) in Distance (a different one was used at that time), and the analysis of those years were re-run with this projection's surface area so no noise is introduced in the comparison from this source.

I.4 Discussion

Survey logistics

Survey coverage

A situation like that in sub-area E outside and G inside, where the homogeneous coverage is not achieved with much more effort in some areas than in others (G) or barely no effort (E), should be strongly avoided when possible, as it may lead to biases of unknown level. When there are not enough resources to complete a replica, it is best to distribute the little time available either homogeneously or randomly across the study area, than localize it all on one side. And even more important, do not start a second replica without finishing completely the first one, and even worse start it where most of the effort of the first one already is (this is what happened in G inside). This leads to a much worse problem than when a single replica is not finished. In 2015, these problems were caused by several factors, only partly depending from the contractor, because of the many restrictions in some air spaces, partly communicated to the aircrafts at the very last moment for military reasons (area G), or even additional unforecastable factors, like the extremely limited fuel availability in Malta (area E), which reduced the operative area. In a large survey like the one carried out in 2015 these problems can be important.

The abundance estimate in sub-areas C, D and F, can be obtained only after adjusting the actual surveyed areas to eliminate the southernmost sections of D and F and the not surveyed corners in B and C, in order to maintain the equal coverage probability in the survey area. But given that no observation were made in F, and only one in D and C and 2 in B, this issue remains irrelevant now for these areas, as estimates are anyway unreliable and meaningless at this point.

Perpendicular distances

Looking at the detection functions by team, there is an obvious undesirable effect for the team of Unimar (Figure I.21), where there is a strong drop of detections in the first 500 meters from the line transect, exactly as what happened in 2013, despite having a bubble window. The smallest distance recorded for BFT was 324m (an off effort observation) (Figure I.19). This is probably a case of unfortunate effect of small sample size, as there were only 14 observations of BFT. Smaller perpendicular distances were obtained, though, for other species (down to 41m), demonstrating the casuality of the events and not a sighting habit limit. In the case of Action-Air there is a lack of sightings beyond 1000m. Air-Med had a much better pattern of distances (Figure I.20), although a strange drop in intermediate distances is observed, probably due to different searching behaviours of different observers. This will be explored in the second phase of the analysis.

Another problem was the rounding of angles especially in sub-areas B and G by Action-Air (in E they seem not-rounded). Rounded angles yield rounded perpendicular distances and lack of accuracy in this important measure. Therefore the detection function may not fit properly.

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 models varied between 40 % and 72% for the 'inside' sub-areas and 73 - 106% for 'outside' sub-areas. The precision of mean school size had a very large range, between 19 and 67% for the 'inside' sub-areas (much larger for E and G than for A and C). There was not enough data on the 'outside' sub-areas to estimate the mean school size CV except for A outside with 43% CV and B with 92%, but both based only on two observations, so rather useless[1]. CVs for estimates of total weight were high in all sub-areas: 46 - 98% for 'inside' sub-areas, and 89 – 118% for 'outside' sub-areas. Summing over all sub-areas surveyed, the CV of total abundance was 43% for the 'inside' sub-areas and 83% for the 'outside' sub-areas.

In Table I.4 it is obvious that, within the 'inside' sub-areas the largest CVs correspond to G followed by C and E. This is probably due to the heterogeneity in coverage in G inside as described above and the heterogeneity in the distribution of the sightings (see Figure I.10.2) which has probably increased greatly the variance for the encounter rate, together with having the highest CV for mean cluster size due to the small sample size. This is also possibly linked to the different timing in spawning in area G, which is usually anticipated compared to other areas.

The CVs of the 'outside' sub-areas were extremely high, due to extremely small number of observations there, making those estimates rather useless.

The number of schools seen in the sub-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 sub-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 sub-areas generates correlation in the estimates which was taken into account (in software DISTANCE) in estimating the CV of total abundance.

The main way to reduce the estimated CVs in future surveys is to potentially increase the number of sightings. This can be achieved partly by more efficient searching and mostly by increasing the amount of searching effort (transect length or more replicas).

Increasing searching effort will lead to a decrease in CV of abundance but it is not possible to make exact predictions about how much. CV should improve approximately as a function of the square root of sample size, as shown in Hammond, Cañadas & Vázquez (2010). As a rough idea of the effect, if total sample size were doubled from, for example, 72 sightings to 144 sightings by increasing searching effort, we might expect the CV of total abundance to decrease from 0.33 to about 0.24 (example extracted from 2011 data).

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 an undefined amount of their time beneath the surface and therefore they are unavailable for the detection (so-called availability bias). Estimates of abundance from these surveys are thus anyway 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 bias cannot be assumed stable over time. The patterns in tuna vertical movement depend on many factors, some of which can be controlled (constant time and geographical coverage of the survey) and thus reduce the uncertainty, but also some others which are not predictable (like oceanography/weather conditions interactions). Furthermore, the potential distribution of bluefin tuna in the Mediterranean is still partly unknown. To minimise and smoothing natural variation in using survey estimates as indices of abundance over time, surveys in future years should ideally occur in the same areas at the same time of year.

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[1] This problem is mostly linked to the choice of surveying areas where spawning was not a usual event and, therefore, the presence of tunas at the surface is not frequent.

Comparison between inside and outside areas in 2015

Table I.6 shows this comparison. With only 23% less effort in the outside sub-areas, there were 68% less observations, 58% less encounter rate and 46% less density of schools than in the inside sub-areas. The overall mean weight was much larger outside mainly due to sub-area B. The smallest weights were recorded in the easternmost sub-areas (G, both inside and outside, and E outside) with a very large difference with the other sub-areas, but the sample size is so small in them that these results are most probably irrelevant. Weight was double in C outside than in C inside, but again, with only one observation outside and three inside, this comparison is thus irrelevant. In A outside weight was 3 times that of A inside; there are a few more observations in A inside but still too few (only 2 in A outside) to make reliable comparisons. Density of animals was slightly larger overall in the inside sub-areas (1.329 animals/km^2, 43%CV) than in the outside sub-areas (1.191 animals/km^2, 83%CV), but the very large CV in the outside areas precludes reliable comparisons.

It is interesting to highlight that there were no BFT sightings on effort in 'outside' sub-area F and only 1 sighting in C, D, E and G. The majority were observed in A and B (only 2 in each). Therefore the CVs of density of animals are very large in the outside areas, yielding rather meaningless results in each of them. Hence, it would not be advisable to consider the comparison of density of animals between the inside and outside areas in 2015. As long as the CVs are so large, neither results not comparisons are meaningful.

Comparison with previous years estimates

'Inside' sub-areas

A comparison between the estimates in 2010, 2011, 2013 and 2015 in each of the sub-areas is discussed in the second section of this report, after reanalysing all years only for the overlapped 'inside' areas. But a table with the pre-overlapping results for all years is given in Table I.7 for all inside sub-areas and Table I.9 for the total of inside sub-areas.

'Outside' sub-areas

A comparison of results in the 'outside' sub-areas in 2013 and 2015 is given in Table I.8 for each sub-areas and Table I.9 for the total of outside sub-areas. Due to the new excluded outside areas, either because of air space exclusion or because of being considered non-spawning areas, the surface area to be explored in 2015 was 25% smaller than in 2013 (972,368 km^2 in 2015 *vs*. 1,303,470 km^2 in 2013). Additionally, in 2015, there was 16% less on effort time (line length) than in 2013: 11,121 km in 2015 *vs*. 13,278 km in 2013. The reasons for this decrease are unknown, but assumed to be weather conditions during the survey period, logistic constraints and air-space limitations. .

With only 16% less effort in 2015 with respect to 2013, there was 33% less amount of observations (12 in 2013 and 8 in 2015) yielding smaller encounter rate of schools in 2015, but larger density of schools (given that the surface area in 2015 was much smaller than in 2013). On the other hand, both mean cluster size and mean weight are considerable larger in 2015 than in 2013, especially weight (100 times larger, while cluster size was 8 times larger). As result, both the total abundance of animals and the total weight are larger much in 2015. It is important to highlight once more that as long as the CVs of these out-side sub-areas remain that large with such small sample size, these comparisons may be meaningless.

TABLES

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

Covariate	Type	Levels
Sighting related		
School size	integer	
Weight	integer	
Cue	factor	ripples shining splash travelling other
Weight class	factor (tn)	0-50 50.1-200 200.1-500 500.1-3000
School size class	factor	1-50 51-200 201-1000 1001-8000
Environment related		
Beaufort sea state	factor	calm (glassy) calm (rippled) smoothed (wavelets) slight moderate rough
Air haziness	factor	clear slight moderate diffused heavy
Water turbidity	factor	clear slight medium heavy
Glare intensity	factor	null slight moderate strong
Subjective	factor	poor moderate good
Clouds	factor	0 to 8
Effort related		
Observer type	factor	Scientific spotter Professional spotter

Team	factor	Air-Med Action-Air Unimar
Airplane	Factor	Cessna Partenavia
Altitude	integer	

Table I.2. Areas, number and total length of transects and number of sightings of bluefin tuna for each survey sub-area.

Sub-area	Area (km^2)	Number of transects	Length of transects (km)	Number of observations (after truncation)
Inside				
A	62,150	15	4,143	7
C	64,610	7	3,237	3
E	117,718	12	5,862	13
G	68,013	10	1,172	2
Subtotal Inside	312,491	44	14,404	25
Outside				
A	123,351	8	1,508	2
B	87,334	6	888	2
C	149,607	6	1,866	1
D	147,666	6	2,122	1
E	92,378	2	284	10
F	130,585	11	1,171	0
G	241,447	8	3,241	1
Subtotal Outside	972,368	47	11,079	8
Total	1,284,859	91	25,493	33

Table I.3. Parameters and diagnostics of the detection functions.

Detection function	Average probability of detection (p)	Effective strip width (esw) (km)	K-S test (p)	Cramer-von Mises test (unweighted) (p)
Cluster size	0.184	0.92	0.851	0.80
Weight	0.183	0.92	0.880	0.88

Table I.4. Mean school size, density and total weight and abundance of bluefin tuna for each "inside" sub-area.

		Sub-area				
		A	**C**	**E**	**G**	**TOTAL**
Survey area (km^2)		62,150	64,610	117,718	68,013	**312,491**
Number of transects		15	7	12	10	**44**
Transect length (km) (L)		4,143	3,237	5,862	1,172	14,413
Effective strip width x2 (km)		5.0	5.0	5.0	5.0	5.0
Area searched (km^2)		13,435	10,496	19,010	3,799	46,740
% coverage		21.6	16.2	16.1	5.6	15
Number of sightings (n)		7	3	13	2	25
Encounter rate of schools	**n/L**	0.0017	0.0009	0.0022	0.0017	0.0017
	CV (%)	37.9	60.5	26.1	70.6	30.5
Density of schools (km^2)	**Density of schools**	0.521	0.286	1.203	0.723	0.941
	CV (%)	40.2	61.9	29.7	71.1	29.1
Weight (tonnes)	**Mean weight**	160.7	190.0	391.62	9.0	**140.2**
	CV (%)	11.7	19.9	54.76	66.7	26.6
School size (animals)	**Mean school size**	708	1,533	2,030	600	**827**
	CV (%)	19.8	19.0	56.83	66.7	19.7
Density of animals (per km^2)	**Density of animals**	0.369	0.438	2.442	0.478	**1.329**
	CV (%)	44.8	64.8	64.1	98.3	42.9
Total weight (tonnes)	**Total weight**	**5,419**	**3,654**	**56,004**	**484**	**70,412**
	CV (%)	40.4	65.2	62.3	98.2	53.4
	Lower 95% CL	2,449	1,099	16,957	55	
	Upper 95% CL	11,991	12,150	184,960	4,265	
Total abundance (animals)	**Total abundance**	**22,912**	**28,317**	**287,420**	**32,523**	**415,301**
	CV (%)	44.8	64.8	64.1	98.3	42.9
	Lower 95% CL	9,814	8,569	84,285	3,688	
	Upper 95% CL	53,491	93,569	980,150	286,780	

Table I.5. Mean school size, density and total weight and abundance of bluefin tuna for each "outside" sub-area.

		Sub-area							
		A	B	C	D	E	F	G	TOTAL
Survey area		123,351	87,334	149,607	147,666	92,378	130,585	241,447	**972,368**
Number of transects		8	6	6	6	2	11	8	**47**
Transect length (km) (L)		1,508	888	1,866	2,122	284	1,171	3,241	**11,079**
Effective strip width x2 (km)		5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Area searched (km2)		4,889	2,880	6,051	6,881	922	3,797	10,509	35,928
% coverage		4.0	3.3	4.0	4.7	1	2.9	4.4	3.7
Number of sightings (n)		2	2	1	1	1	0	1	7
Encounter rate of schools	**n/L**	0.0013	0.0023	0.0005	0.0005	0.0035		0.0003	0.0007
	CV (%)	72.2	73.7	105.2	101.4	97.1		103.0	44.8
Density of schools (per sq km)	**Density of schools**	0.719	1.221	0.291	0.256	1.908		0.167	0.507
	CV (%)	73.5	75.0	106.1	102.3	98.1		103.9	57.1
Weight (tonnes)	**Mean weight**	240.0	1575.0	300.0	200.0	0.3		20.0	**592.9**
	CV (%)	50.0	90.5						68.1
School size (animals)	**Mean school size**	1,400	7,800	2,500	1,000	8		1,333	**3,319**
	CV (%)	42.9	92.3						59.2
Density of animals (per sq km)	**Density of animals**	1.007	9.527	0.727	0.256	0.015		0.223	**1.191**
	CV (%)	85.1	119.0	106.1	102.3	98.1		103.9	83.0
Total weight (tonnes)	**Total weight**	**21,513**	**169,700**	**13,176**	**7,625**	**57**		**816**	**212,887**
	CV (%)	88.9	117.5	106.1	102.3	98.1		103.9	103.8
	Lower 95% CL	3,861	7,090	2,210	1,294	8		146	
	Upper 95% CL	119,870	4,061,300	78,545	44,919	417		4,572	
Total abundance (animals)	**Total abundance**	**124,250**	**832,060**	**108,710**	**37,746**	**1,410**		**53,867**	**1,158,043**
	CV (%)	85.1	119.0	106.1	102.3	98.1		103.9	83.0
	Lower 95% CL	25,424	31,921	18,238	6,408	193		9,618	
	Upper 95% CL	607,170	21,688,000	648,010	222,350	10,315		301,680	

Table I.6. Mean school size, density and total weight and abundance of bluefin tuna for the total “inside” and “outside” sub-areas in 2015.

Sub-area	2015 ‘inside’	2015 ‘outside’	TOTAL
Survey area (km^2)	312,491	972,368	**1,284,859**
Number of transects	44	47	**91**
Transect length (km)	14,413	11,079	25,493
Effective strip width x2 (km)	5.0	5.0	5.0
Area searched (km2)	46,740	35,928	82,668
% Coverage	15.0	3.7	6.4
Number of schools	25	8	33
Encounter rate of schools	0.0017	0.0007	0.0013
%CV encounter rate	30.5	44.8	25,2
Density of schools (1000 km^{-2})	0.941	0.507	0.613
%CV density of schools	29.1	57.1	31.5
Mean weight (t)	140.2	592.9	257.6
%CV mean weight	26.6	68.1	42.5
Mean cluster size (animals)	**827**	**3,319**	**1,473**
%CV mean cluster size	19.7	59.2	36.6
Density of animals	**1.329**	**1.191**	**1.225**
%CV density of animals	42.9	83.0	66.0
Total weight (t)	**70,412**	**212,887**	**283,299**
%CV total weight	53.4	103.8	72.9
Total abundance (animals)	**415,301**	**1,158,043**	**1,573,344**
%CV total abundance	42.9	83.0	66.0

Table I.7. Mean school size, density and total weight and abundance of bluefin tuna for the "inside" sub-areas the four years of surveys.

Year	**2010**				**2011**			**2013**				**2015**			
Sub-area	**A inside**	**C inside**	**E inside**	**G inside**	**A inside**	**C inside**	**E inside**	**A inside**	**C inside**	**E inside**	**G inside**	**A inside**	**C inside**	**E inside**	**G inside**
Survey area (km^2)	62,150	54,636	132,453	68,819	62,150	54,636	104,366	62,194	54,177	82,054	56,329	62,150	64,610	117,718	68,013
Transect length (km)	6,301	8,703	12,393	3,482	7,977	8,771	11,429	6,807	2,791	4,371	1,700	4,143	3,237	5,862	1,172
Truncation distance right(km)	7.5	4.0	7.5	4.0	7.7	7.7	0.8	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Truncation distance left (km)	1.3	0.30	1.25	0.30			0.1								
Effective strip width x2 (km)	7.07	2.92		2.92	7.03	7.03	0.76	4.6	4.6	4.6	4.6	3.2	3.2	3.2	3.2
Area searched (km^2)	44,539	25,372		10,151	56,066	61,646	8,635	31,311	12,838	20,106	7,821	13,435	10,496	19,010	3,799
% coverage	71.7	46.4		14.8	90.2	112.8	8.3	50.3	23.7	24.5	13.9	21.6	16.2	16.1	5.6
Number of schools ON effort	7	6	28	31	11	10	35	13	11	20	12	7	3	13	2
Abundance of schools	10	12	65	169	12	9	403	28	40	260	132	57	32	142	63
%CV abundance of schools	55	53		40	36.7	35.7	29.4	51	49	54	48	40.2	62.1	29.7	72.0
Encounter rate of schools	0.0011	0.0007	0.0023	0.0089	0.0014	0.0011	0.0031	0.0018	0.0039	0.0046	0.0071	0.0017	0.0009	0.0022	0.0017
%CV encounter rate	51.0	43.0		25.0	32.0	31.0	24.0	42	44	47	41	37.6	60.5	26.1	70.6
Density of schools (1000 km^{-2})	0.157	0.237	0.491	3.054	0.197	0.162	4.011	0.447	0.742	3.164	2.343	0.916	0.503	1.203	0.926
%CV density of schools	55.0	54.4		41.0	36.7	35.7	29.3	51	49	54	48	40.2	62.1	29.7	72.0
Mean weight (t)	127.1	124.2		62.1	84.8	42.7	110.7	90.1	189.0	4.2	3.3	132.2	190.0	391.6	9.0
%CV weight	8.0	5.6		13.0	26.0	44.0	27.0	32	22	103	62	21.3	19.9	54.8	66.7
Mean cluster size (animals)					789	291	1,362	439	1,536	111	272	708	1,533	2,030	600
%CV abundance					26.0	31.0	32.0	35	19	108	57	19.8	19.0	56.8	66.7
Density of animals (km^{-2})					0.154	0.047	5.463	0.196	1.139	0.351	0.638	0.648	0.771	2.442	0.555
%CV density of schools					42.9	45.8	41.9	45	53	99	63	44.8	64.9	64.1	98.1
Total weight (t)	**1,242**	**1,604**	**6,264**	**13,047**	**1,031**	**378.6**	**46,877**	**1,083**	**6,633**	**949**	**436**	**7,603**	**6,233**	**56,004**	**572**
%CV total weight	54.8	54.7		43.0	42.9	54.4	41.3	40	59	96	68	45.5	65.2	62.3	98.1
L 95% CI total weight	447	579		5,766	458	138	21,311	504	2204	193	124	3,217	1,873	16,957	65
U 95% CI total weight	3,453	4,442		29,521	2,321	1,041	103,112	2327	19965	4671	1532	17,971	20,737	184,960	5,055
Total abundance (animals)					**9,598**	**2,579**	**570,130**	**12,194**	**61,725**	**28,819**	**35,911**	**40,298**	**49,802**	**287,420**	**37,781**
%CV total abundance					42.9	45.8	41.9	45	53	99	63	44.8	64.9	64.1	98.1
L 95% CI total abundance					4,264	1,084	256,567	5,191	22,874	5,603	11,034	17,279	15,047	84,285	4,278
U 95% CI total abundance					21,602	6,135	1,266,912	28,647	166,562	148,238	116,870	93,980	164,830	980,150	333,700

Table I.8. Mean school size, density and total weight and abundance of bluefin tuna for the "outside" sub-areas 2013 and 2015.

Year	**2013**							**2015**						
Sub-area	**A outside**	**B**	**C outside**	**D**	**E outside**	**F**	**G outside**	**A outside**	**B**	**C outside**	**D**	**E outside**	**F**	**G outside**
Survey area (km²)	112,140	157,455	179,121	171,047	137,682	296,961	249,064	123,351	87,334	149,607	147,666	92,378	130,585	241,447
Transect length (km)	1,777	2,946	1,444	1,399	1,127	2,080	2,505	1,508	888	1,866	2,122	284	1,171	3,241
Truncation distance right(km)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Truncation distance left (km)														
Effective strip width x2 (km)	4.6	4.6	4.6	4.6	4.6	4.6	4.6	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Area searched (km²)	8,173	13,552	6,645	6,436	5,184	9,568	11,523	4,889	2,880	6,051	6,881	690	3,797	10,509
% coverage	7.3	8.6	3.7	3.8	3.8	3.2	4.6	4.0	3.3	4.0	4.7	0.7	2.9	4.4
Number of schools ON effort	2	0	0	1	1	0	8	2	2	1	1	1	0	1
Abundance of schools	20	0	0	26	68	0	308	89	107	43	38	176		40
%CV abundance of schools	97	0	0	103	106	0	100	73.5	75.0	106.1	102.3	98.1		103.9
Encounter rate of schools	0.0011	0.0000	0.0000	0.0007	0.0009	0.0000	0.0032	0.0013	0.0023	0.0005	0.0005	0.0035		0.0003
%CV encounter rate	96	0	0	101	103	0	99	72.2	73.7	105.2	101.4	97.1		103.0
Density of schools (1000 km⁻²)	0.174	0.000	0.000	0.153	0.495	0.000	1.235	0.719	1.221	0.291	0.256	1.908		0.167
%CV density of schools	97	0	0	103	106	0	100	73.5	75.0	106.1	102.3	98.1		103.9
Mean weight (t)	87.5	0.0	0.0	20.0	1.5	0.0	4.4	240.0	1575.0	300.0	200.0	0.3		20.0
%CV weight	0	0	0	0	0	0	61	50.0	90.5					
Mean cluster size (animals)	700	0	0	1,500	6	0	418	1,400	7,800	2,500	1,000	8		1,333
%CV abundance	0	0	0	0	0	0	60	42.9	92.3					
Density of animals (km⁻²)	0.122	0.000	0.000	0.229	0.003	0.000	0.517	1.007	9.527	0.727	0.256	0.015		0.223
%CV density of schools	97	0	0	103	106	0	117	85.1	119.0	106.1	102.3	98.1		103.9
Total weight (t)	**1,104**	**0**	**0**	**477**	**98**	**0**	**1,309**	**21,513**	**169,700**	**13,176**	**7,625**	**57**		**816**
%CV total weight	96	0	0	103	105	0	117	88.9	117.5	106.1	102.3	98.1		103.9
L 95% CI total weight								3,861	7,090	2,210	1,294	8		146
U 95% CI total weight								119,870	4,061,300	78,545	44,919	417		4,572
Total abundance (animals)	**13,693**	**0**	**0**	**39,133**	**409**	**0**	**128,745**	**124,250**	**832,060**	**108,710**	**37,746**	**1,410**		**53,867**
%CV total abundance	97	0	0	103	106	0	117	85.1	119.0	106.1	102.3	98.1		103.9
L 95% CI total abundance								25,424	31,921	18,238	6,408	193		9,618
U 95% CI total abundance								607,170	21,688,000	648,010	222,350	10,315		301,680

Table I.9. Mean school size, density and total weight and abundance of bluefin tuna for the total "inside" and "outside" sub-areas.

Sub-areas	**Inside**				**Outside**		**Inside + Outside**	
Year	**2010**	**2011**	**2013**	**2015**	**2013**	**2015**	**2013**	**2015**
Survey area (km^2)	318,058	221,151	254,754	312,491	1,303,470	972,368	1,558,224	1,284,859
Transect length (km)	30,879	28,177	15,669	14,413	13,278	11,079	28,947	25,493
Truncation distance right(km)			5.0	5.0	5.0	5.0	5.0	5.0
Truncation distance left (km)								
Effective strip width x2 (km)			4.6	3.2	4.6	3.2	4.6	3.2
Area searched (km^2)	80,063	126,348	72,075	46,740	61,079	35,928	133,155	82,668
% coverage	25.2	57.1	28.3	15.0	4.7	3.7	8.5	6.4
Number of schools ON effort	72	56	56	25	12	8	68	33
Abundance of schools	256	424	460	294	421	493	881	787
%CV abundance of schools	29.9	24.7	34	29	75	57		31
Encounter rate of schools	0.0023	0.0020	0.00357	0.0017	0.0009	0.0007	0.0023	0.0013
%CV encounter rate	20.0	46.9	23	31	69	45		25,2
Density of schools (1000 km^{-2})	0.805	1.917	1.804	0.941	0.323	0.507	0.001	0.613
%CV density of schools	30.0	25.0	34	29	76	57		31
Mean weight (t)			22.6	140.2	5.5	**592.9**		**257.6**
%CV weight			51	27	75	68		43
Mean cluster size (animals)			302	**827**	432	**3,319**		**1,473**
%CV abundance			43	20	49	59		37
Density of animals (km^{-2})		**2.6086**	0.544	1.329	0.140	**1.191**	0.206	**1.225**
%CV density of schools		41.0	35	43	86	83	0	66
Total weight (t)	**22,157**	**48,287**	**9,100**	**70,412**	**2,988**	**212,887**	**12,088**	**283,299**
%CV total weight		40.0	45	53	65	104		73
Total abundance (animals)		**582,307**	**138,650**	**415,301**	**181,980**	**1,158,043**	**320,629**	**1,573,344**
%CV total abundance		41.0	35	43	86	83		66

FIGURES

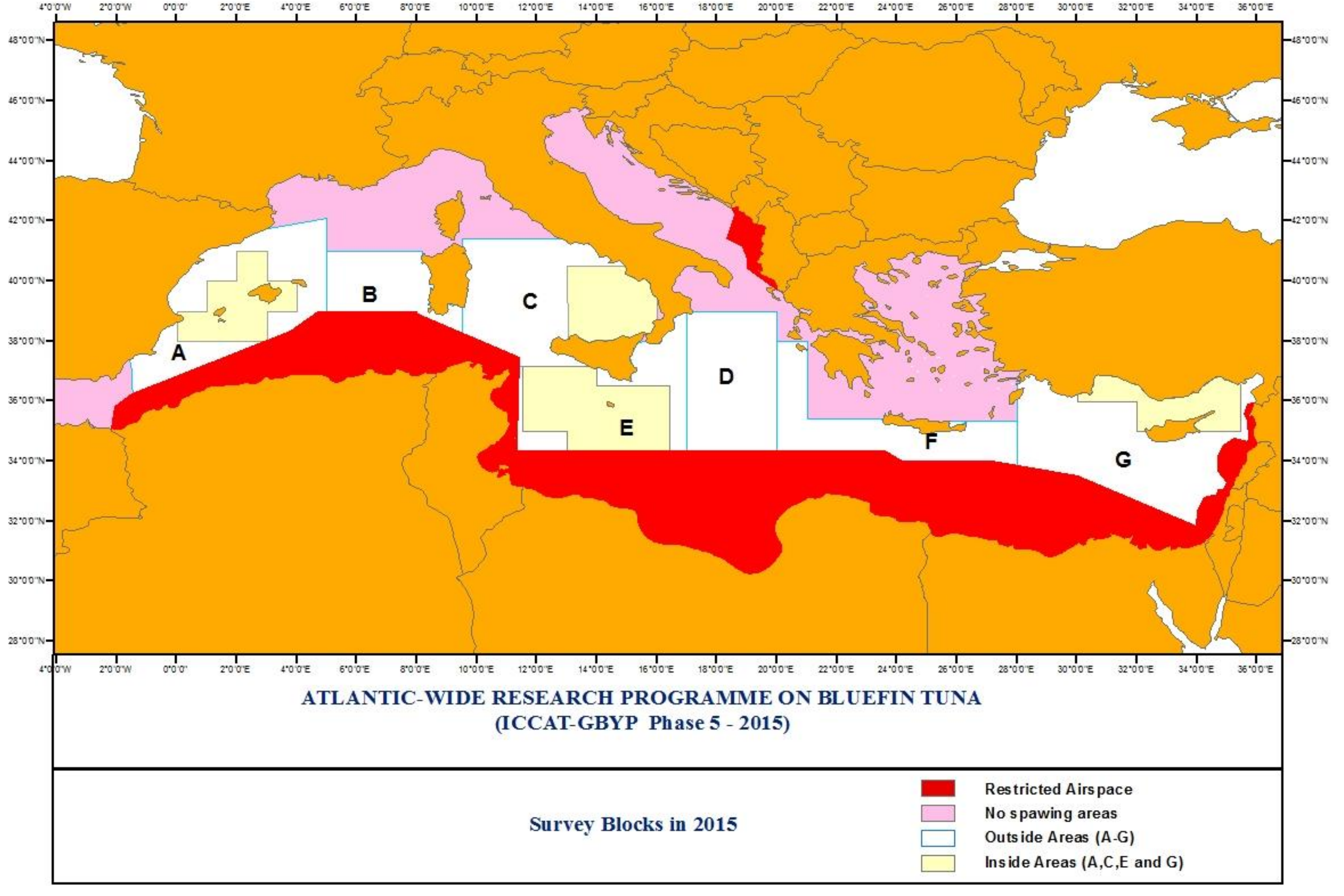


Figure I.1. Survey blocks

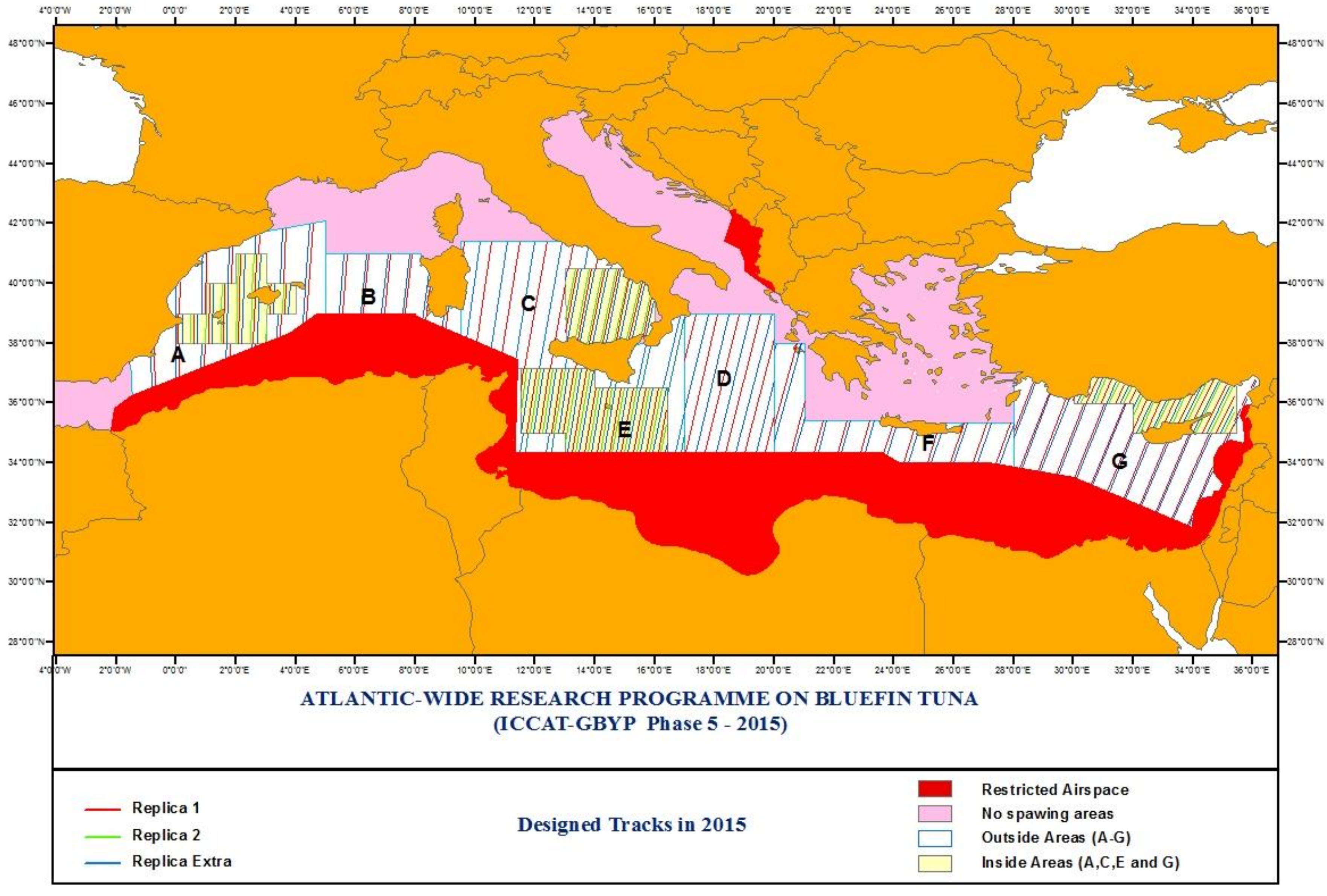


Figure I.2. Originally designed transects.

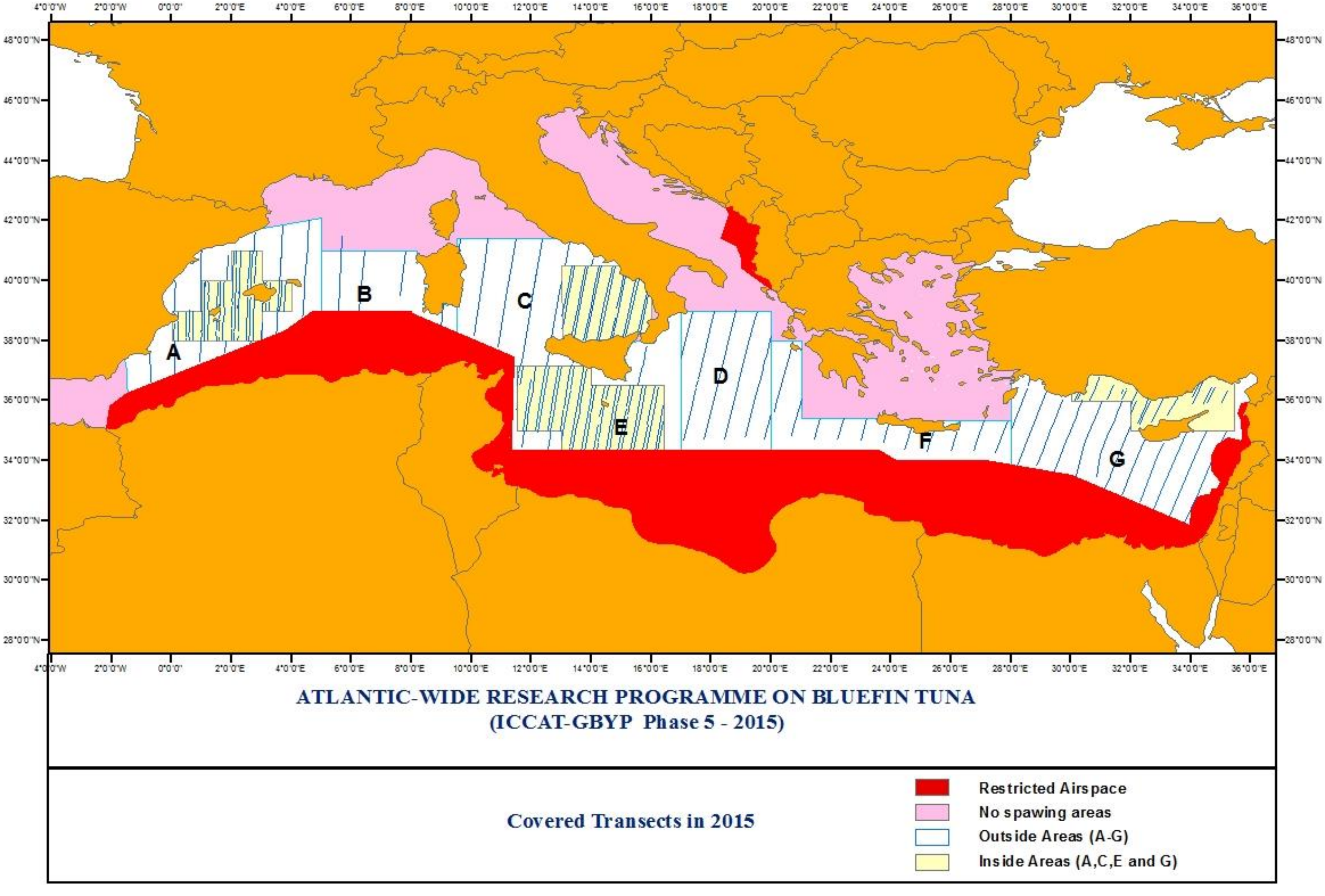


Figure I.3. Covered Transects on effort.

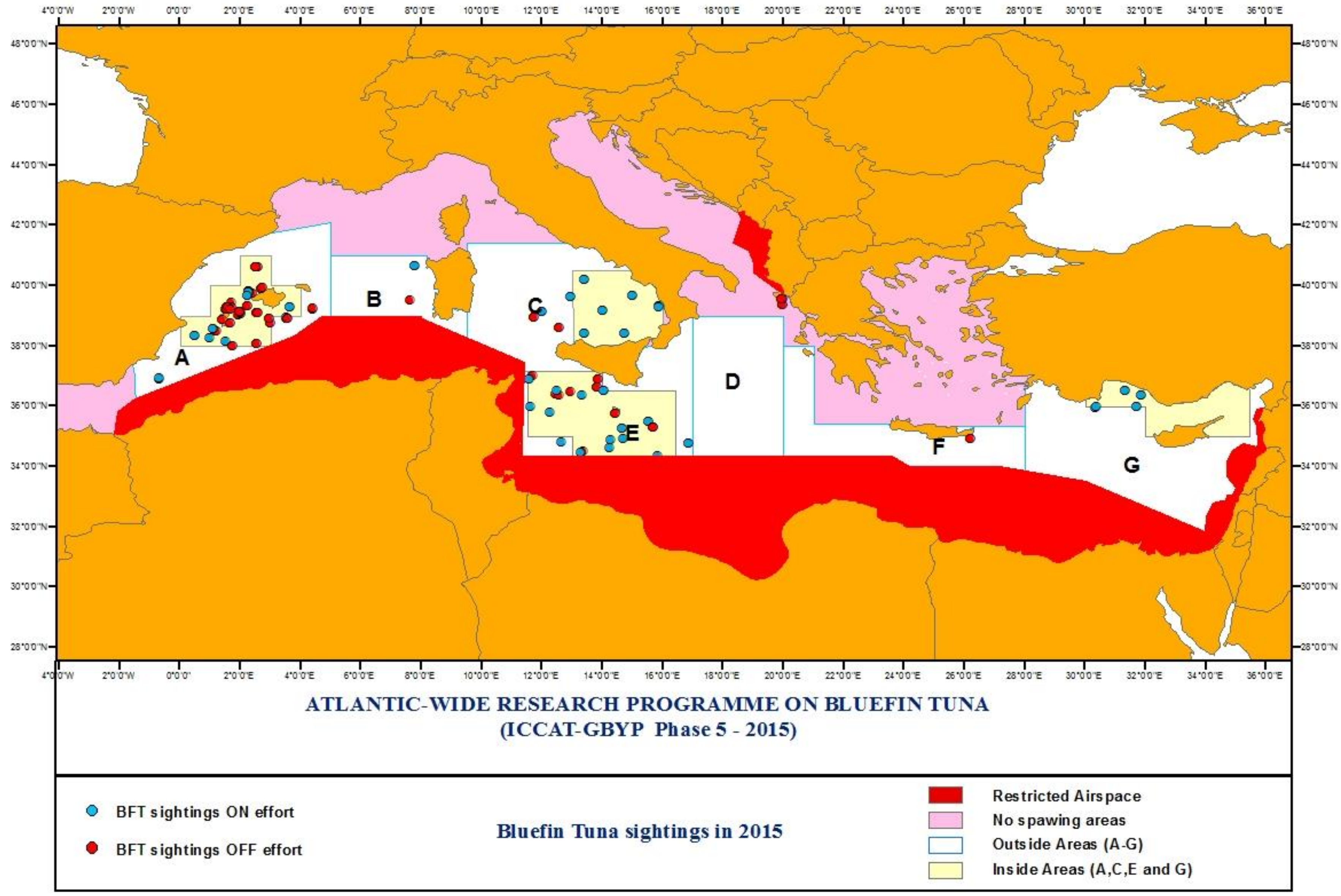


Figure I.4. Sightings of bluefin tuna on and off effort.

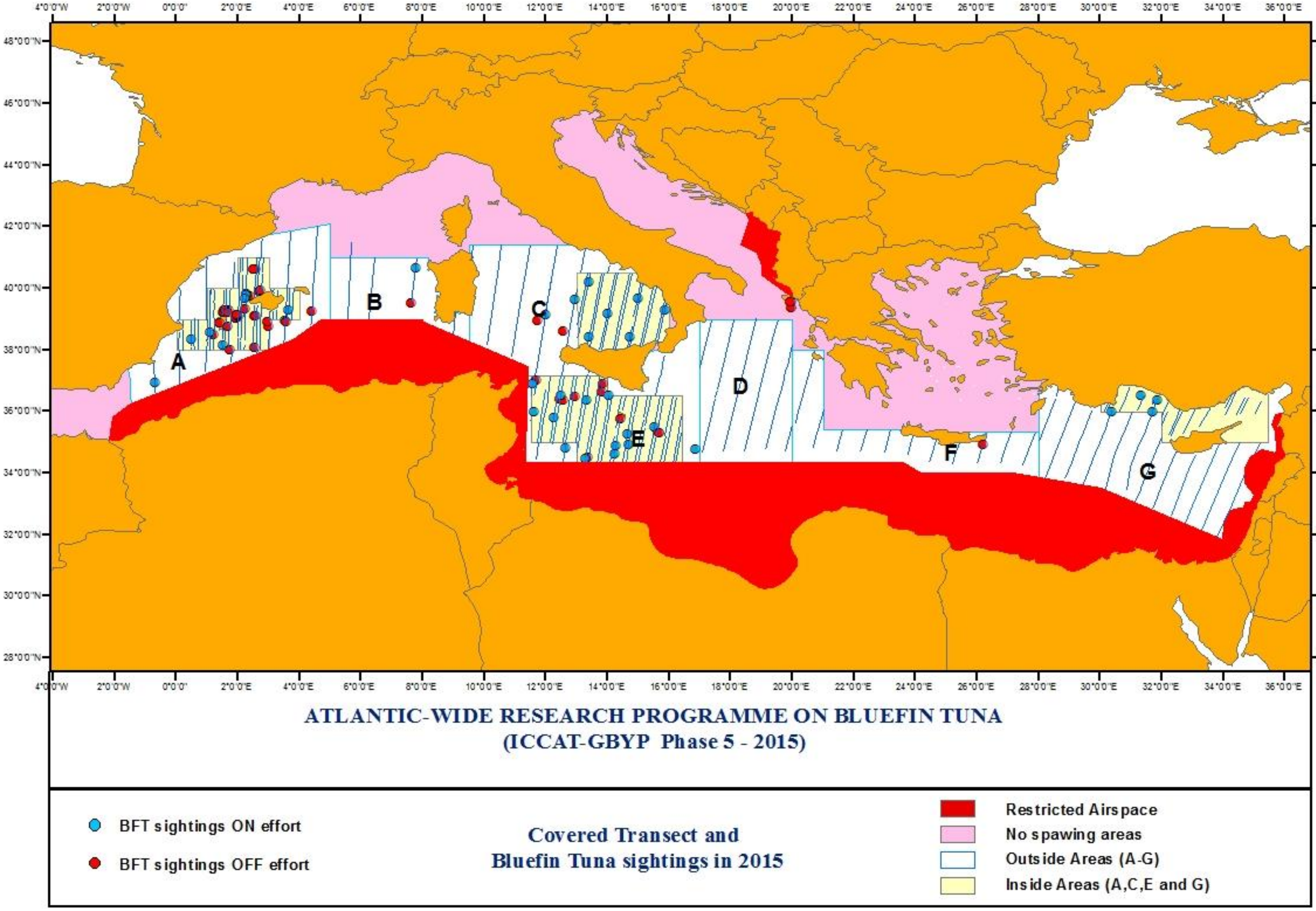


Figure I.5. Transects flown on effort and sightings of bluefin tuna on and off effort.

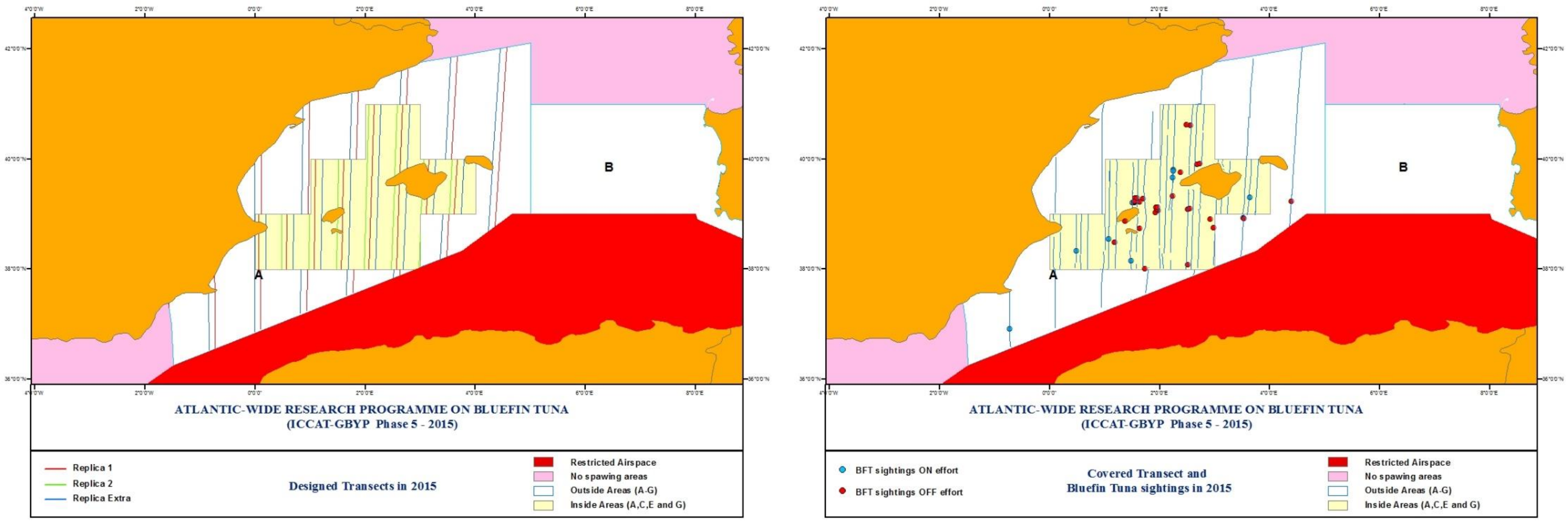


Figure I.6. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area A (4 of the A outside observations are in the border with A inside, so they may seem to be withinh A inside in the map) .

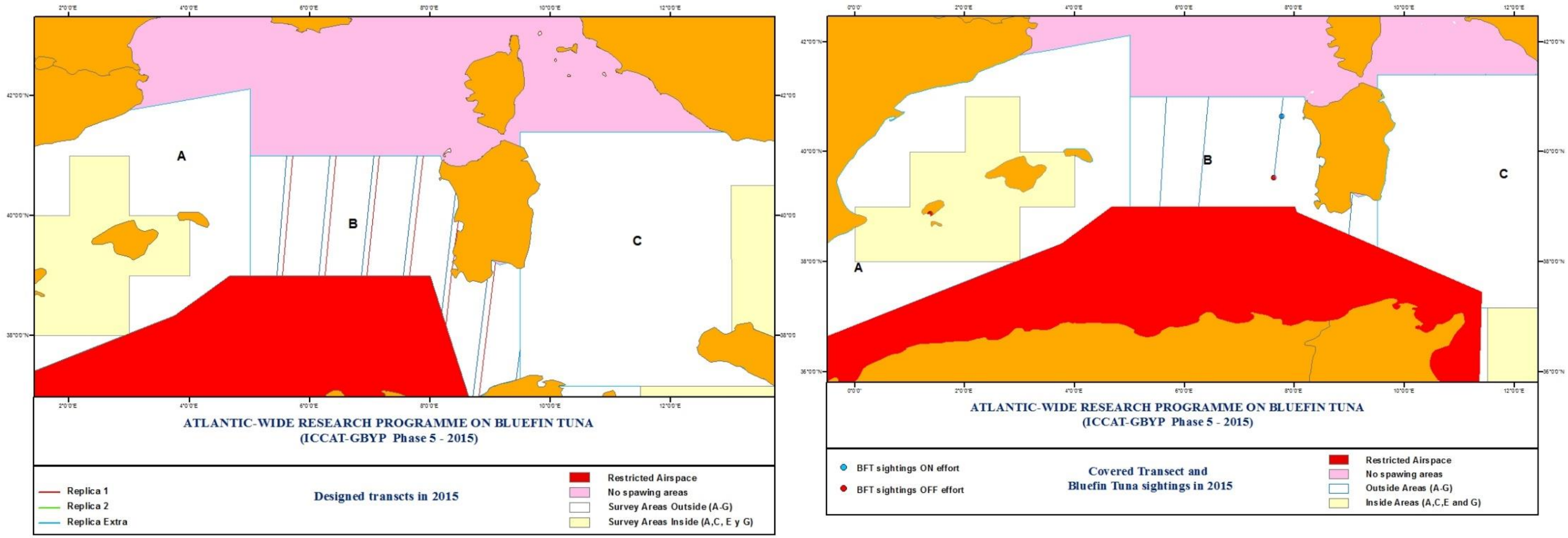


Figure I.7. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area B.

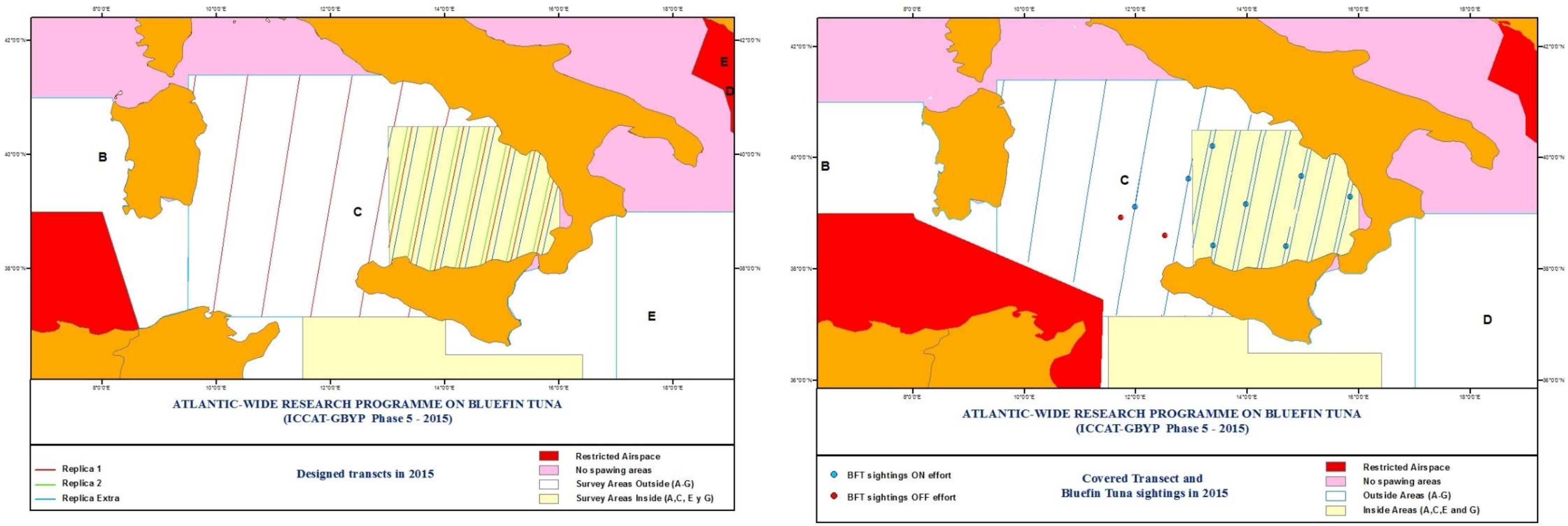


Figure I.8. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area C (one of the on effort observations lacked information on perpendicular distance, so could ont be used for analysis).

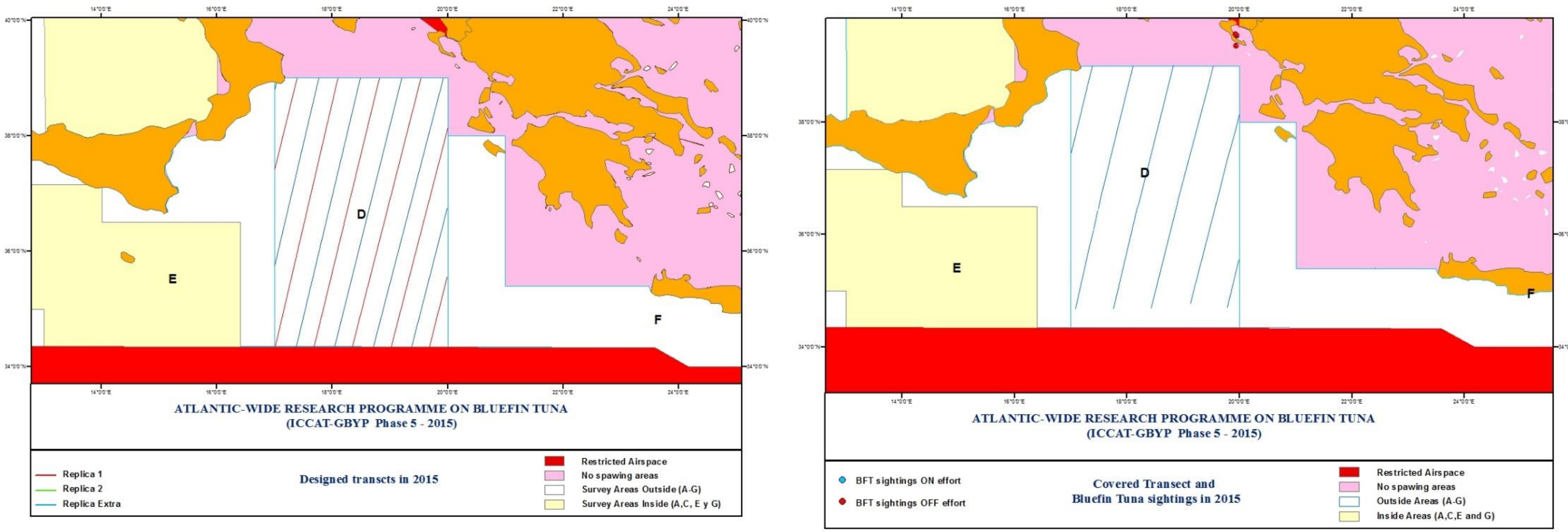


Figure I.9. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area D.

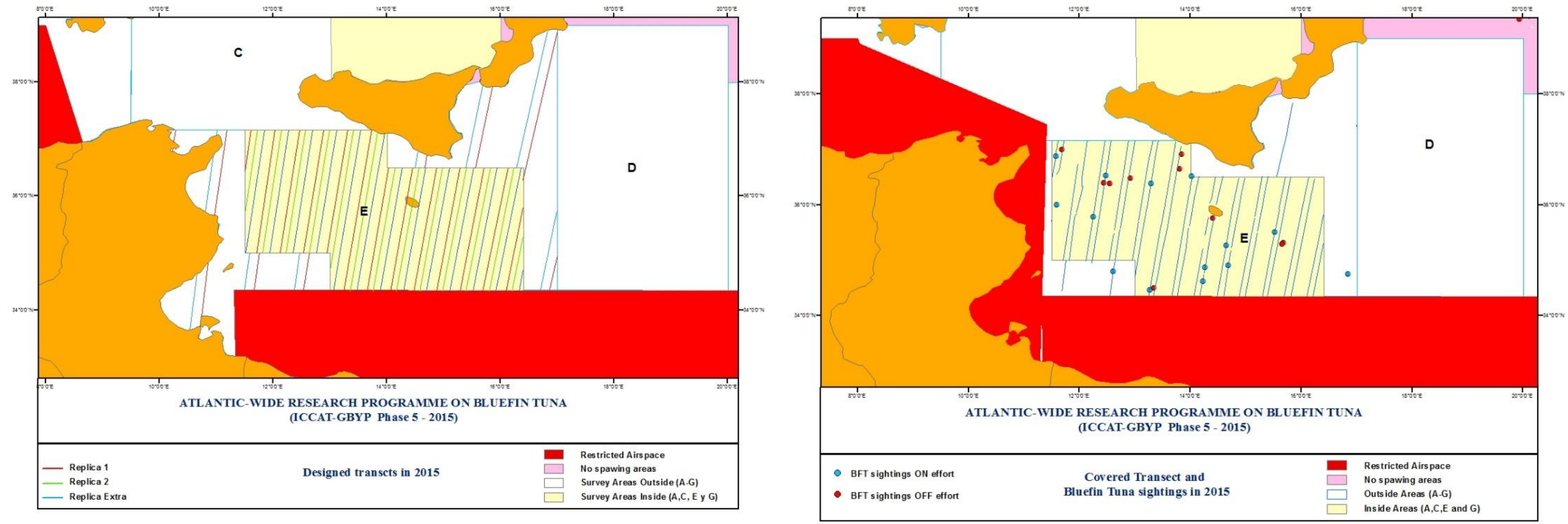
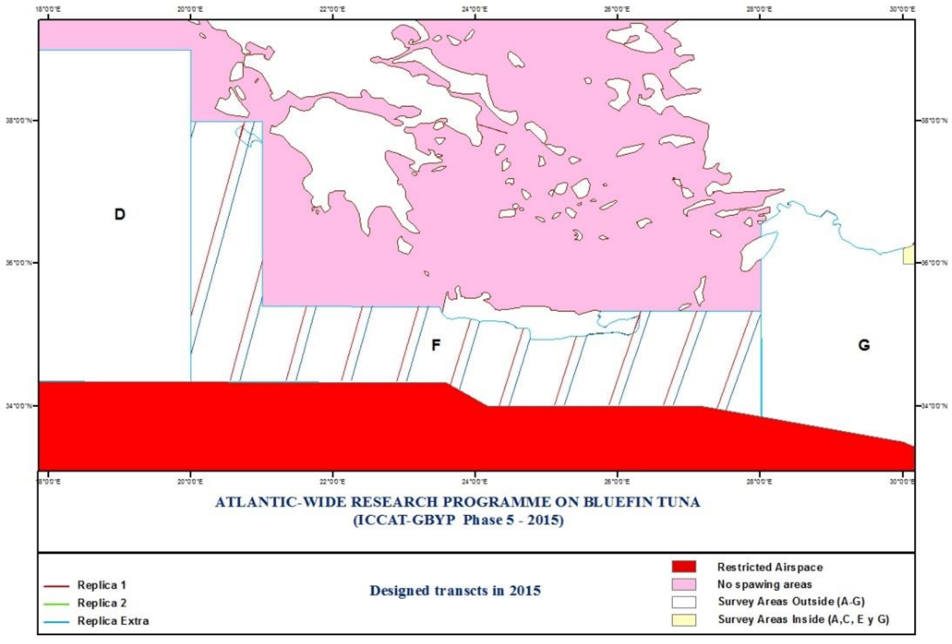


Figure I.10. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area E.



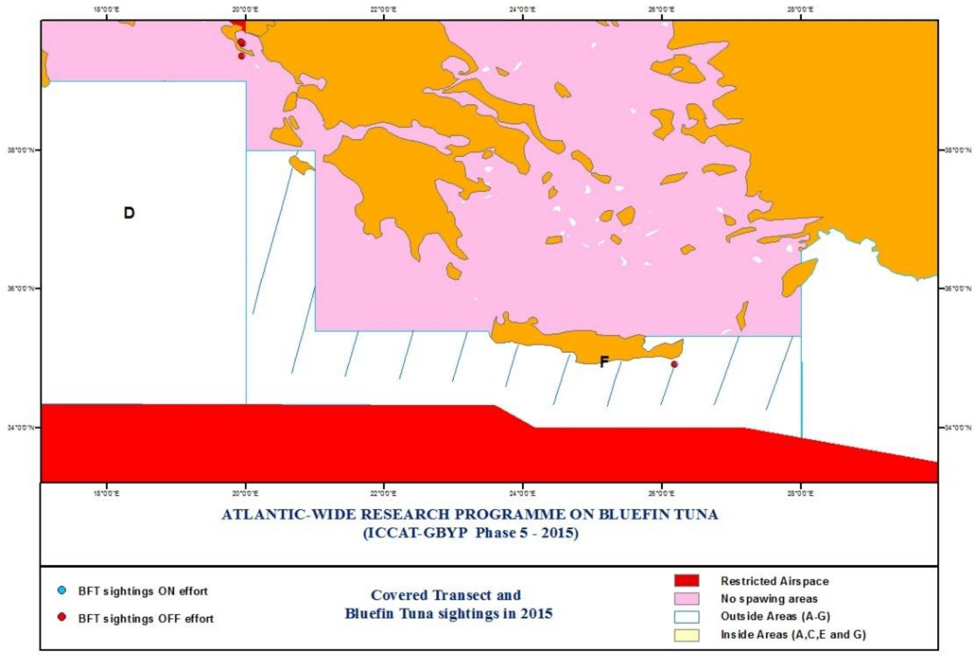


Figure I.11. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area F.

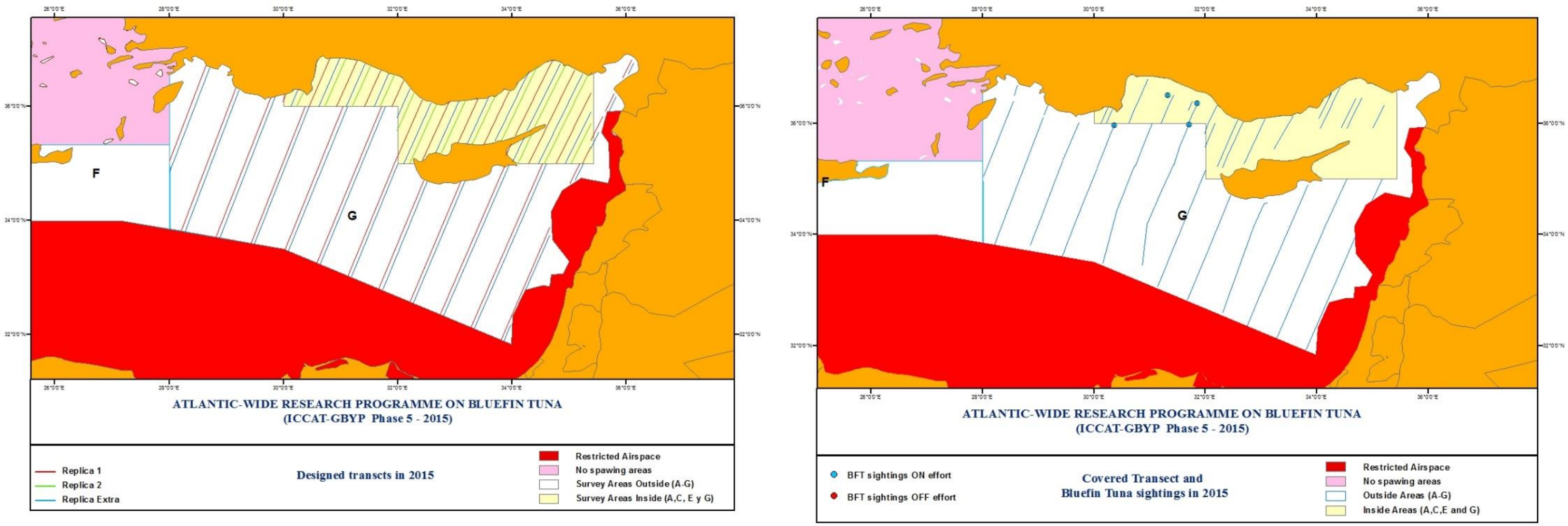


Figure I.12. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area G.

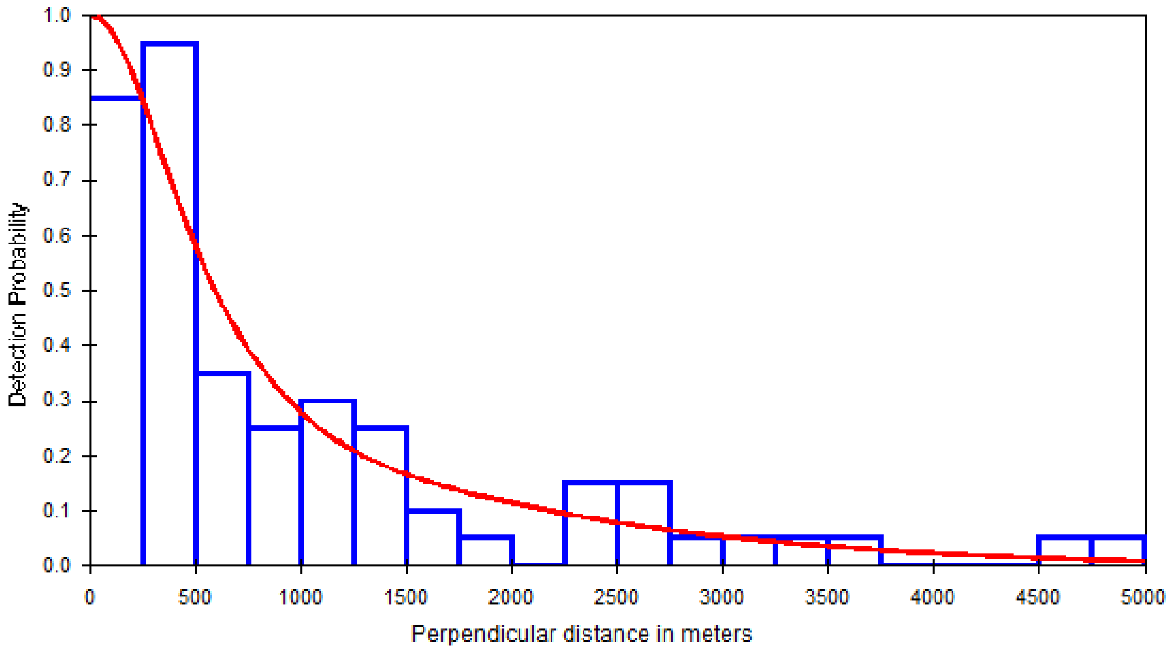


Figure I.13. Detection function for cluster size, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings.

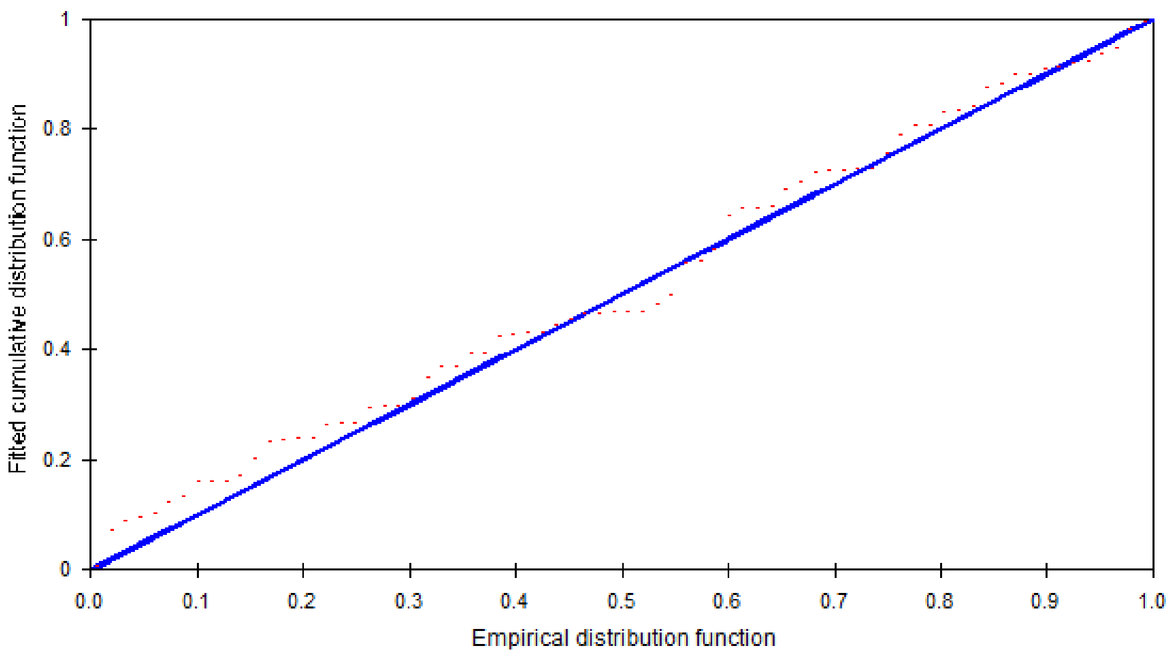


Figure I.14. Q-Q plot for cluster size.

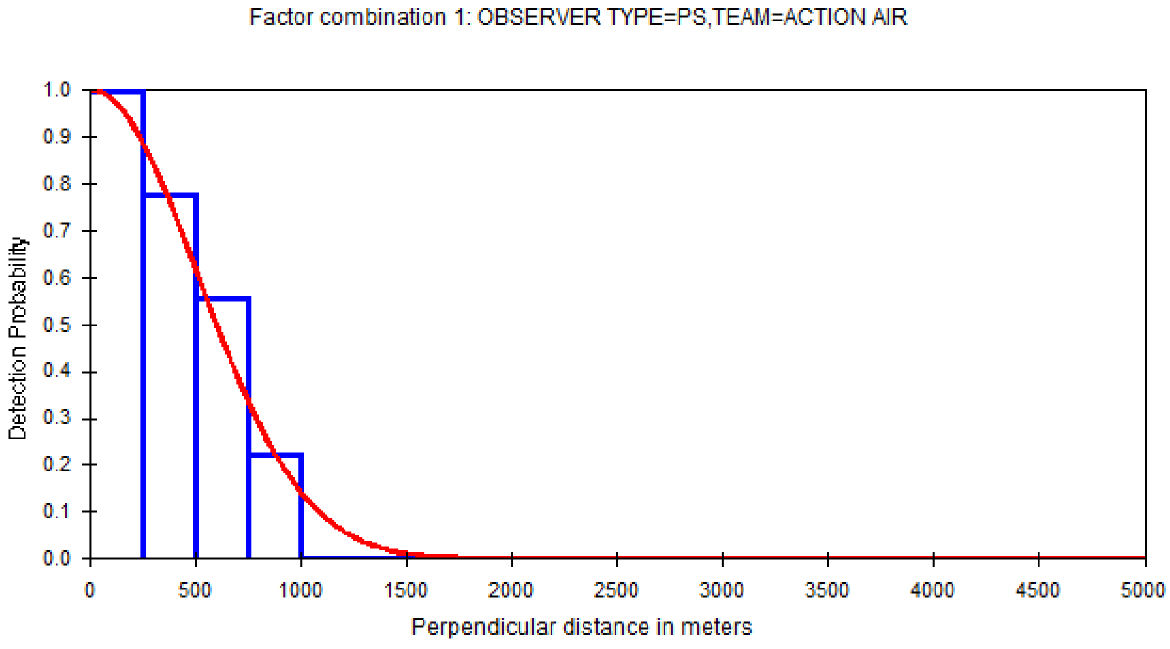


Figure I.15. Detection function for Professional spotter in Action-Air.

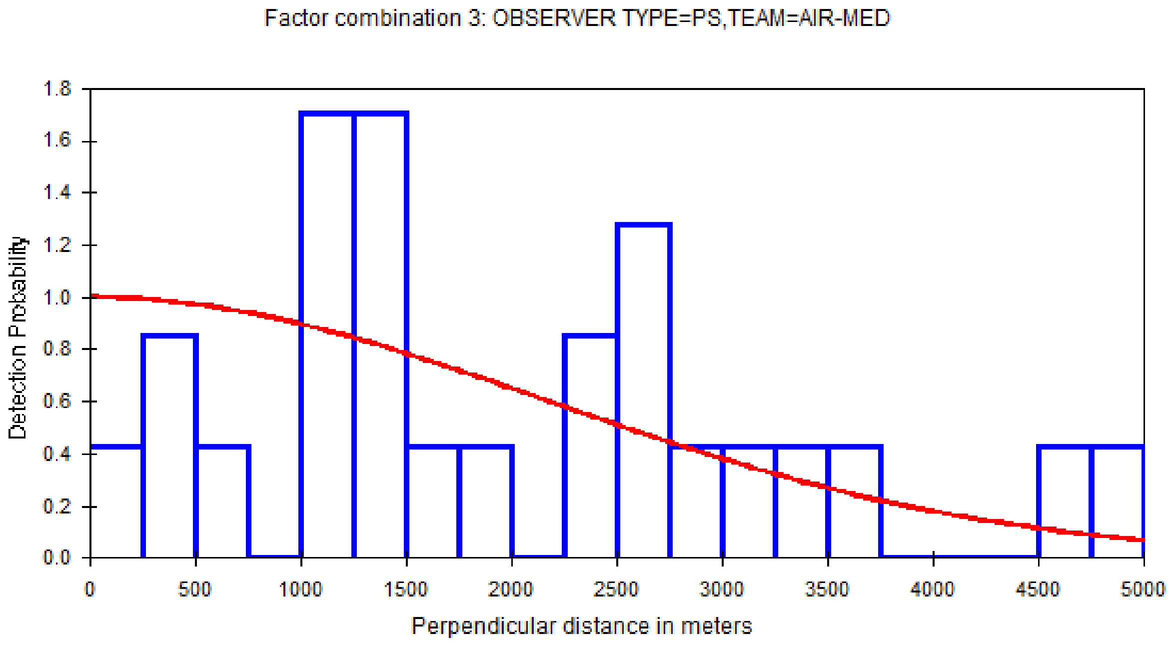


Figure I.16. Detection function for Professional spotter in Air-Med.

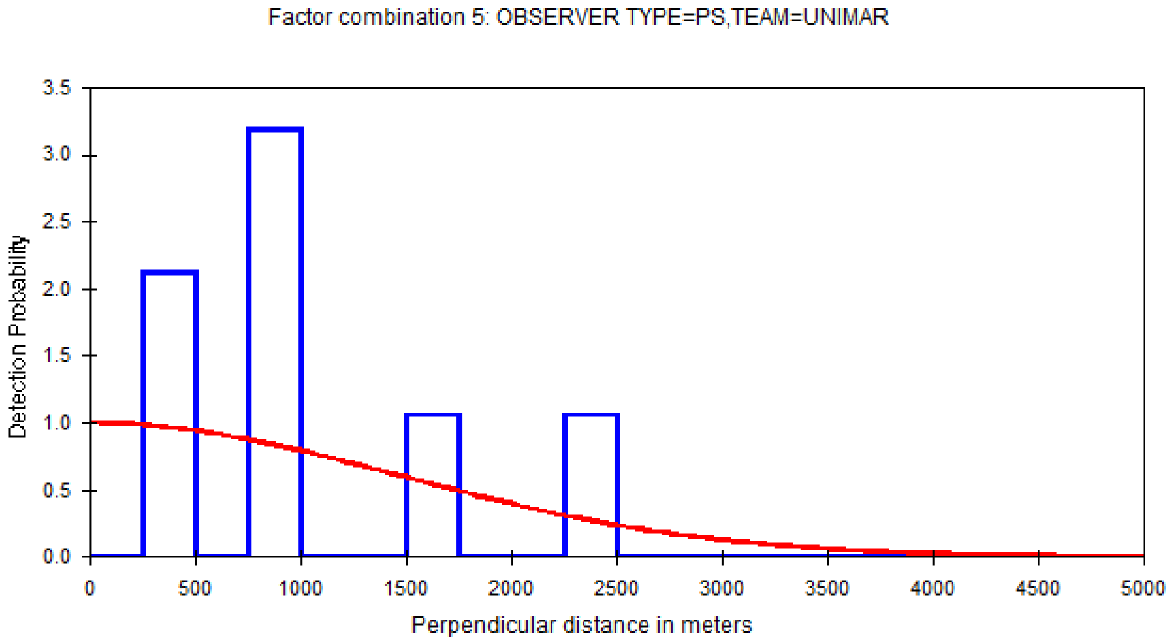


Figure I.17. Detection function for Professional spotter in Unimar.

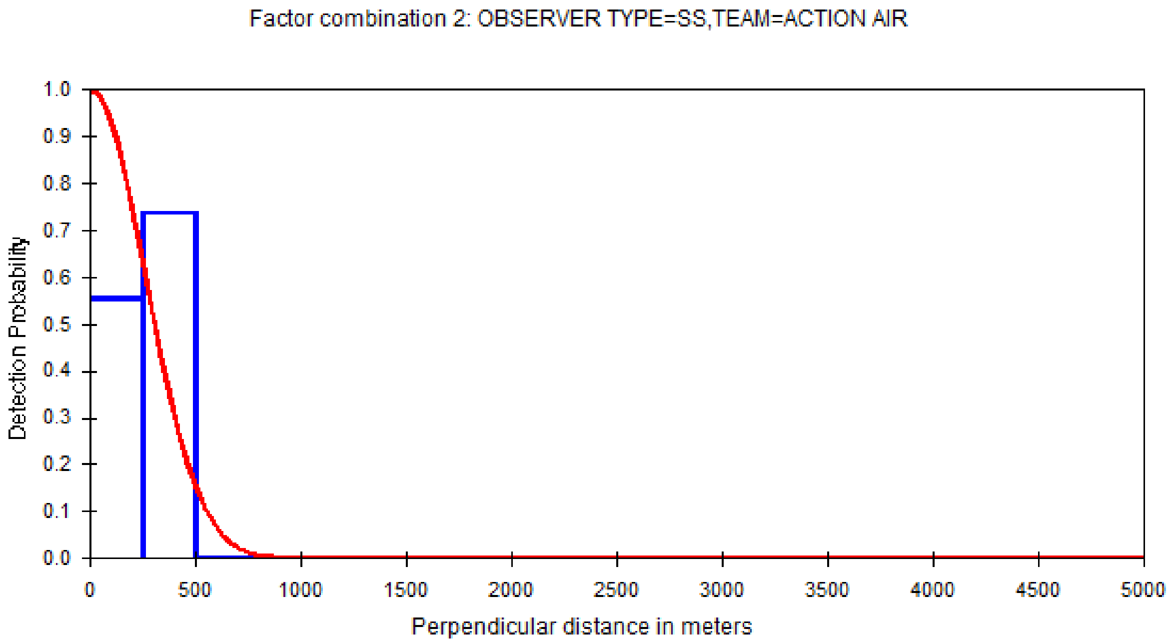


Figure I.18. Detection function for Scientific spotters in Action-Air.

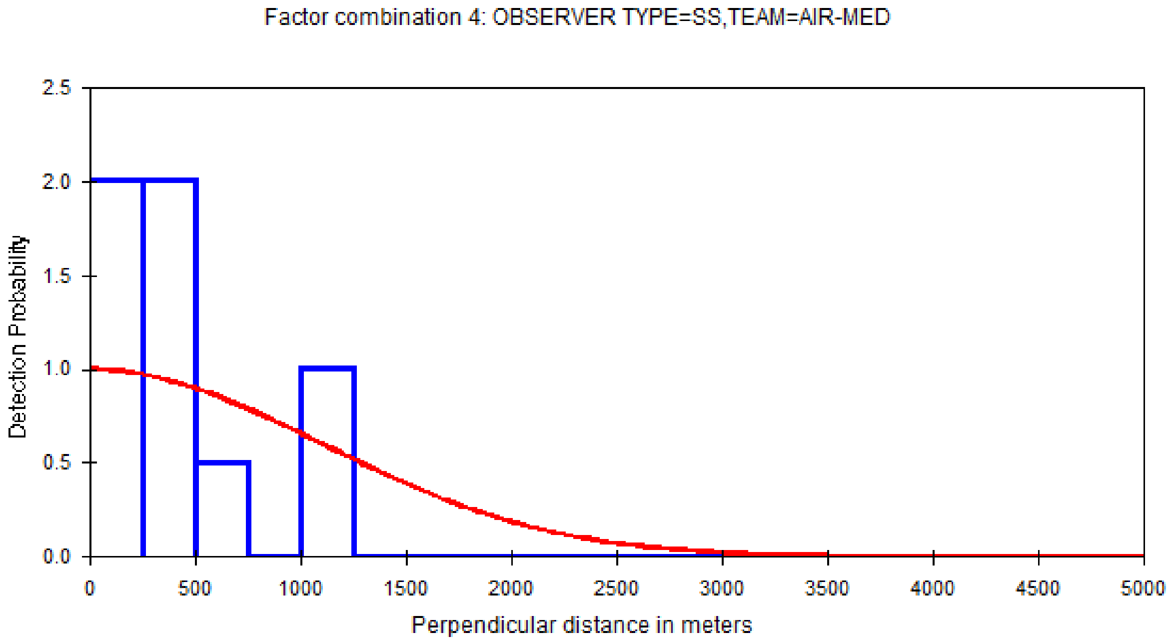


Figure I.19. Detection function for Scientific spotters in Air-Med.

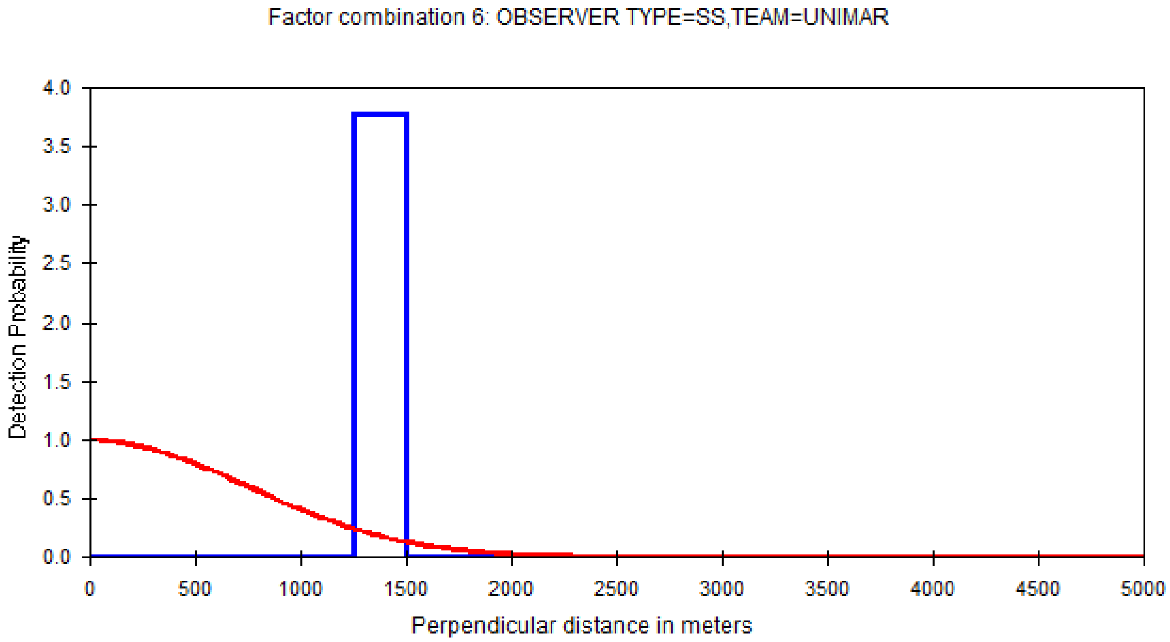


Figure I.20. Detection function for Scientific spotters in Unimar.

II. Analyses of overlapped areas for 2010 to 2015

II.1 Data processing

Overlapping of Inside areas

The inside areas of the 4 years of survey, 2010, 2011, 2013 and 2015, were plotted in ArcGis. The tool "Clip" was used to find the overlapping areas among the four years and to extract such intersection as new overlapped area common to all years. Therefore a new area ("overlapped area" from now on) was extracted for all years for the 4 inside areas. An exception occurred in area G inside which was not surveyed in 2011. Figure II.1 shows the resulting overlapped areas.

The surface areas were calculated in Distance using the Transverse Mercator projection (in WGS 1984). For purpose of comparison, the surface areas of 2010 and 2011 prior to the overlapping process were recalculated again with this projection (a different one was used at that time), and the analysis of those years were re-run with this projection's surface area so no noise is introduced in the comparison from this source. The resulting surface areas of the new overlapped areas are shown in Table II.1. The new surface areas (and results) for the previous 2010 and 2011 analysis are shown in Tables II.8 and II.9 respectively.

Given the poor coverage in areas E in 2013 and G in 2015, it could be possible to reduce the overlap areas to discard the non-surveyed sectors of E in 2013 (as it was actually done in that sub-area at that time) and G in 2015. This would reduce considerably those survey areas and therefore the amount of effort and observations from other years.

Data processing

Once the overlapped areas were ready, both track segments and observations were plotted over these overlapped areas to identify the pieces of tracks and the observations that fell outside the overlapped area and which would be discarded from the new analysis. In the case of tracks, new coordinates were identified to set beginning or end of tracks within the overlapped areas and adjust the line length of the tracks accordingly, with tools "Add X Y coordinates" in Xtoolspro in ArcGis. The identification of observations was done using tool "Spatial Join" of the ArcToolbox" in ArcGis. This yielded 45 observations that were discarded as they fell outside the overlapped inside areas, leaving 274 observations, of which 18 were discarded due to lack of information on perpendicular distance, 19 did not have information on cluster size, and 24 did not have information on weight. See remaining observations per sub-area and year in Table II.1. Figures II.2 to II.16 show the resulting on effort tracks and off and on effort sightings in the overlapped areas for each year.

During the whole process, some small remaining errors were still found in the previous datasets that were corrected now. This, together with the different truncation distances (right and left) used, and the cropping process yielded slightly different numbers for on effort tracks and observations.

In terms of tracks, this process discarded 6,016 km of tracks on effort, leaving 83,122 km of tracks on effort for analysis (from 89,138 km prior to the overlapping process).

As in the previous analyses, two analyses for each sub-area were performed considering both measures of school size: number of animals and weight.

And equally, sightings "off effort" were also used to estimate the detection function, but not to estimate abundance.

A combined dataset was created that was consistent across all data fields. This dataset was entered into software DISTANCE for analysis.

II.2 Data analysis

Analysis of the data followed the same methodology of standard line transect methodology (Buckland *et al.* 2001) than for each year's analysis.

Fitting the detection function

Given the small amount of sightings “on effort” per area and year in all cases, the same process as before was followed: (a) all off effort tracks and corresponding sightings were associated to an artificial area “OFF” with surface area = 0; (b) a detection function was fitted to all sightings, on and off effort; and (c) an estimate of abundance was obtained using the fitted detection function. As the off effort tracks and sightings were associated to the artificial OFF area, and only the on effort ones to the actual survey blocks, the estimates of abundance only applied to the on effort tracks/sightings within the survey areas.

The same method as in 2015 was used to fit the detection functions and the same covariates were explored.

Analysis were done for each year separately but, following the same methodology adopted for 2015 data, they were not done for each sub-area independently because of small sample size. Instead, they were post-stratified by sub-areas in the analysis.

After initial exploration of the data, different right truncation distances were chosen for each year, plus a left truncation of 250 m in 2010 given the lack of bubble window that year (see Table II.2 for the particular truncation distances).

Model diagnostics and selection

The same criteria as for 2015 data was followed for model diagnostics and selection in this analysis.

II.3 Results

Table II.1 shows the new overlapped area of each survey sub-area, the length of searched transects and the number of sightings of bluefin tuna schools used for analysis, compared with those prior to the overlapping process.

The final models selected, both for cluster size and weight, for 2010 and for 2011 had “sub-area” as covariate with a Hazard-rate key function, and 2013 had the covariate “team” also with a Hazard-rate key function and for 2015 it had the covariate “airplane” (with two factors: Partenavia and Cessna) with a Half-normal key function. 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 in the q-q plots for 2010, 2013 and 2015, but not as well for 2011 were fitting was more difficult. Table II.2 shows the main parameters for the detection functions and the results of the diagnostics tests for each year (identical for cluster size and for weight). Figures II.17 to II.20 shows the fitted detection functions. The individual effect of each covariate factor in the detection functions for each are shown in Figures II.21 to II.24.

Tables II.3 and II.6 show the estimates of density of schools, number of individuals and total weight of bluefin tuna in each sub-area and year. Previously, an estimate of animal abundance was not obtained for 2010 due to the lack of information on school size by some teams. However, data in sub-areas C and E did have this information (100% of the sightings in C and 80% in E) so it was estimated in this new analysis for those sub-areas.

Table II.7 shows the results for all areas pooled together in each year.

Tables II.8 to II.11 show a comparison between the results before and after cropping the sub-areas to obtain the overlapped areas, for each year.

II.4. Discussion

Survey inside areas

Sub-area A remained almost identical every year, while the others suffered some changes, especially sub-area E, which has had large variations among years. Grey areas in Figure II.1 show the overlap areas among all years for each sub-area.

Comparison among overlapped sub-areas

Total inside sub-areas

Being the same areas for each year now, comparisons are more meaningful than before. There seems to be large inter-annual variations as well as geographical variations (see Table II.7). Overall, pooling all areas together, there is a strong interannual variability both in terms of total weight and density of animals (and taking into account that sub-area G was not surveyed in 2011, the variability may be even larger). In 2010 the total weight (density of animals not being available due to the lack of information that year on cluster size) was almost half as that in 2011, but still much larger than in 2013, but in 2015 we observe the highest total weight of all years, much larger than in 2011. In terms of abundance of animals, 2011 has the larger estimate (and even more considering that area G was not surveyed that year), decreasing to around one third in 2013 (considering only A, C and E) but increasing again to less than two thirds in 2015.

It has to be taken into account that the effort put in surveying those areas in 2013 and 2015 was considerably lower than in 2010 and 2011 due to the effort allocated to the outside area in those two last years. It is not just a two blocks of effort, before and after the extension to the outside sub-areas, but there has been a progressive reduction in effort over the years: 2011 with 12% less effort than 2010, 2013 with 43% less effort than 2011 and 2015 with 19% less effort than 2013. This was caused by the extreme logistic induced by the outside areas. The number of observations has been decreasing over the years too, as has the density of schools, total weight and total abundance of animals. The most marked decrease has occurred in 2015, both with respect to 2013 and the first phase of 2010-2011. It is interesting to note that with a reduction of 19% effort in 2015 with respect to 2013, there was a reduction of 54% in the number of observations. However, mean cluster size and mean weight of schools were much larger in 2015 than in 2013 (2.6 and 5 times larger respectively), yielding an increase in total abundance of animals (double), and in weight (4 times larger) in 2015 with respect to 2013. This is possibly the result of a different behaviour and aggregation patters for spawners.

However, the CVs of most sub-areas are quite large, and although the CVs of the overall estimates for each year are quite acceptable, the 95% Confidence Intervals overlap between consecutive years, so there is no real confidence in that the observed decrease is significant. Therefore, all results need to be taken cautiously given the many problems observed during data collection each year, which may be biasing the results, especially for some sub-areas. These issues will be explored and discussed in the second phase of this contract, to be reported in February 2016.

Sub-area A-inside

Sub-area A-inside seems to be the most stable sub-area in terms of density of schools, animals and weight, except for a decrease in density of animals to half in 2013 while weight remained fairly stable from 2010 to 2013, with an increase almost to double in 2015. It is interesting to note that, unlike all the other sub-areas, the effort in sub-area A remained very similar over the years, even when time was allocated to the outside areas. Only in 2015 there was some decrease in effort.

Sub-area C-inside

In sub-area C-inside there was much less effort in 2013 and 2015 than in 2010 and 2011 (but very similar within the two blocks of years), while in 2013 there was an increase in number of sightings with respect to 2010 and the same amount with respect to 2011, resulting in a density of schools 5 times larger in 2013 with respect to 2010 and 1.4 times larger than in 2011. In 2015 there were less than one third of the number of sightings in 2013, with almost identical amount of effort resulting in a density of schools 3.4 times smaller in 2015 than in 2013. Climate factors might be the cause in the last year.

The total weight remained very similar in 2010 and 2011, but increased by 6 and 7 times in 2013 respect to 2011 and 2010 respectively, while in 2015 the total weight was around 3 times larger than in the first two years. At the same time, in terms of abundance of animals, the total estimated abundance in 2013 was much larger than in any other year, especially 2010 and 2011. The 95% CI of the 2013 estimate does not overlap those from 2010 and 2011 but overlaps those in 2015 when the CV is very large due to the very small sample size. In 2015 the abundance of animals was also much larger than in 2010 and 2011, although 44% smaller than in 2013.

Sub-area E-inside

This sub-area has the largest interannual variability. The amount of effort in this sub-area has been decreasing progressively, with 20% less effort in 2011 than in 2010, and 62% less effort in 2013 than in 2011. In 2015 there was a bit more effort than in 2013 (the year with very bad coverage) but still 54% less than in 2011.

In terms of weight, 2011 had a much larger total weight than 2010 and 2013, the year with the smallest weight than any other year (but keeping in mind that the coverage this year in the resulting overlap sub-area was not complete). Total weight in 2015 was much larger than all the other years (probably because of the larger mean weight).

In terms of animal abundance, 2010 and 2013 are similar, while being extremely high in 2011, and very high in 2015 (although half of that in 2011). The encounter rate of schools was much larger in 2013 than 2010, 2011 and 2015, but the mean cluster size was much smaller than the other years (which compensates and overtakes the larger encounter rate of schools this year), yielding a smaller estimate of abundance of animals than the rest of the years.

This area certainly had serious coverage issues in 2013 (when several additional security issues where there), which may be leading to biases this year. As can be seen in Figure II.12, effort in 2013 was very incomplete and heterogeneous in the overlapped area. Therefore, estimates of 2013, based on extrapolation of the information from the most surveyed parts of this sub-area to the whole overlapped E inside including not covered sectors, are not very reliable as the assumption of equal coverage probability is not met. Thus, in 2013, the non-surveyed sector was removed from analysis to minimise the bias (resulting in a reduction from the original 107,673 km^2 to the 82,054 km^2 used in the analysis). This removal has not been done for the overlap area, so the estimates this year are quite unreliable.

Sub-area G-inside

In this sub-area there is also the problem of very poor and heterogeneous coverage in 2015, which together with the fact that there were only two observations of Bluefin tuna on effort, yields very unreliable estimates, rather useless[2]. Furthermore, this sub-area was not surveyed in 2011, due to the lack of permit. This means that only 2010 and 2013 may be compared. Unfortunately, no estimates of animal abundance is available for 2010 due to failure in data collection that year.

The density of schools was 40% smaller in 2013 than in 2010, but the total weight was 96% smaller in 2013 than 2010. This huge difference is due to the mean weight per school, being only 4 tonnes in 2013 *vs*. 63.6 tonnes in 2010. The reasons for this difference are unknown but they are possibly linked to the different age classes in the various parts of the same season. As a curiosity, the 2 observations on effort in 2015 were estimated to be 15 and 3 tonnes each, and the observation off effort of 1 ton, therefore closer to the estimates in 2013.

Comparison between previous and overlapped sub-areas

2010

In the overlap areas, effort has been reduced by around 900 km in total. The number of sightings available for the estimates has varied also with respect to the previous survey areas, mainly due to the different truncation distances applied, both on the right and on the left. Due to these differences, results are somehow different too, but more importantly the CVs got smaller.

Total weight has increased slightly in all areas, except in sub-area A where the increase is substantial (almost 3 times), and therefore as total for 2010, but this difference is not significant. As in the previous analysis, different detection functions were used for different sub-areas, an overall CV for total weight for the whole 2010 survey was not possible to obtain with the Distance analysis, making this comparison difficult. However, the point estimate was larger in the new analysis, as was the density of schools. The main increase is observed in sub-area A, followed by E, probably due to the reduction of the left truncation from 1.25 km to 0.25 km. Sub-area C remains very similar, and in G there is also an increase due to the extension of the right truncation from 4 to 6 km. These changes in truncation allowed the inclusion of a few more sightings of BFT with similar effort or even less (this is the case mainly in sub-area G).

The CVs of the density of groups were reduced considerably in the overall estimate, and also in sub-areas C and G (this is the case for the CVs of weight too). CV for density of schools and for weight was not available in the Distance analysis for sub-area E as it was actually composed by two different detection functions (one for the block 3 and one for blocks 7 and 8 as labelled in 2010).

[2] According to the information on fishery, most of the effort was in a period before the aerial survey and, therefore, it is possible that most of the tunas left the surface or the area before the survey.

2011

In the overlap areas, effort has been reduced by almost 2,000 km in total. The number of sightings remained the same in sub-area C, with one observation less in sub-area A, which was outside the overlapped area. There are 20% more observations in sub-area E in the overlapped area, due to a large increase in the right truncation distance (because in the new analysis all sub-areas were pulled together and therefore the same truncation distance was applied to all of them) and elimination of the left truncation.

These changes in truncation, together with changes in the probability of detection in a new detection function, yield large changes in the effective searched area (*esw**2*L, being *esw* the effective strip width and L the transect length). The effective searched area decreased substantially in sub-areas A and C and increased in E. In sub-areas A and C, with much smaller effective searched area, the amount of observations was basically the same, and therefore the estimated density of schools, of animals and the weight increased substantially. On the other hand, in sub-area E, with increased effective searched area but increased number of observations too, this effect did not occur and the estimates are much more similar to the previous estimates. The overall estimates of weight and abundance are similar in the two analyses, despite the variations between sub-areas.

The CVs are smaller in sub-area E in the overlapped area due to the largest number of observations available. In C they are similar and in A slightly larger. But overall, the CV in 2011 is smaller considering all sub-areas together.

2013

In 2013, the overlapping process reduced the on effort tracks by 800 km, and discarded 4 observations, 3 of them in sub-area A and 1 in C. The truncation distance was reduced from 5km to 4.4km. As the changes were relatively small, the effective searched area remained similar. Some changes can be observed also in mean cluster size and mean weight. This is because in the previous analysis in some sub-areas Distance chose the “expected cluster size” (estimated with a regression) and in the new analysis we have taken by default the actual mean cluster size given that in some cases (especially 2015) there were too few observations to fit a regression line, so the mean cluster size was used in all models to ensure some homogeneity in the way of estimating mean cluster size and mean weight across sub-areas and years in the new analysis of the overlapped areas.

An important consideration for sub-area E is that in 2013, the original area in the design (107,673 km^2) was cropped during the analysis at the time to 82,054 km^2 to eliminate the not surveyed section of the sub-area. Therefore, the comparison for E 2013 before and after creating the overlap area is meaningless unless the overlap area is reduced accordingly to the crop done in 2013. In fact, the previous estimate is more reliable in this case given that in the new overlap area the coverage is not homogeneous in E in 2013, and the density estimated in the surveyed section is being extrapolated to the un-surveyed section where no information is available. The SCRS, in 2015, discussed this issue and recommended to keep all data for area E, including the reduced area in 2013. Cropping this area in a consistent way over the years would produce more comparable data, but at the same time implies loosing several data for 2010 and 2011; considering that this is one of the main spawning area, this balance is already difficult. If the overlap area is not reduced, then the 2013 estimate should not be taken into account.

Overall, the resulting estimate of abundance in the overlap areas is 50% times larger than in the previous analysis, and double in the case of weight. If we consider only sub-areas A, C and G (discarding E due to the problems just mentioned), total abundance in the previous analysis was 109,830 animals, and 148,872 in the new analysis. Therefore, still around 40% increase overall. In terms of weight, the estimate for those three sub-areas would be 8,151 tonnes in the previous analysis, and 15,936 tonnes in the new ones, thus almost double. In both cases the main increases occurred in A and C because of the reason mentioned above.

However, all CVs resulted much smaller with the new analysis.

2015

The reduction of effort in 2015 after cropping the areas is larger than other years, with a total of more than 2,200 km of on effort tracks and one observation discarded (in A). However, the results in terms of total weight and abundance of animals remain similar between the previous analysis and the new one in the overlapped area, because the effective strip width remain the same. The CVs both of weight and of abundance of animals remain very similar in all sub-areas.

Sources of additional variance

Additional variance is the name given to the uncertainty introduced into abundance estimates by changes in the spatial distribution of animals over time. The sample variances estimated for individual sub-areas do not take into account this variability in true abundance. There is no problem if all sub-areas are surveyed in a sufficiently short period that the surveys can be considered synoptic. But if not all sub-areas are surveyed every year, the precision of estimates of total abundance summed across sub-areas surveyed in different years needs to incorporate variability in true abundance in each sub-area. If additional variance is not included in these situations, the uncertainty in estimates of total abundance will be underestimated.

The additional variance calculations will be done shortly following the indications of the way proposed by the recent SCRS paper (Quilez Badia et al., in press).

5. Recommendations for future survey design

Recommendations will be provided in the report of the second phase of this contract after analyzing all the other issues, to make them more complete.

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TABLES

Table II.1. Areas, total length of transects and number of sightings of bluefin tuna for each survey sub-area and year.

		Previous			Overlapping		
Inside Sub-area	**Year**	**Area (km^2)**	**Length of transects (km)**	**Number of observations (after truncation)**	**Area (km^2)**	**Length of transects (km)**	**Number of observations (after truncation)**
A	2010	62,150	6,301	7	61,933	6,277	8
	2011	62,150	7,977	11	61,933	7,975	10
	2013	62,194	6,807	13	61,933	6,743	10
	2015	62,150	4,143	7	61,933	4,119	6
C	2010	54,636	8,703	6	53,868	8,168	6
	2011	54,636	8,711	10	53,868	8,466	10
	2013	56,329	2,791	11	53,868	2,682	10
	2015	64,610	3,237	3	53,868	2,658	3
E	2010	132,453	12,393	28	93,614	12,621	29
	2011	104,366	11,429	35	93,614	9,806	45
	2013	82,054	4,371	20	93,614	3,720	20
	2015	117,718	5,862	8	93,614	4,484	13
G	2010	68,819	3,482	31	56,211	2,900	33
	2011						
	2013	56,329	1,700	12	56,211	1,716	12
	2015	68,013	1,172	2	56,211	785	2
Total	2010	318,058	30,879	72	265,627	29,967	76
	2011	221,151	28,177	56	265,627	26,247	65
	2013	254,754	15,669	56	265,627	14,862	52
	2015	312,491	14,413	20	265,627	12,046	19

Table II.2. Parameters and diagnostics of the detection functions.

Year	**Covariate**	**Right Truncation distance (km) (left)**	**Average probability of detection (p)**	**Effective strip width (esw) (km)**	**K-S test (p)**	**Cramer-von Mises test (unweighted) (p)**
2010	Sub-area	6.0 (0.25)	0.247	1.48	0.912	1.000
2011	Sub-area	4.3	0.158	0.68	0.018	0.025
2013	Team	4.4	0.341	1.50	0.871	0.800
2015	Airplane	5.0	0.195	0.97	0.073	0.100

Table II.3. Results for abundance of animals and weight for overlapped sub-area A inside for each year.

A inside				
Year	**2010**	**2011**	**2013**	**2015**
Survey area (km^2)	61,933	61,933	61,933	61,933
Transect length (km)	6,277	7,975	6,743	4,119
Effective strip width x2 (km)	2.96	1.36	3.00	3.03
Area searched (km^2)	18,602	10,846	20,207	12,499
% coverage	30.0	17.5	32.6	20.2
Number of schools ON effort	8	10	10	6
Abundance of schools	27	57	31	30
%CV abundance of schools	56.2	35.9	36.1	43.5
Encounter rate of schools	0.0013	0.0013	0.0015	0.0015
%CV encounter rate	54.6	33.8	35.0	41.1
Density of schools (1000 km^{-2})	0.430	0.922	0.495	0.480
%CV density of schools	56.2	35.9	36.1	43.5
Mean weight (t)	131.25	122.43	194.1	160.7
%CV weight	6.2	19.2	23.8	11.7
Mean cluster size (animals)		678.1	611	825
%CV abundance		27.9	26.0	11.0
Density of animals (km^{-2})		0.625	0.302	0.618
%CV density of animals		45.5	44.5	44.7
Total weight (t)	**3,496**	**4,296**	**3,572**	**8,736**
%CV total weight	56.6	46.2	40.6	41.9
L 95% CI total weight	1,218	1,775	1,640	3,956
U 95% CI total weight	10,037	10,398	7,780	19,296
Total abundance (animals)		**38,720**	**18,717**	**38,248**
%CV total abundance		45.5	44.5	44.7
L 95% CI total abundance		16,249	7,990	16,510
U 95% CI total abundance		92,266	43,845	88,610

Table II.4. Results for abundance of animals and weight for overlapped sub-area C inside for each year.

C inside				
Year	**2010**	**2011**	**2013**	**2015**
Survey area (km^2)	53,868	53,868	53,868	53,868
Transect length (km)	8,168	8,466	2,682	2,658
Effective strip width x2 (km)	2.96	1.36	3.00	3.03
Area searched (km^2)	24,205	11,514	8,038	8,067
% coverage	44.9	21.4	14.9	15.0
Number of schools ON effort	6	10	10	3
Abundance of schools	13	47	67	20
%CV abundance of schools	46.6	33.4	34.3	62.9
Encounter rate of schools	0.0007	0.0012	0.0037	0.0011
%CV encounter rate	44.6	31.2	33.2	61.2
Density of schools (1000 km^{-2})	0.248	0.868	1.244	0.372
%CV density of schools	46.6	33.4	34.3	62.9
Mean weight (t)	124.17	38.87	173.5	190.0
%CV weight	5.6	44.4	22.1	19.9
Mean cluster size (animals)	733	291	1,285	1,533
%CV abundance	36.5	30.7	17.0	19.0
Density of animals (km^{-2})	0.182	0.253	1.599	0.889
%CV density of animals	59.2	45.3	38.3	65.5
Total weight (t)	**1,658**	**1,999**	**11,830**	**5,965**
%CV total weight	46.9	54.9	40.9	65.8
L 95% CI total weight	678	689	5,365	1,776
U 95% CI total weight	4,056	5,794	26,081	20,034
Total abundance (animals)	**9,797**	**13,614**	**86,114**	**47,900**
%CV total abundance	59.2	45.3	38.3	65.5
L 95% CI total abundance	3,187	5,677	40,959	14,331
U 95% CI total abundance	30,016	32,649	181,040	160,100

Table II.5. Results for abundance of animals and weight for overlapped sub-area E inside for each year.

E inside				
Year	**2010**	**2011**	**2013**	**2015**
Survey area (km^2)	93,614	93,614	93,614	93,614
Transect length (km)	12,621	9,806	3,720	4,484
Effective strip width x2 (km)	2.96	1.36	3.00	3.03
Area searched (km^2)	37,401	13,336	11,149	13,608
% coverage	40.0	14.2	11.9	14.5
Number of schools ON effort	29	45	20	13
Abundance of schools	73	316	168	50
%CV abundance of schools	32.7	24.1	34.0	50.8
Encounter rate of schools	0.0023	0.0046	0.0054	0.0029
%CV encounter rate	29.9	21.0	32.9	26.2
Density of schools (1000 km^{-2})	0.775	3.374	1.794	0.534
%CV density of schools	32.7	24.1	34.0	50.8
Mean weight (t)	110.14	118.05	11.0	391.6
%CV weight	33.9	19.2	66.0	54.8
Mean cluster size (animals)	1015	1,715	361	2,030
%CV abundance	19.0	21.5	67.3	56.8
Density of animals (km^{-2})	0.787	5.786	0.647	3.024
%CV density of animals	37.8	32.3	75.4	64.1
Total weight (t)	**7,995**	**39,344**	**1,882**	**54,889**
%CV total weight	47.1	32.2	74.3	62.2
L 95% CI total weight	3,284	21,147	486	16,632
U 95% CI total weight	19,464	73,198	7,284	181,140
Total abundance (animals)	**73,676**	**541,634**	**60,614**	**283,100**
%CV total abundance	37.8	32.3	75.4	64.1
L 95% CI total abundance	35,741	290,700	15,391	83,058
U 95% CI total abundance	151,880	1,009,200	238,710	964,970

Table II.6. Results for abundance of animals and weight for overlapped sub-area G inside for each year.

G inside				
Year	**2010**	**2011**	**2013**	**2015**
Survey area (km^2)	56,211		56,211	56,211
Transect length (km)	2,900		1,716	785
Effective strip width x2 (km)	2.96		3.00	3.03
Area searched (km^2)	8,594		5,144	2,382
% coverage	15.3		9.2	4.2
Number of schools ON effort	33		12	2
Abundance of schools	216		131	47
%CV abundance of schools	29.4		40.7	69.0
Encounter rate of schools	0.0114		0.0070	0.0025
%CV encounter rate	26.3		38.7	67.5
Density of schools (1000 km^{-2})	3.840		2.333	0.840
%CV density of schools	29.4		40.7	69.0
Mean weight (t)	63.621		4.0	9.0
%CV weight	12.7		40.2	66.7
Mean cluster size (animals)			336	600
%CV abundance			36.7	66.7
Density of animals (km^{-2})			0.783	0.786
%CV density of animals			54.8	95.9
Total weight (t)	**13,733**		**534**	**666**
%CV total weight	32.1		57.2	95.8
L 95% CI total weight	7,387		181	73
U 95% CI total weight	25,532		1,574	6,070
Total abundance (animals)			**44,041**	**44,162**
%CV total abundance			54.8	95.9
L 95% CI total abundance			15,587	4,844
U 95% CI total abundance			124,440	402,600

Table II.7. Results for abundance of animals and weight for all overlapped sub-areas together for each year.

All sub-areas				
Year	**2010**	**2011**	**2013**	**2015**
Survey area (km^2)	265,627	209,416	265,627	265,627
Transect length (km)	29,967	26,247	14,862	12,046
Effective strip width x2 (km)	2.96	1.36	3.00	3.03
Area searched (km^2)	88,803	35,697	44,539	36,556
% coverage	33.4	17.0	16.8	13.8
Number of schools ON effort	76	65	52	24
Abundance of schools	328	420	397	147
%CV abundance of schools	23.3	20.6	22.0	33.0
Encounter rate of schools	0.0025	0.0025	0.0035	0.0020
%CV encounter rate				20.2
Density of schools (1000 km^{-2})	1.236	2.004	1.494	0.553
%CV density of schools	23.3	20.6	22.0	33.0
Mean weight (t)	87.9	101.1	52.5	272.2
%CV weight	1.7	2.8	1.8	41.4
Mean cluster size (animals)		1,275	582	1,548
%CV abundance		37.3	18.5	40.5
Density of animals (km^{-2})		**2.8363**	**0.789**	**1.556**
%CV density of animals		30.0	30.4	46.9
Total weight (t)	**26,882**	**45,639**	**17,818**	**70,256**
%CV total weight	25.6	28.7	30.1	49.4
L 95% CI total weight	14,243	26,133	9,902	26,420
U 95% CI total weight	38,347	79,703	32,061	186,820
Total abundance (animals)		**593,968**	**209,486**	**413,410**
%CV total abundance		30.0	30.4	46.9
L 95% CI total abundance		332,640	116,000	165,000
U 95% CI total abundance		1,060,600	378,330	1,035,800

Table II.8. Comparison between the results before and after cropping the sub-areas to obtain the overlapped areas, for 2010.

	Previous					**Overlapping**				
Year	**2010**					**2010**				
Sub-area	**A inside**	**C inside**	**E inside**	**G inside**	**2010**	**A inside**	**C inside**	**E inside**	**G inside**	**2010**
Survey area (km^2)	62,150	54,636	132,453	68,819	318,058	61,933	53,868	93,614	56,211	265,627
Transect length (km)	6,301	8,703	12,393	3,482	30,879	6,277	8,168	12,621	2,900	29,967
Trunc. Dist. right (km)	7.5	4.0	7.5	4.0		6.0	6.0	6.0	6.0	6.0
Trunc. Dist. left (km)	1.3	0.30	1.25	0.30		0.25	0.25	0.25	0.25	0.25
Prob. of detection	0.471	0.364		0.364		0.247	0.247	0.247	0.247	0.247
Eff. strip width x2 (km)	7.07	2.92		2.92		2.96	2.96	2.96	2.96	2.96
Area searched (km^2)	44,539	25,372		10,151	80,063	18,602	24,205	37,401	8,594	88,803
% coverage	71.7	46.4		14.8	25.2	30.0	44.9	40.0	15.3	33.4
N. of schools ON effort	7	6	28	31	72	8	6	29	33	76
Abundance of schools	10	12	65	169	256	27	13	73	216	328
%CV Ab. of schools	55	53		40	29.9	56.2	46.6	32.7	29.4	23.3
Enc. rate of schools	0.0011	0.0007	0.0023	0.0089	0.0023	0.0013	0.0007	0.0023	0.0114	0.0025
%CV encounter rate	51.0	43.0		25.0	20.0	54.6	44.6	29.9	26.3	
D. schools (1000 km^{-2})	0.157	0.237	0.491	3.054	0.805	0.430	0.248	0.775	3.840	1.236
%CV density of schools	55.0	54.4		41.0	30.0	56.2	46.6	32.7	29.4	23.3
Mean weight (t)	127.1	124.2		62.1		131.25	124.17	110.14	63.621	87.9
%CV weight	8.0	5.6		13.0		6.2	5.6	33.9	12.7	1.7
Mean cluster size							733	1015		
%CV cluster size							36.5	19.0		
Dens. animals (km^{-2})							0.182	0.787		
%CV density of animals							59.2	37.8		
Total weight (t)	**1,242**	**1,604**	**6,264**	**13,047**	**22,157**	**3,496**	**1,658**	**7,995**	**13,733**	**26,882**
%CV total weight	54.8	54.7		43.0		56.6	46.9	47.1	32.1	25.6
L 95% CI total weight	447	579		5,766		1,218	678	3,284	7,387	14,243
U 95% CI total weight	3,453	4,442		29,521		10,037	4,056	19,464	25,532	38,347
Total abundance							**9,797**	**73,676**		
%CV abundance							59.2	37.8		
L 95% CI abundance							3,187	35,741		
U 95% CI abundance							30,016	151,880		

Table II.9. Comparison between the results before and after cropping the sub-areas to obtain the overlapped areas, for 2011.

	Previous					Overlapping				
Year	**2011**					**2011**				
Sub-area	**A inside**	**C inside**	**E inside**	**G inside**	**2011**	**A inside**	**C inside**	**E inside**	**G inside**	**2011**
Survey area (km^2)	62,150	54,636	104,366		221,151	61,933	53,868	93,614		209,416
Transect length (km)	7,977	8,771	11,429		28,177	7,975	8,466	9,806		26,247
Trunc. Dist. right (km)	7.7	7.7	0.8			4.3	4.3	4.3		4.3
Trunc. Dist. left (km)			0.1							
Prob. of detection	0.456	0.456	0.472			0.158	0.158	0.158		0.158
Eff. strip width x2 (km)	7.03	7.03	0.76			1.36	1.36	1.36		1.36
Area searched (km^2)	56,066	61,646	8,635		126,348	10,846	11,514	13,336		35,697
% coverage	90.2	112.8	8.3		57.1	17.5	21.4	14.2		17.0
N. of schools ON effort	11	10	35		56	10	10	45		65
Abundance of schools	12	9	403		424	57	47	316		420
%CV Ab. of schools	36.7	35.7	29.4		24.7	35.9	33.4	24.1		20.6
Enc. rate of schools	0.0014	0.0011	0.0031		0.0020	0.0013	0.0012	0.0046		0.0025
%CV encounter rate	32.0	31.0	24.0		46.9	33.8	31.2	21.0		
D. schools (1000 km^{-2})	0.197	0.162	4.011		1.917	0.922	0.868	3.374		2.004
%CV density of schools	36.7	35.7	29.3		25.0	35.9	33.4	24.1		20.6
Mean weight (t)	84.8	42.7	110.7			122.43	38.87	118.05		101.1
%CV weight	26.0	44.0	27.0			19.2	44.4	19.2		2.8
Mean cluster size	789	291	1,362			678.1	291	1,715		1,275
%CV cluster size	26.0	31.0	32.0			27.9	30.7	21.5		37.3
Dens. animals (km^{-2})	0.154	0.047	5.463		**2.6086**	0.625	0.253	5.786		**2.8363**
%CV density of animals	42.9	45.8	41.9		41.0	45.5	45.3	32.3		30.0
Total weight (t)	**1,031**	**378.6**	**46,877**		**48,287**	**4,296**	**1,999**	**39,344**		**45,639**
%CV total weight	42.9	54.4	41.3		40.0	46.2	54.9	32.2		28.7
L 95% CI total weight	458	138	21,311			1,775	689	21,147		26,133
U 95% CI total weight	2,321	1,041	103,112			10,398	5,794	73,198		79,703
Total abundance	**9,598**	**2,579**	**570,130**		**582,307**	**38,720**	**13,614**	**541,634**		**593,968**
%CV abundance	42.9	45.8	41.9		41.0	45.5	45.3	32.3		30.0
L 95% CI abundance	4,264	1,084	256,567			16,249	5,677	290,700		332,640
U 95% CI abundance	21,602	6,135	1,266,912			92,266	32,649	1,009,200		1,060,600

Table II.10. Comparison between the results before and after cropping the sub-areas to obtain the overlapped areas, for 2013.

	Previous					Overlapping				
Year	**2013**					**2013**				
Sub-area	**A inside**	**C inside**	**E inside**	**G inside**	**2013**	**A inside**	**C inside**	**E inside**	**G inside**	**2013**
Survey area (km^2)	62,194	56,329	82,054	56,329	254,754	61,933	53,868	93,614	56,211	265,627
Transect length (km)	6,807	2,791	4,371	1,700	15,669	6,743	2,682	3,720	1,716	14,862
Trunc. Dist. right (km)	5.0	5.0	5.0	5.0	5.0	4.4	4.4	4.4	4.4	4.4
Trunc. Dist. left (km)										
Prob. of detection	0.275	0.275	0.275	0.275	0.275	0.341	0.341	0.341	0.341	0.341
Eff. strip width x2 (km)	2.75	2.75	2.75	2.75	2.75	3.00	3.00	3.00	3.00	3.00
Area searched (km^2)	18,698	7,666	12,007	4,670	43,041	20,207	8,038	11,149	5,144	44,539
% coverage	30.1	13.6	14.6	8.3	16.9	32.6	14.9	11.9	9.2	16.8
N. of schools ON effort	13	11	20	12	56	10	10	20	12	52
Abundance of schools	28	40	260	132	460	31	67	168	131	397
%CV Ab. of schools	51.0	49.0	54.0	48.0	33.9	36.1	34.3	34.0	40.7	22.0
Enc. rate of schools	0.0018	0.0039	0.0046	0.0071	0.0036	0.0015	0.0037	0.0054	0.0070	0.0035
%CV encounter rate	41.5	44.0	47.1	41.3	23.0	35.0	33.2	32.9	38.7	
D. schools (1000 km^{-2})	0.447	0.742	3.164	2.343	1.804	0.495	1.244	1.794	2.333	1.494
%CV density of schools	50.8	49.0	53.5	48.4	34.0	36.1	34.3	34.0	40.7	22.0
Mean weight (t)	90.1	189.0	4.2	3.3	22.6	194.1	173.5	11.0	4.0	52.5
%CV weight	32.0	22.0	103.0	62.0	51.0	23.8	22.1	66.0	40.2	1.8
Mean cluster size	439	1,536	111	272	**302**	611	1,285	361	336	582
%CV cluster size	35.4	18.7	107.9	57.2	43.0	26.0	17.0	67.3	36.7	18.5
Dens. animals (km^{-2})	0.196	1.139	0.351	0.638	**0.544**	0.302	1.599	0.647	0.783	**0.789**
%CV density of animals	45.1	52.6	99.2	63.1	35.4	44.5	38.3	75.4	54.8	30.4
Total weight (t)	**1,083**	**6,633**	**949**	**436**	**9,100**	**3,572**	**11,830**	**1,882**	**534**	**17,818**
%CV total weight	39.9	59.1	95.6	67.9	44.6	40.6	40.9	74.3	57.2	30.1
L 95% CI total weight	504	2,204	193	124	3,867	1,640	5,365	486	181	9,902
U 95% CI total weight	2,327	19,965	4,671	1,532	21,413	7,780	26,081	7,284	1,574	32,061
Total abundance	**12,194**	**61,725**	**28,819**	**35,911**	**138,650**	**18,717**	**86,114**	**60,614**	**44,041**	**209,486**
%CV abundance	45.1	52.6	99.2	63.1	35.4	44.5	38.3	75.4	54.8	30.4
L 95% CI abundance	5,191	22,874	5,603	11,034	69,270	7,990	40,959	15,391	15,587	116,000
U 95% CI abundance	28,647	166,562	148,238	116,870	277,517	43,845	181,040	238,710	124,440	378,330

Table II.11. Comparison between the results before and after cropping the sub-areas to obtain the overlapped areas, for 2015.

	Previous					Overlapping				
Year	**2015**					**2015**				
Sub-area	**A inside**	**C inside**	**E inside**	**G inside**	**2015**	**A inside**	**C inside**	**E inside**	**G inside**	**2015**
Survey area (km^2)	62,150	64,610	117,718	68,013	312,491	61,933	53,868	93,614	56,211	265,627
Transect length (km)	4,143	3,237	5,862	1,172	14,413	4,119	2,658	4,484	785	12,046
Trunc. Dist. right (km)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Trunc. Dist. left (km)										
Prrob. of detection	0.324	0.324	0.324	0.324	0.324	0.324	0.324	0.324	0.324	0.324
Eff. strip width x2 (km)	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03	3.03
Area searched (km^2)	12,572	9,822	17,789	3,555	43,739	12,499	8,067	13,608	2,382	36,556
% coverage	20.2	15.2	15.1	5.2	14.0	20.2	15.0	14.5	4.2	13.8
N. of schools ON effort	7	3	13	2	25	6	3	13	2	24
Abundance of schools	57	32	142	63	294	30	20	50	47	147
%CV Ab. of schools	40.2	62.1	29.7	72.0	29.1	43.5	62.9	50.8	69.0	33.0
Enc. rate of schools	0.0017	0.0009	0.0022	0.0017	0.00173	0.0015	0.0011	0.0029	0.0025	0.0020
%CV encounter rate	37.6	60.5	26.1	70.6	30.5	41.1	61.2	26.2	67.5	20.2
D. schools (1000 km^{-2})	0.916	0.503	1.203	0.926	0.941	0.480	0.372	0.534	0.840	0.553
%CV density of schools	40.2	62.1	29.7	72.0	29.1	43.5	62.9	50.8	69.0	33.0
Mean weight (t)	132.2	190.0	391.6	9.0	140.2	160.7	190.0	391.6	9.0	272.2
%CV weight	21.3	19.9	54.8	66.7	26.6	11.7	19.9	54.8	66.7	41.4
Mean cluster size	708	1,533	2,030	600	**827**	825	1,533	2,030	600	**1,548**
%CV cluster size	19.8	19.0	56.8	66.7	19.7	11.0	19.0	56.8	66.7	40.5
Dens. animals (km^{-2})	0.648	0.771	2.442	0.555	**1.329**	0.618	0.889	3.024	0.786	**1.556**
%CV density of animals	44.8	64.9	64.1	98.1	42.9	44.7	65.5	64.1	95.9	46.9
Total weight (t)	**7,603**	**6,233**	**56,004**	**572**	**70,412**	**8,736**	**5,965**	**54,889**	**666**	**70,256**
%CV total weight	45.5	65.2	62.3	98.1	53.4	41.9	65.8	62.2	95.8	49.4
L 95% CI total weight	3,217	1,873	16,957	65		3,956	1,776	16,632	73	26,420
U 95% CI total weight	17,971	20,737	184,960	5,055		19,296	20,034	181,140	6,070	186,820
Total abundance	**40,298**	**49,802**	**287,420**	**37,781**	**415,301**	**38,248**	**47,900**	**283,100**	**44,162**	**413,410**
%CV abundance	44.8	64.9	64.1	98.1	42.9	44.7	65.5	64.1	95.9	46.9
L 95% CI abundance	17,279	15,047	84,285	4,278		16,510	14,331	83,058	4,844	165,000
U 95% CI abundance	93,980	164,830	980,150	333,700		88,610	160,100	964,970	402,600	1,035,800

FIGURES

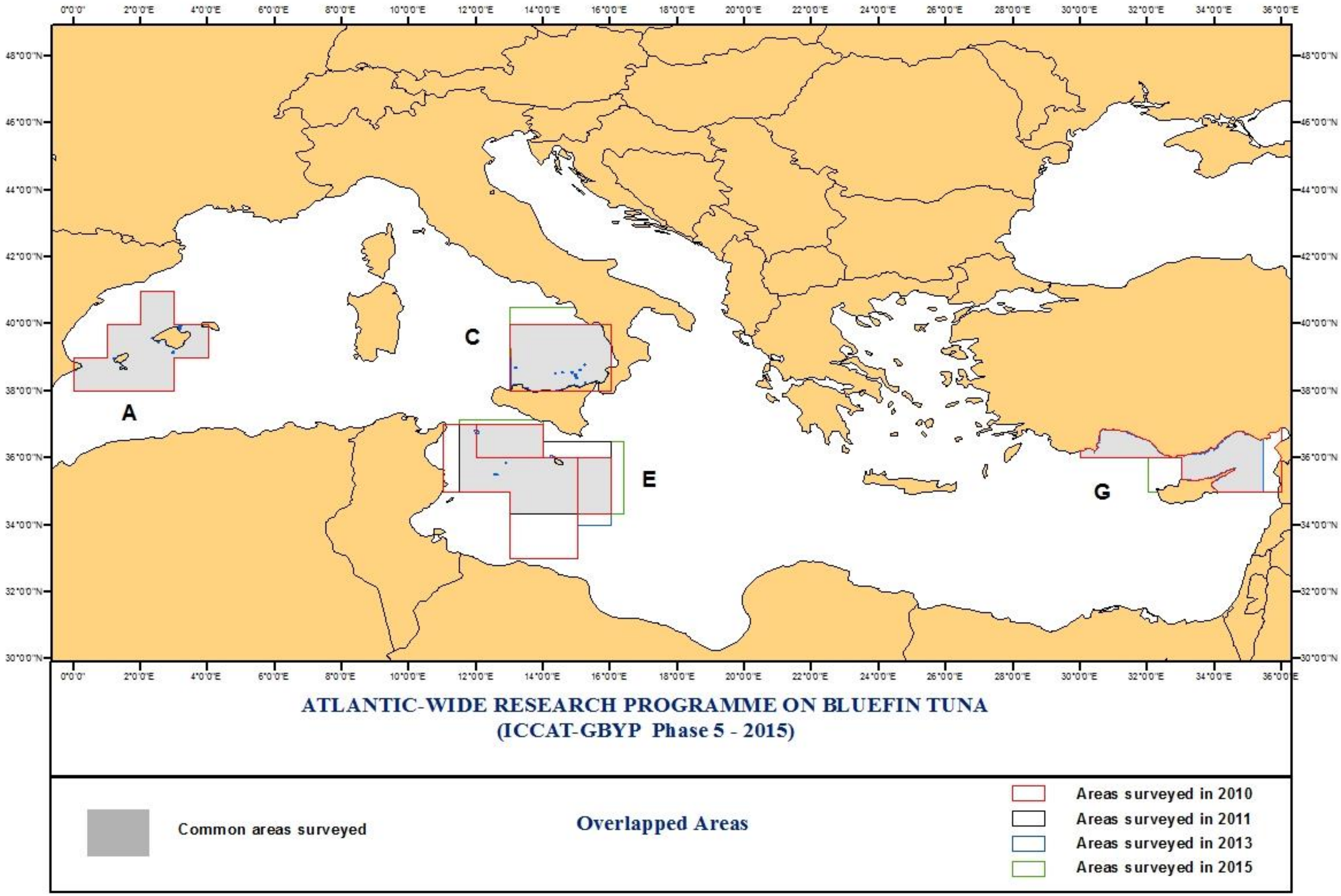

Figure II.1. Overlapped Survey blocks

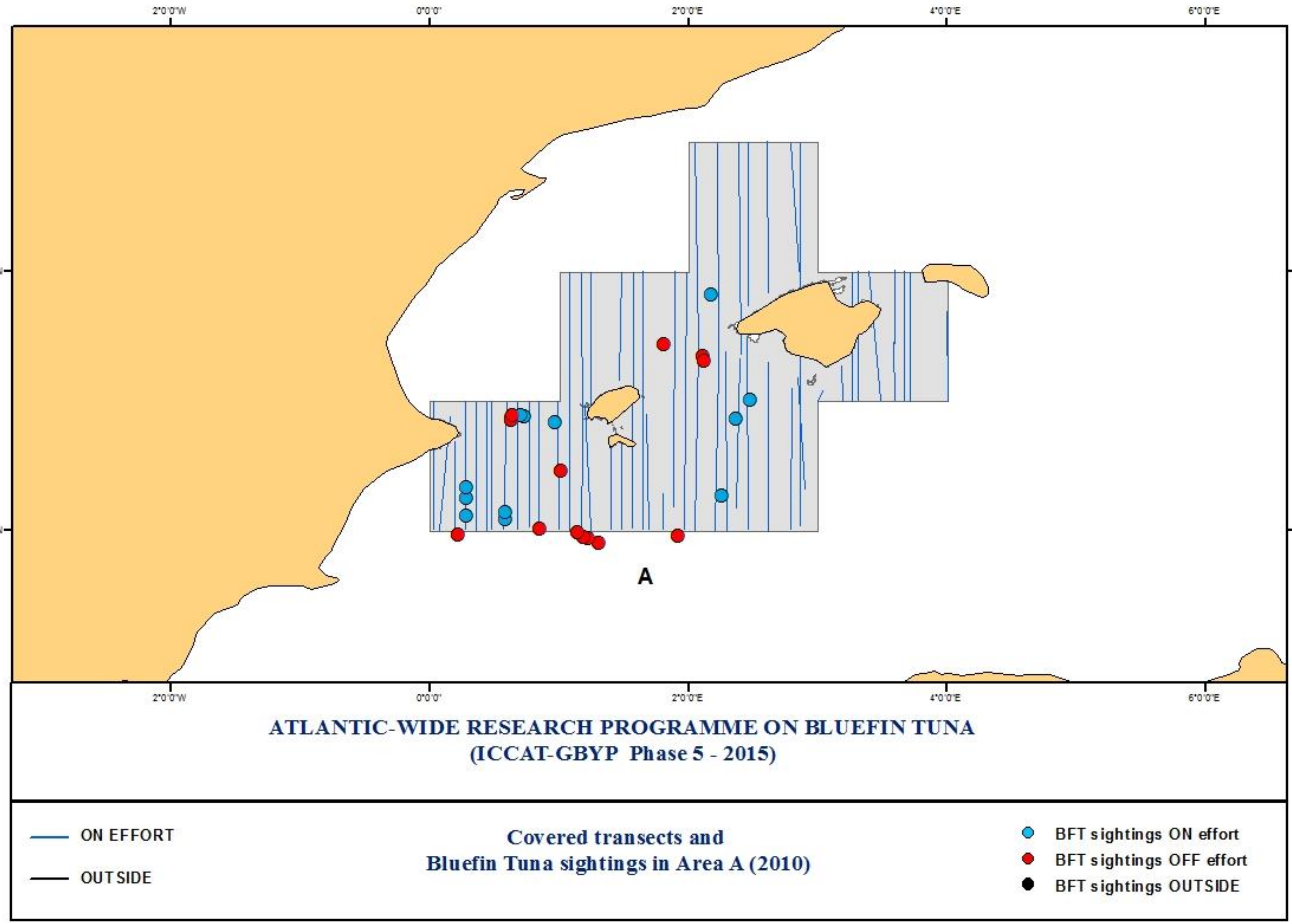

Figure II.2. Tracks and sightings within overlap sub-area A in 2010.

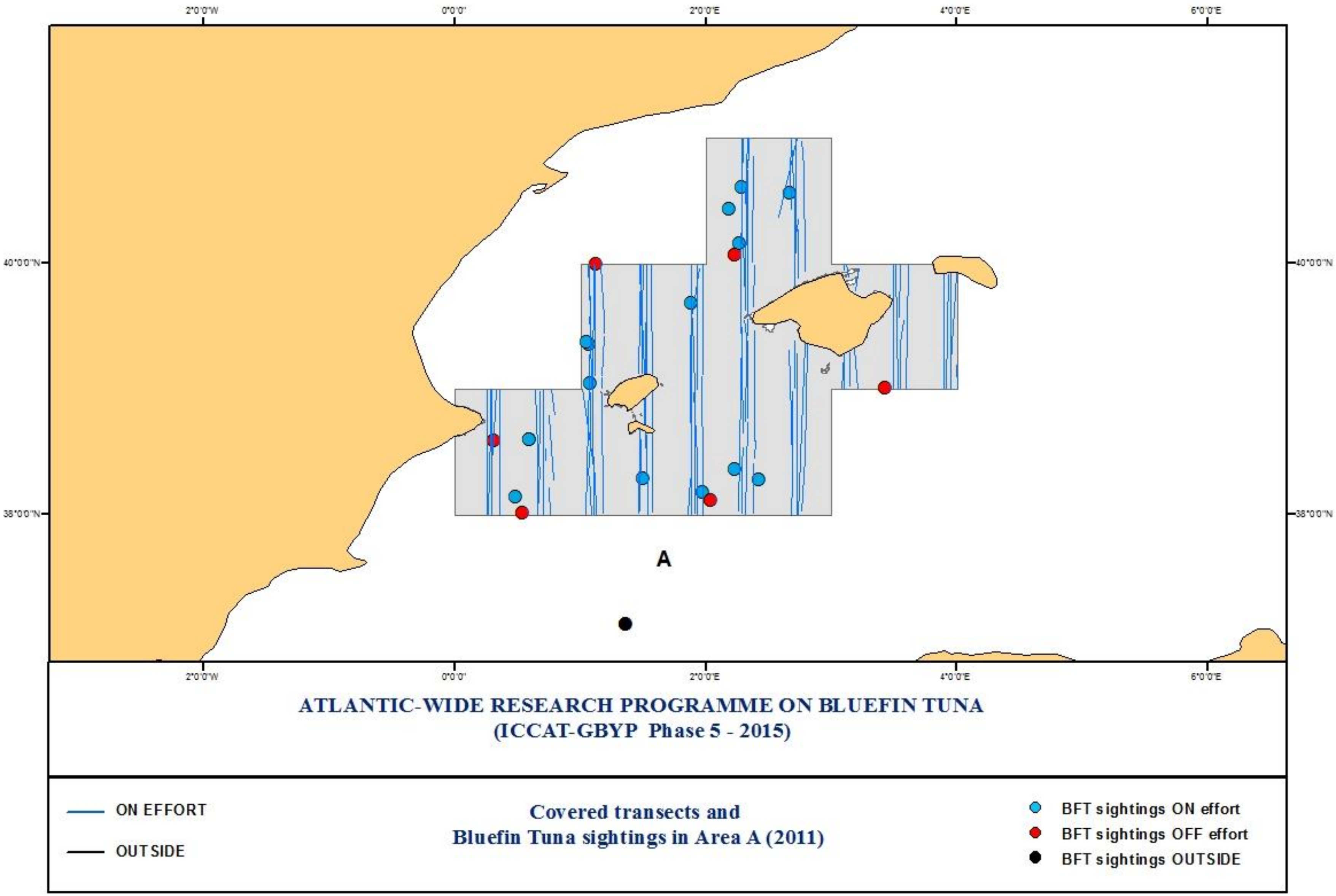

Figure II.3. Tracks and sightings within overlap sub-area A in 2011.

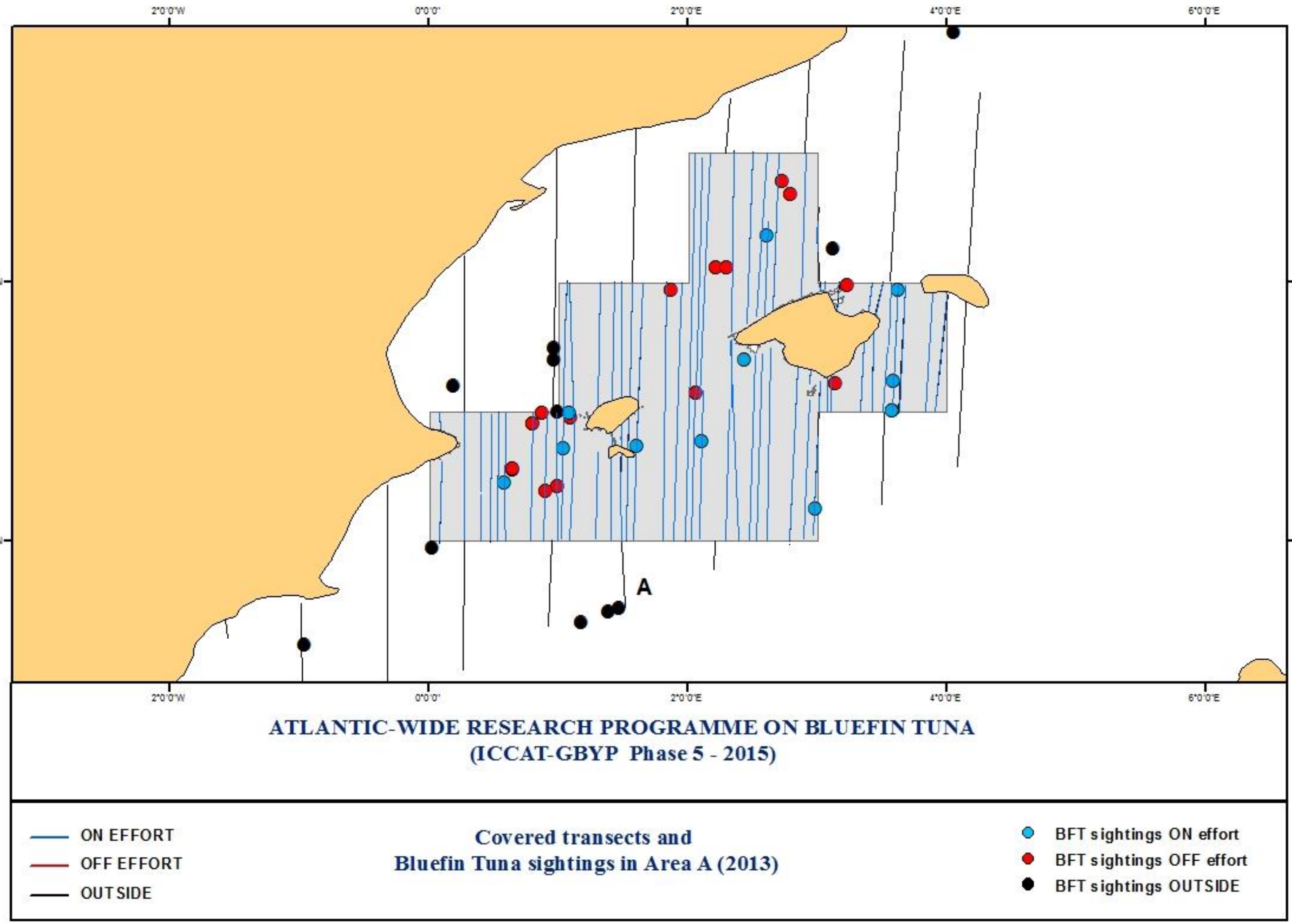

Figure II.4. Tracks and sightings within overlap sub-area A in 2013.

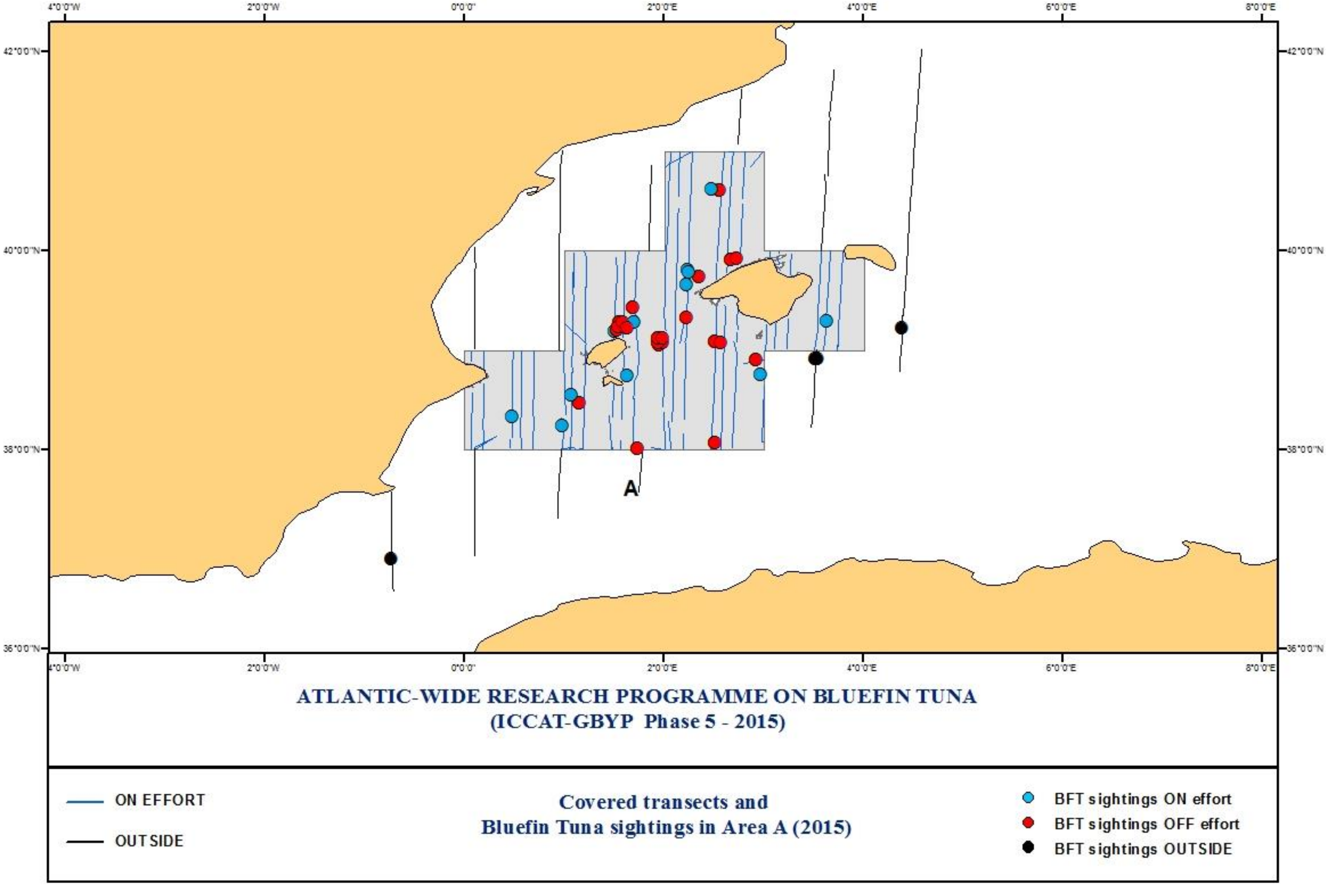

Figure II.5. Tracks and sightings within overlap sub-area A in 2015.

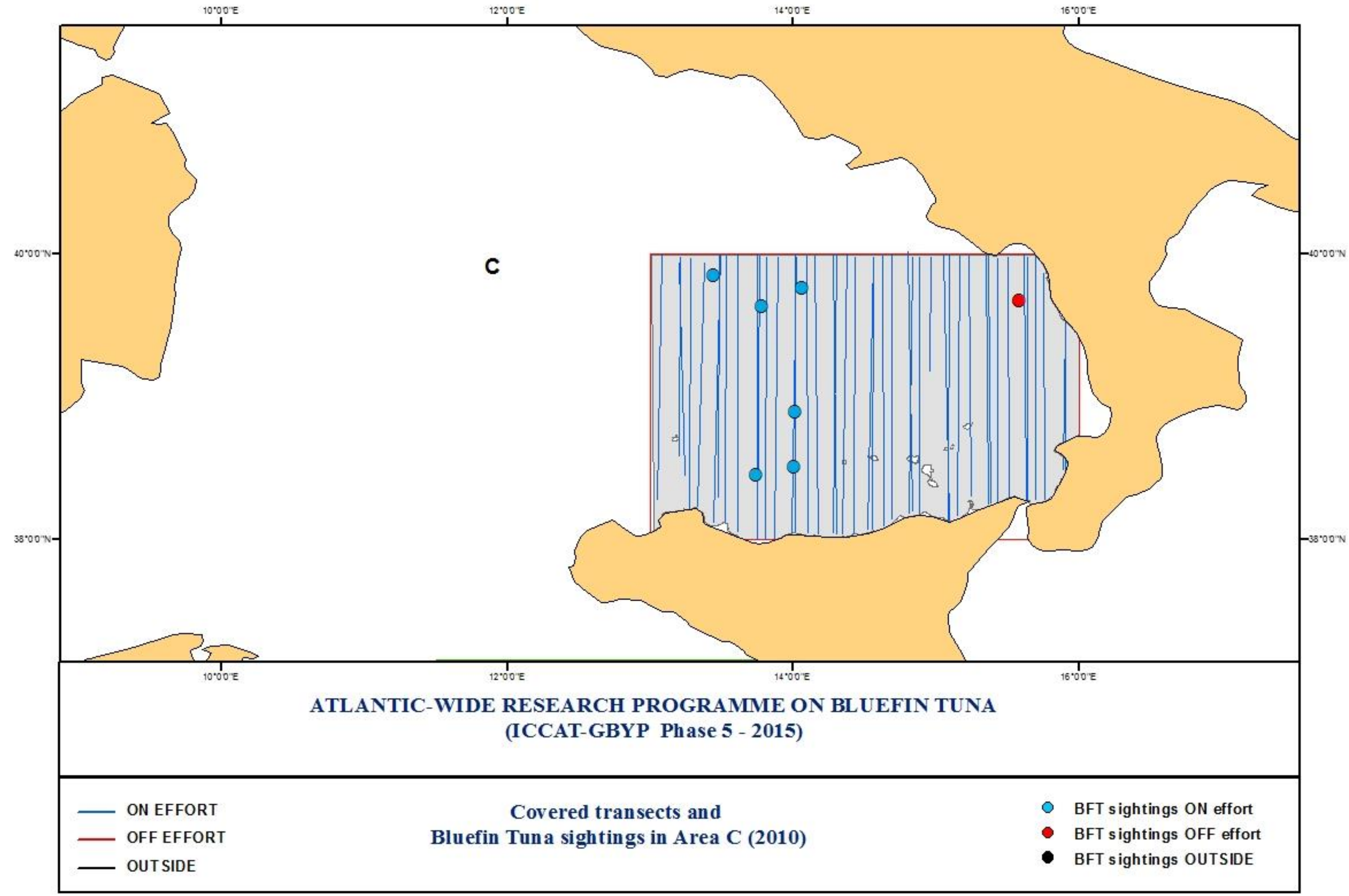

Figure II.6. Tracks and sightings within overlap sub-area C in 2010.

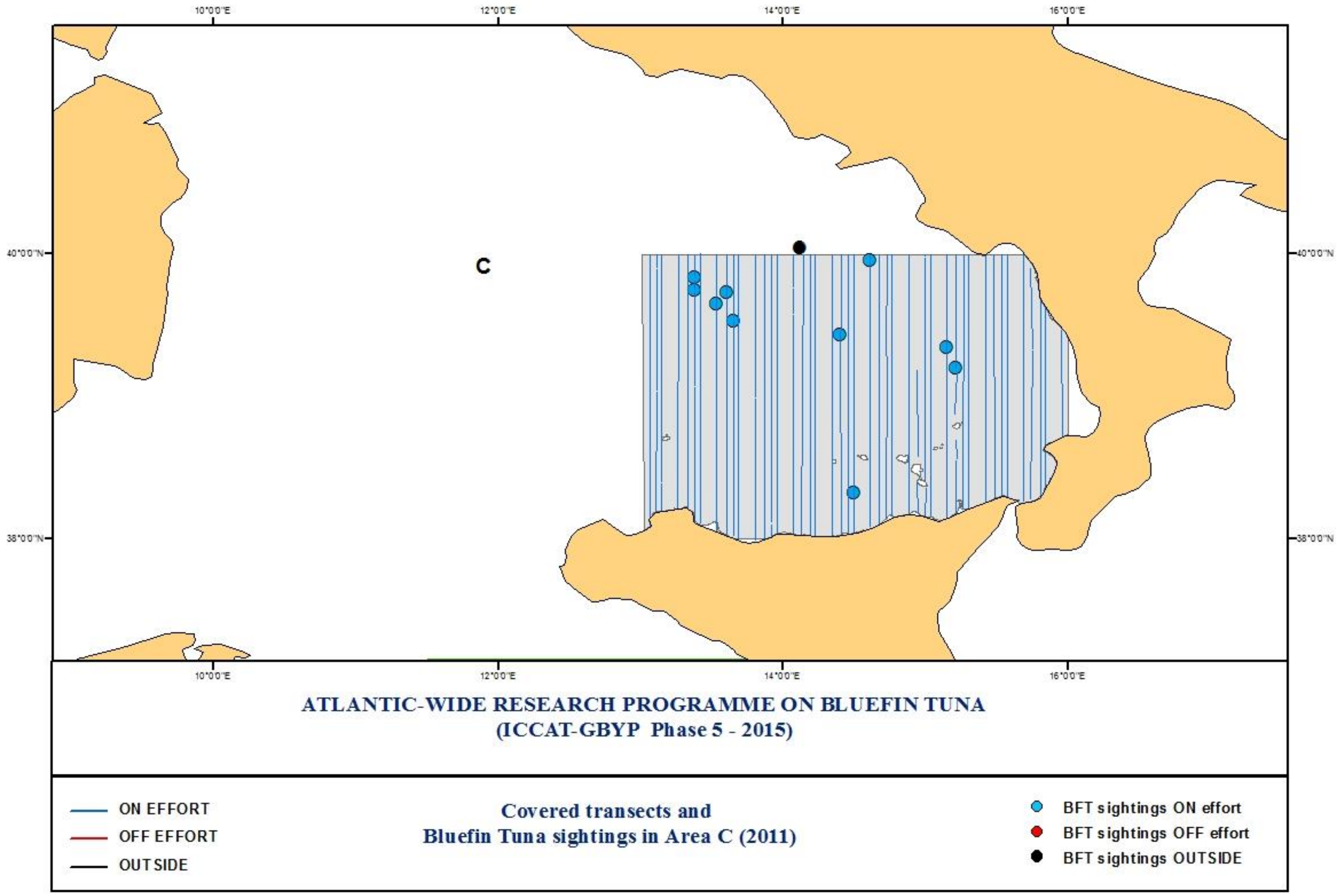

Figure II.7. Tracks and sightings within overlap sub-area C in 2011.

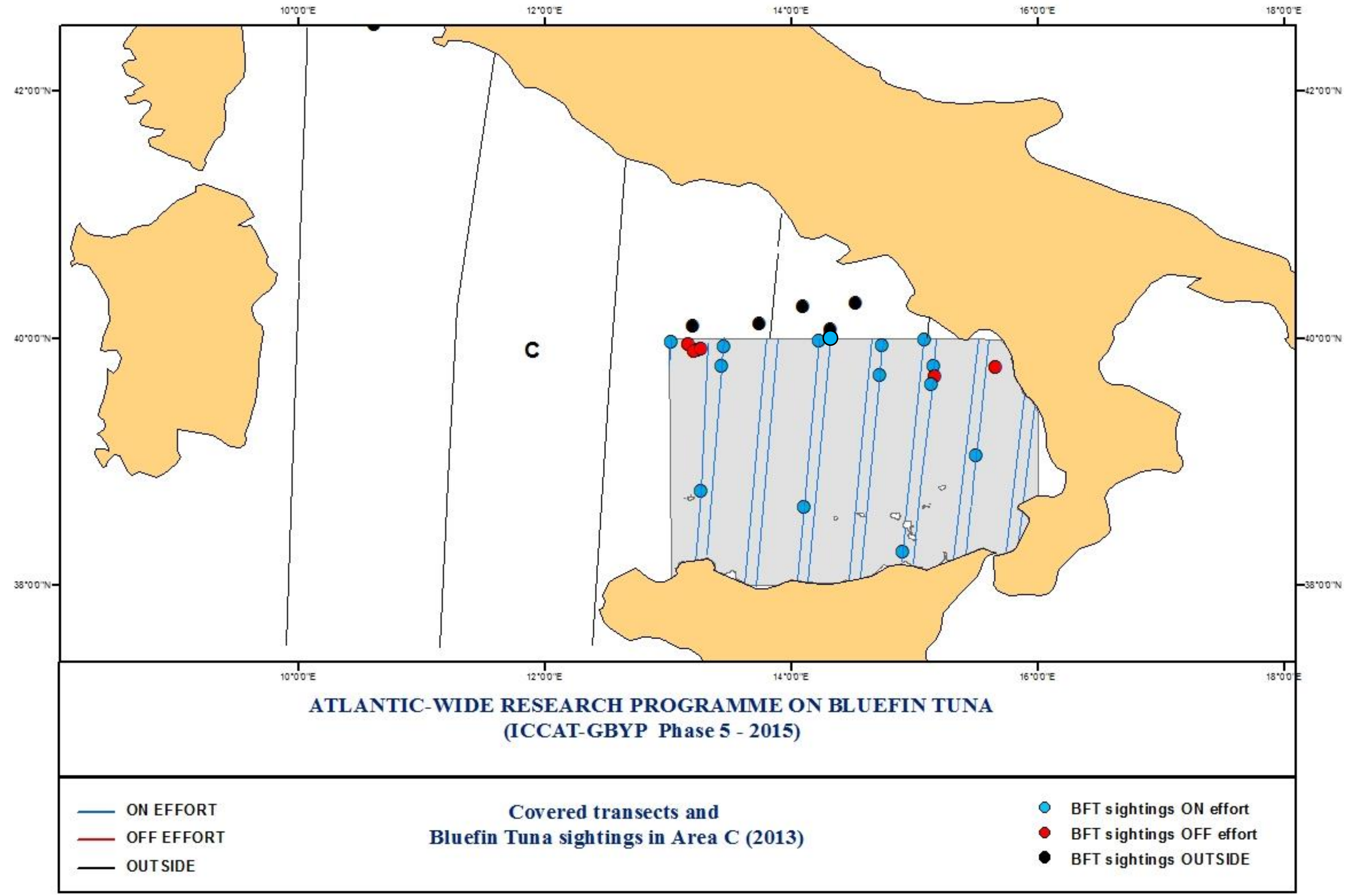

Figure II.8. Tracks and sightings within overlap sub-area C in 2013.

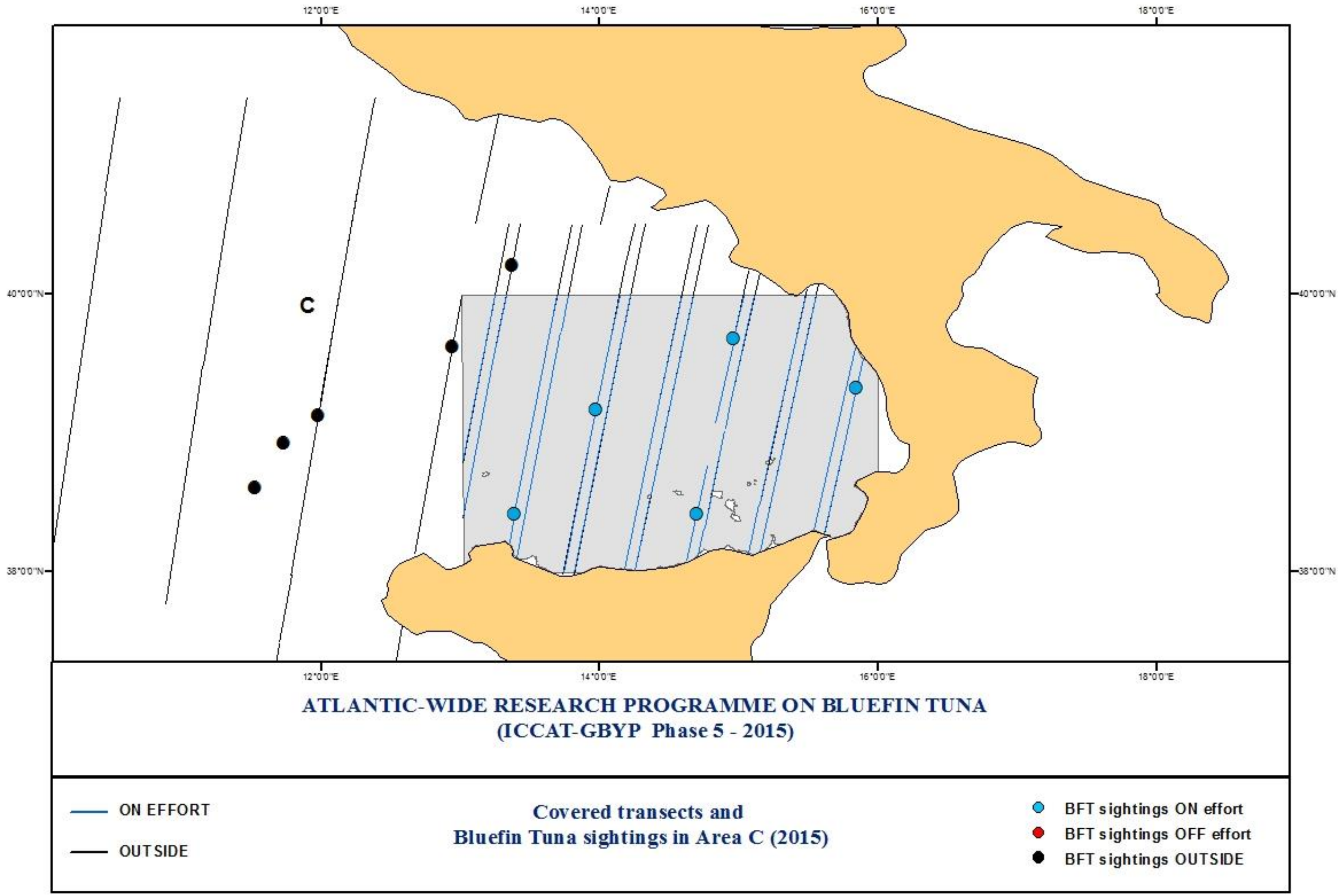

Figure II.9. Tracks and sightings within overlap sub-area C in 2015.

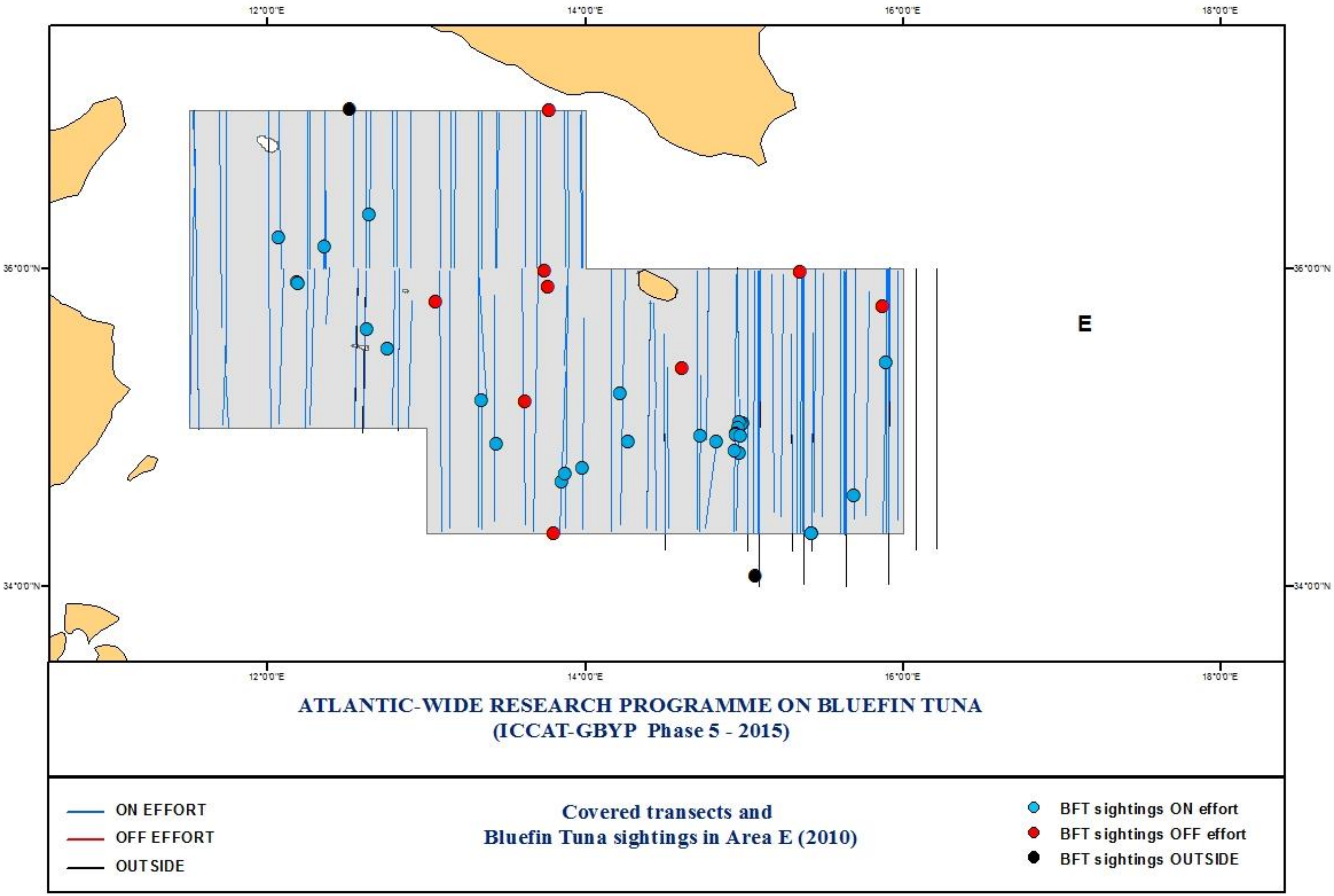

Figure II.10. Tracks and sightings within overlap sub-area E in 2010.

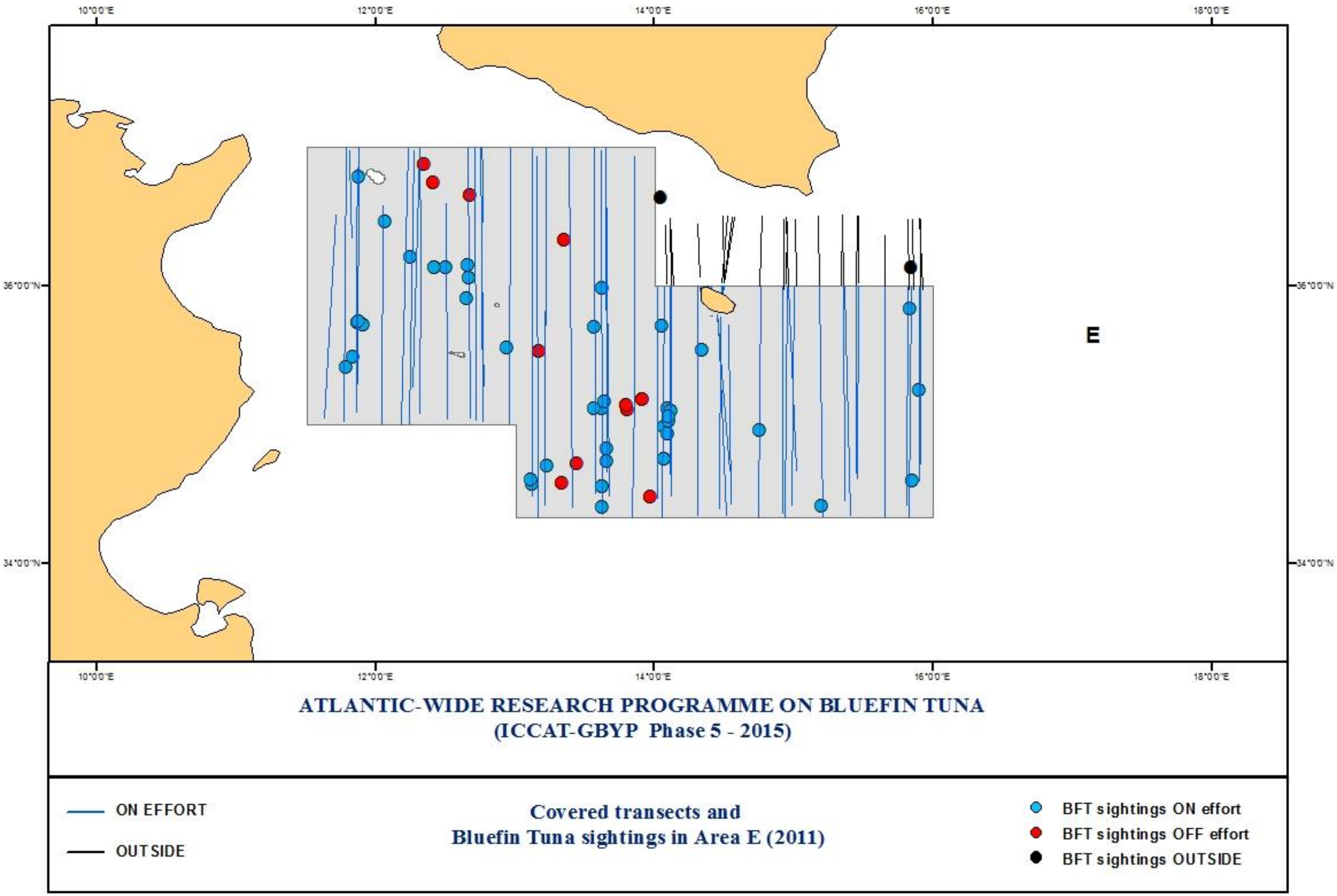

Figure II.11. Tracks and sightings within overlap sub-area E in 2011.

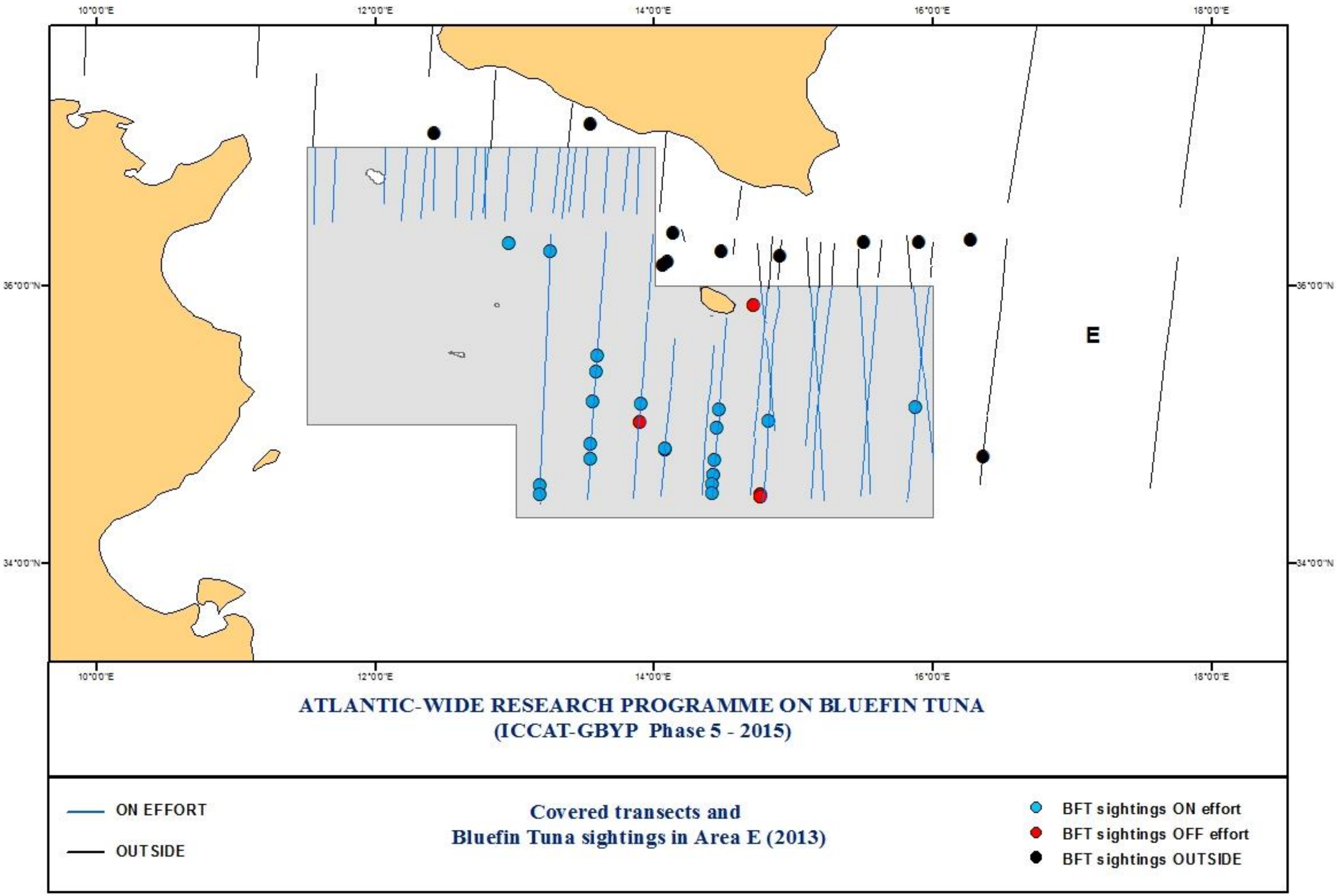

Figure II.12. Tracks and sightings within overlap sub-area E in 2013.

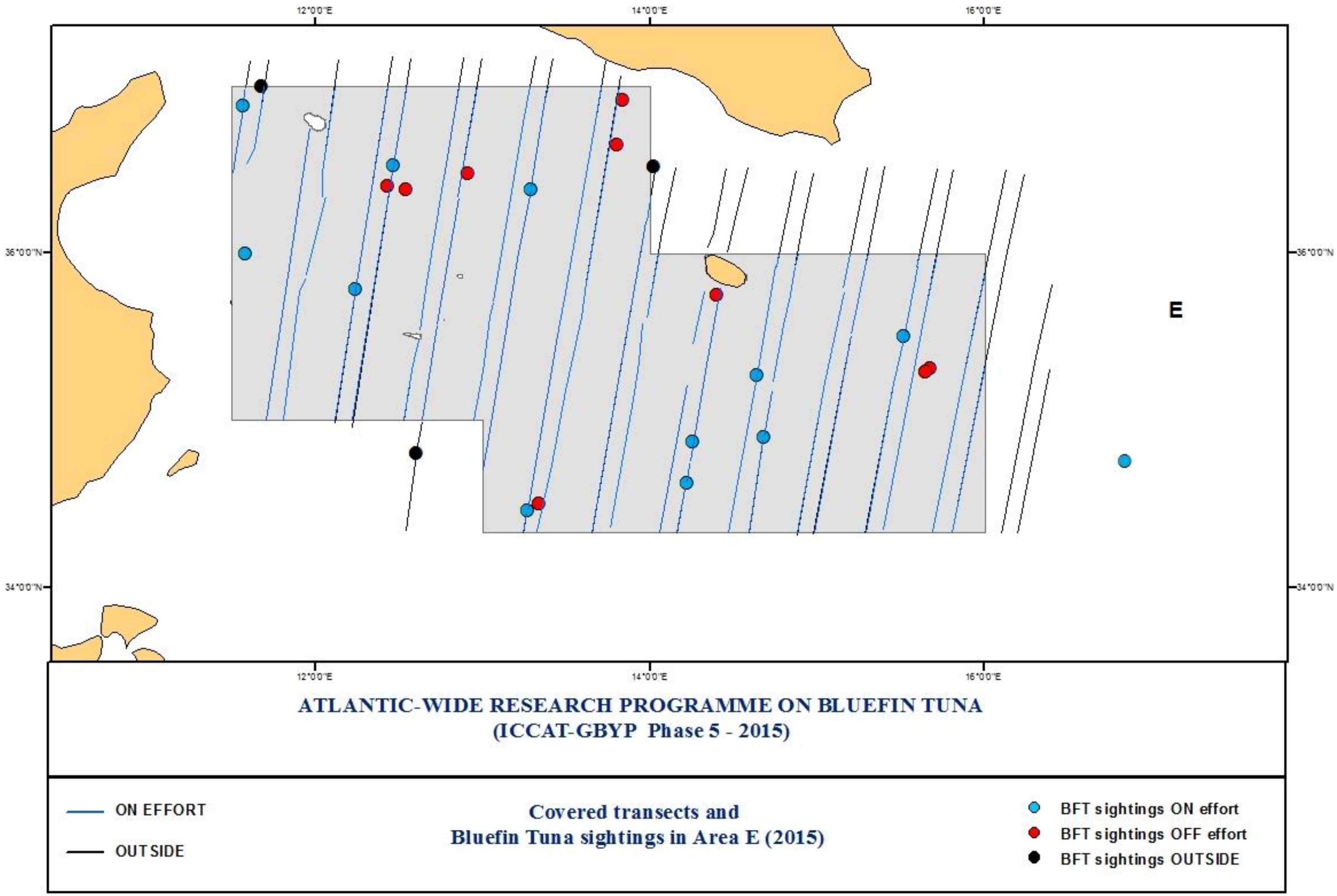

Figure II.13. Tracks and sightings within overlap sub-area E in 2015.

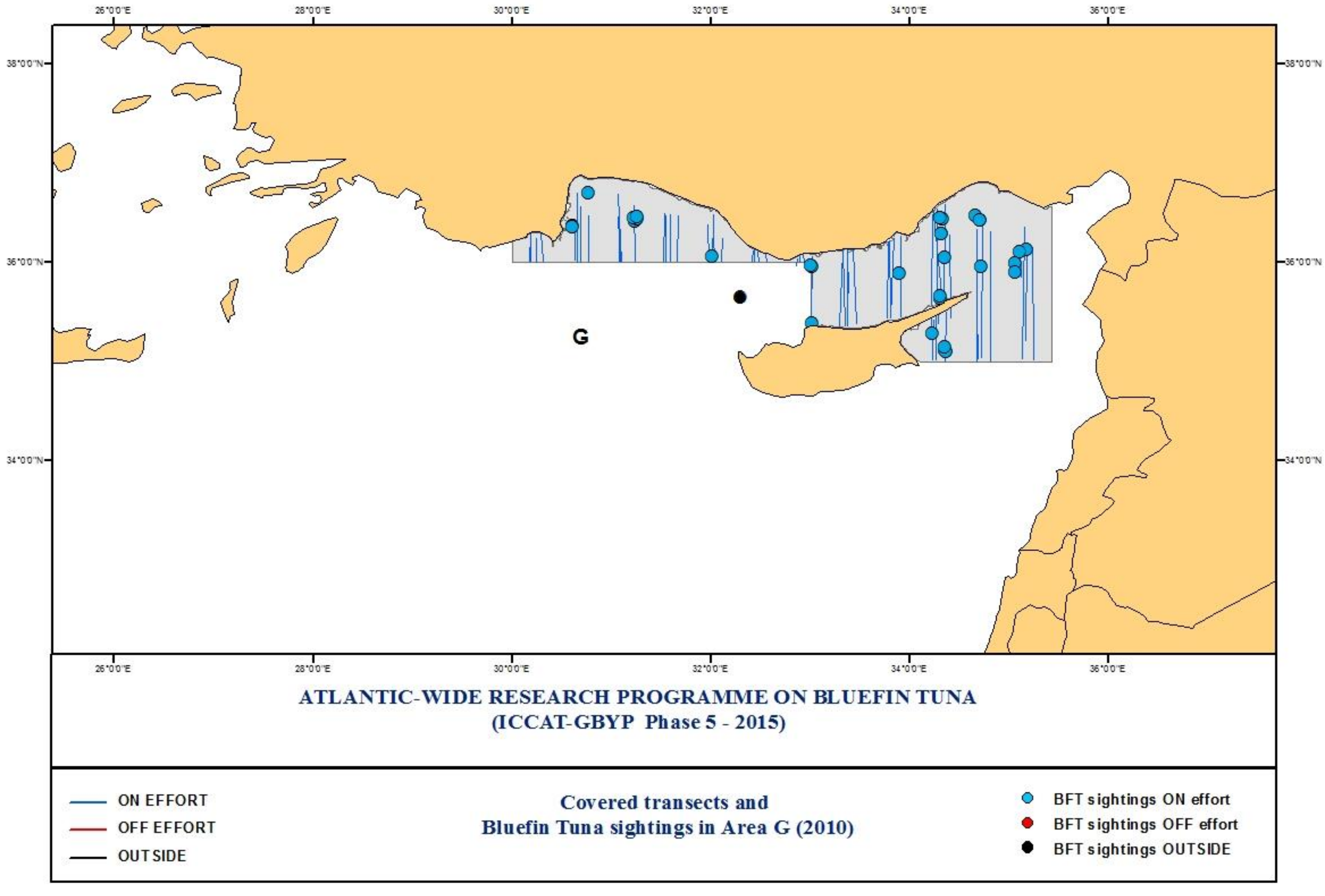

Figure II.14. Tracks and sightings within overlap sub-area G in 2010.

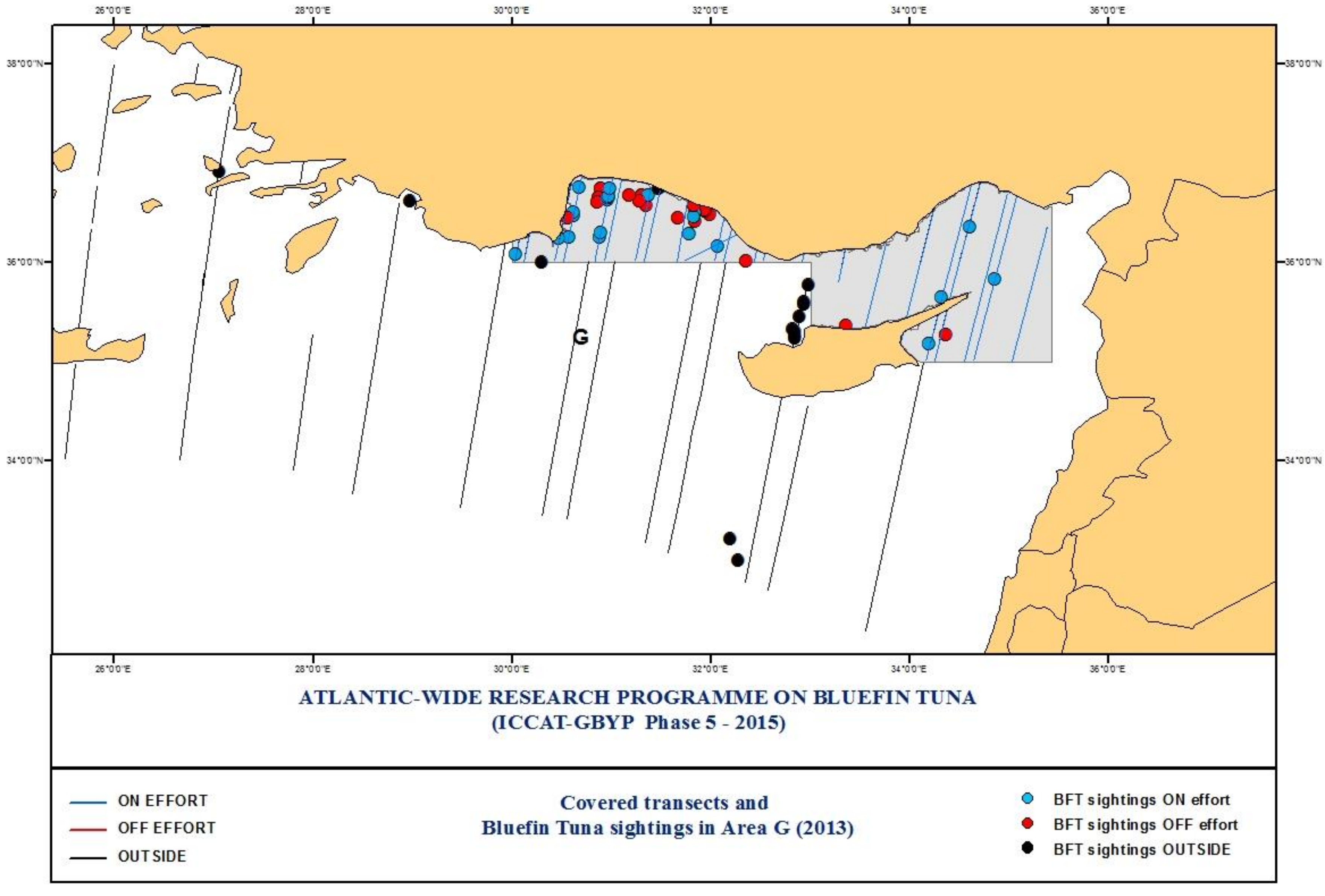

Figure II.15. Tracks and sightings within overlap sub-area G in 2013.

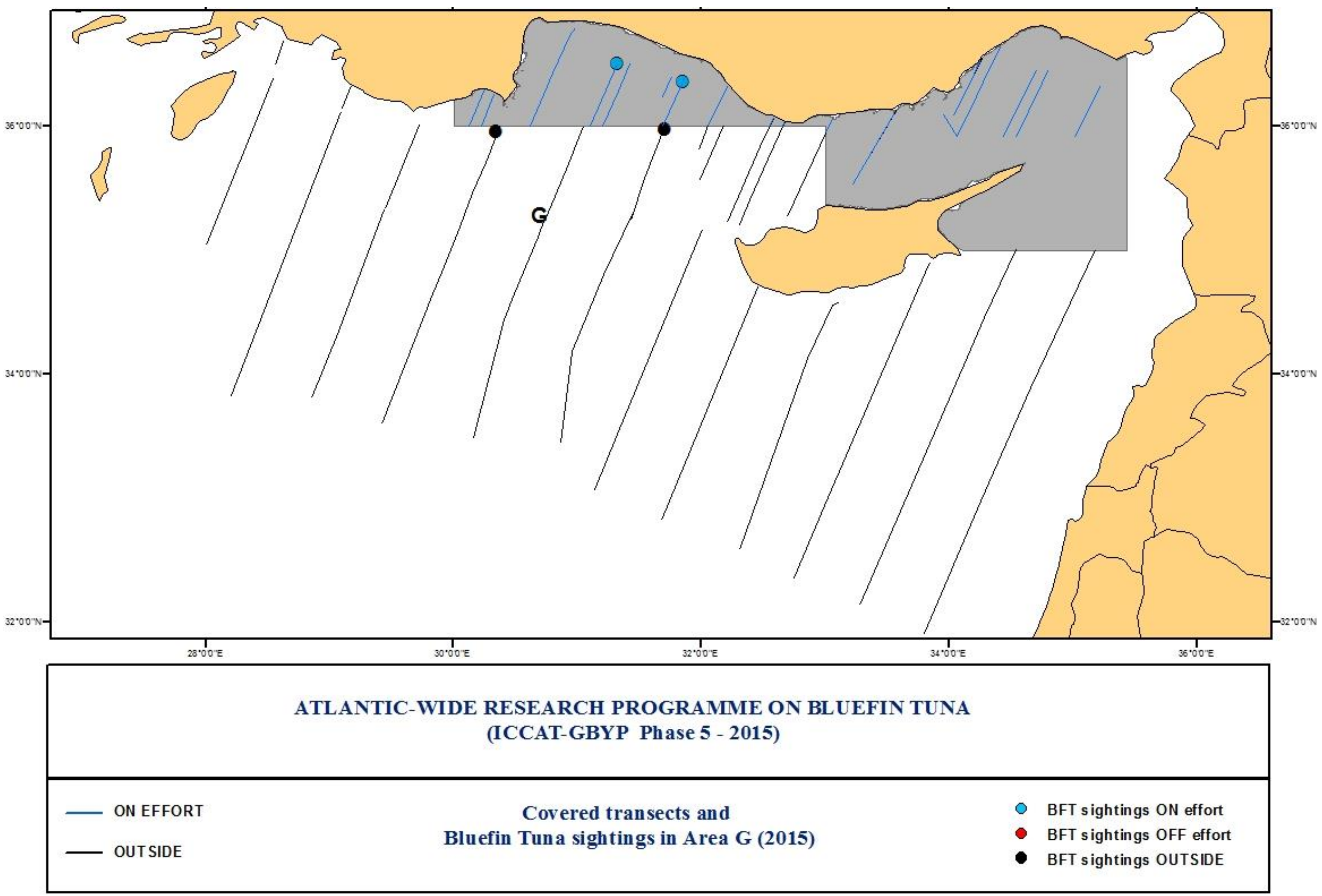

Figure II.16. Tracks and sightings within overlap sub-area G in 2015.

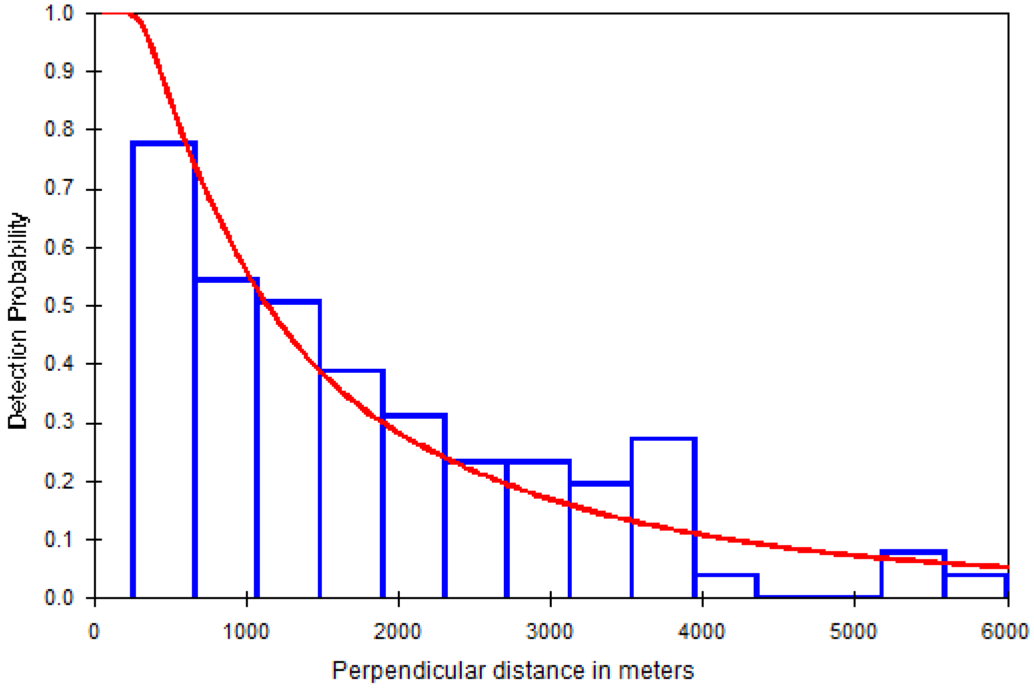

Figure II.17. Detection function for 2010, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings.

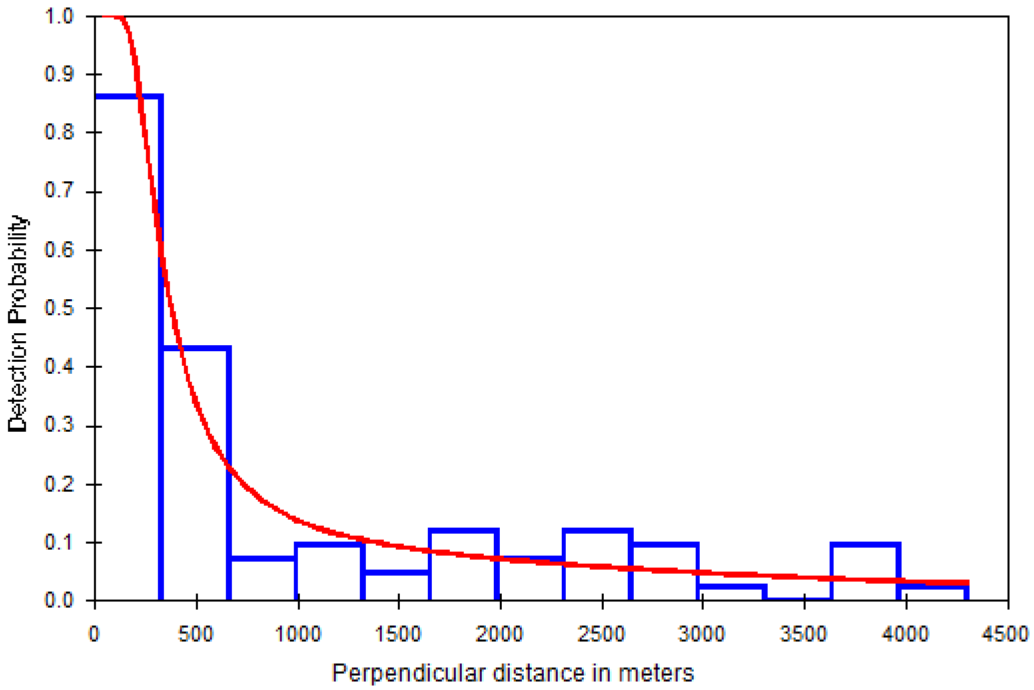

Figure II.18. Detection function for 2011, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings.

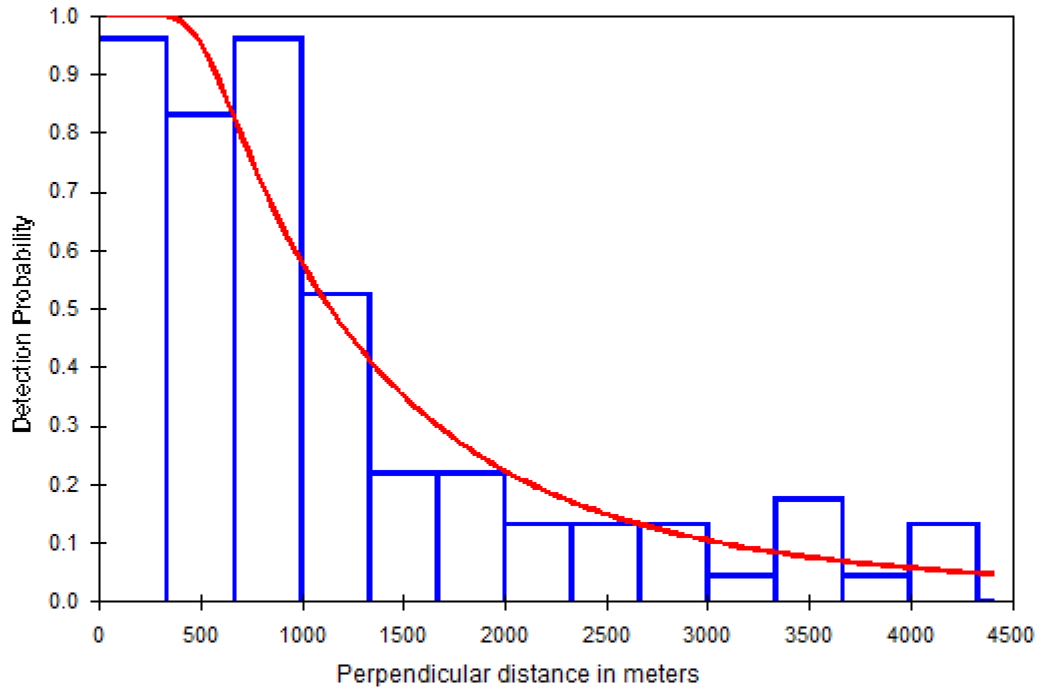

Figure II.19. Detection function for 2013, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings.

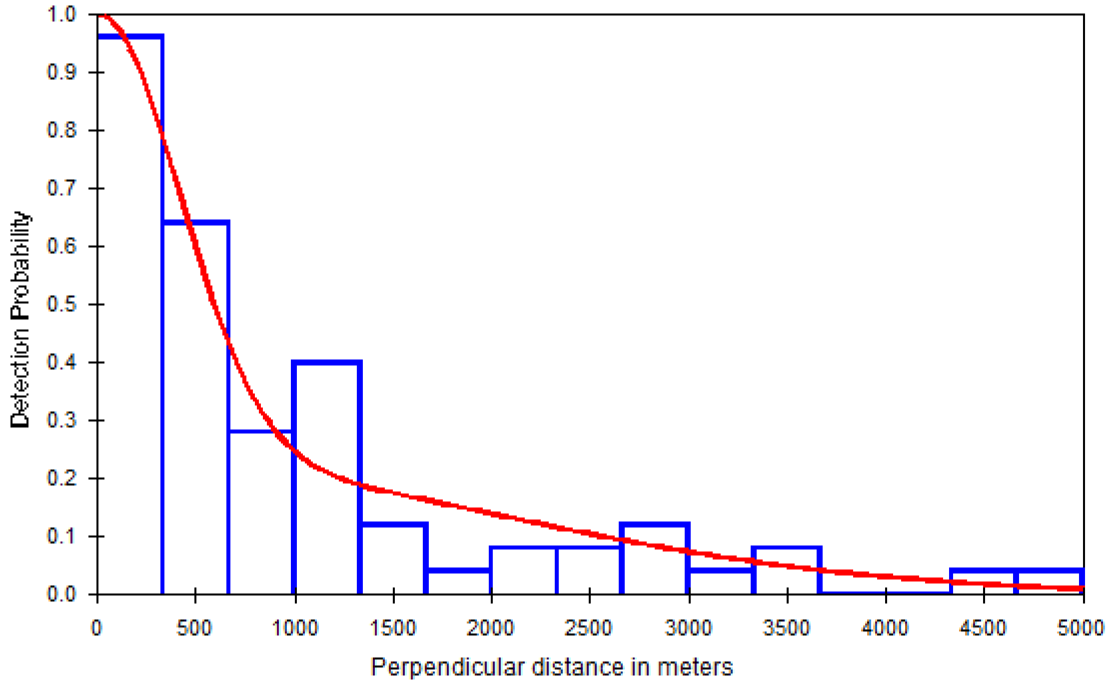

Figure II.20. Detection function for 2015, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings.

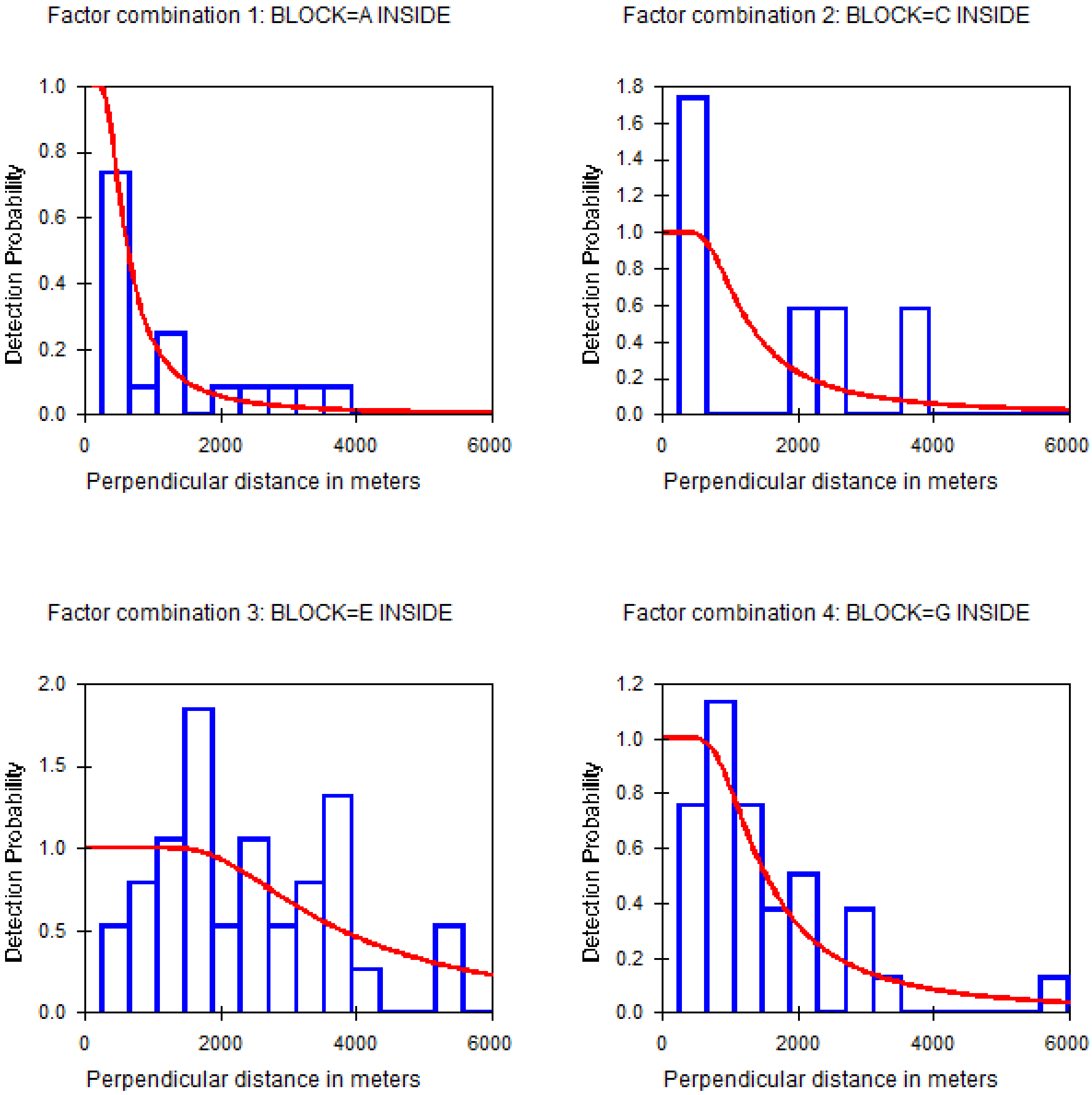

Figure II.21. 2010 detection function for each level of the covariate “sub-area”.

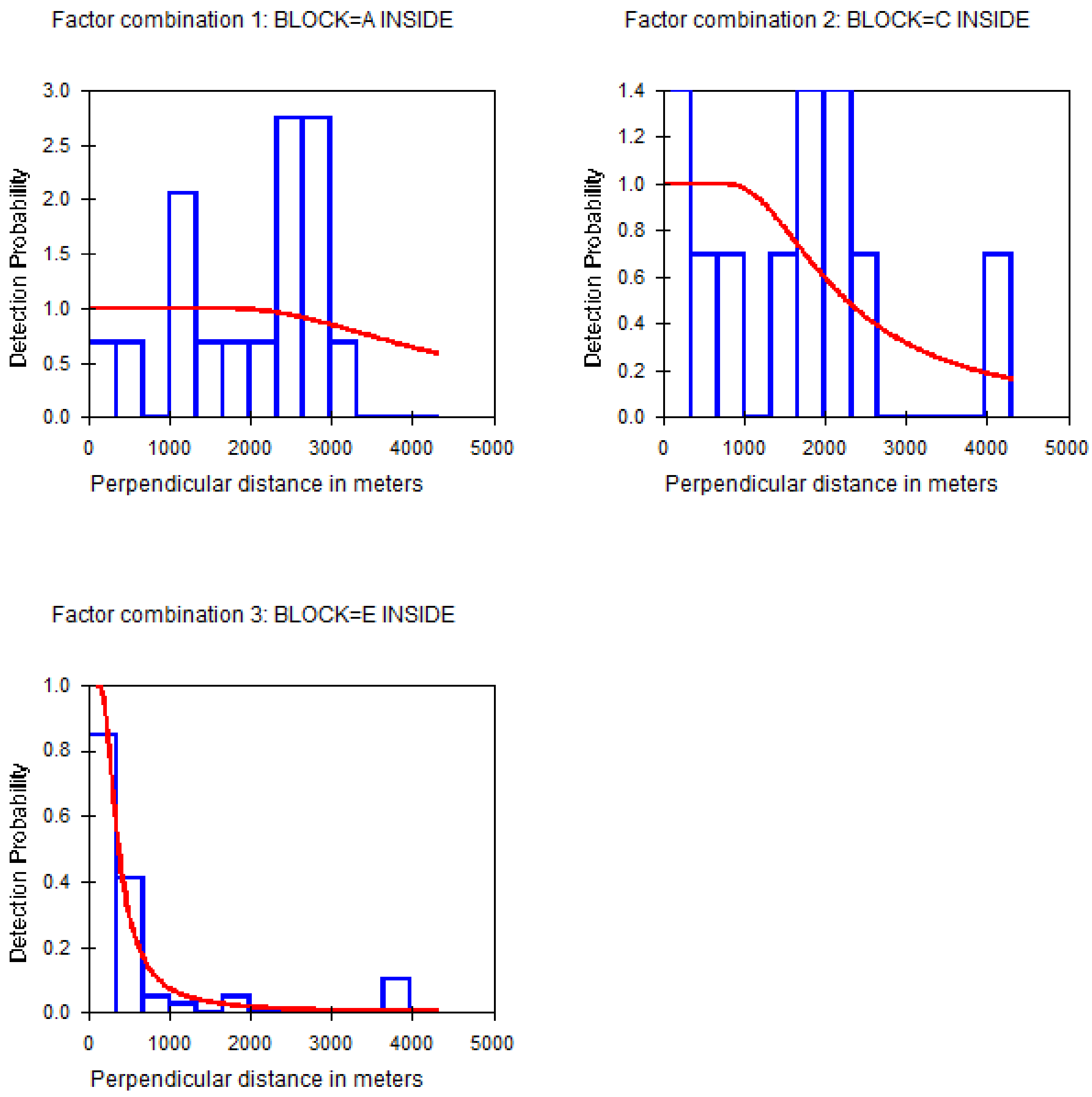

Figure II.22. 2011 detection function for each level of the covariate "sub-area".

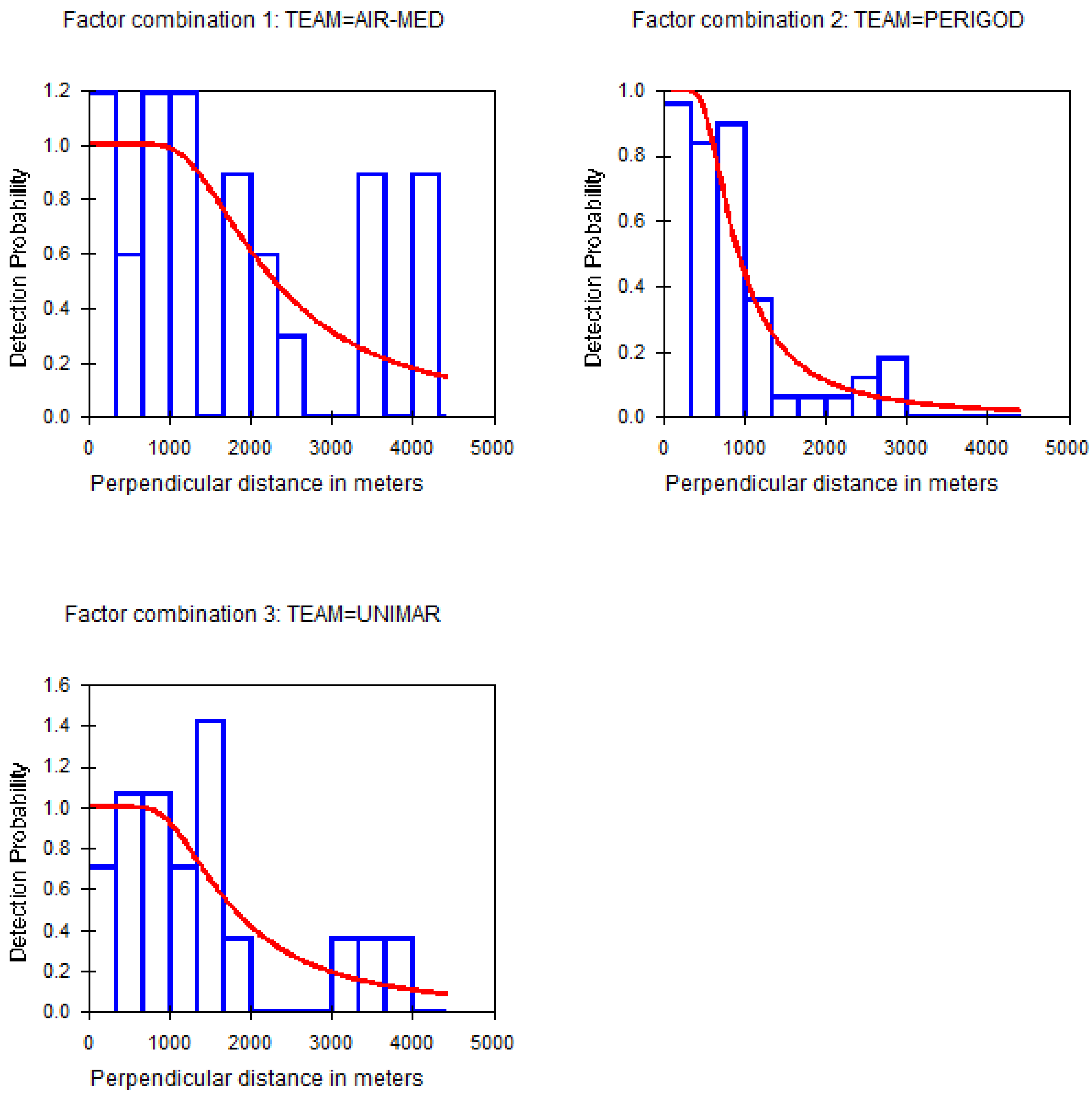

Figure II.23. 2013 detection function for each level of the covariate "team".

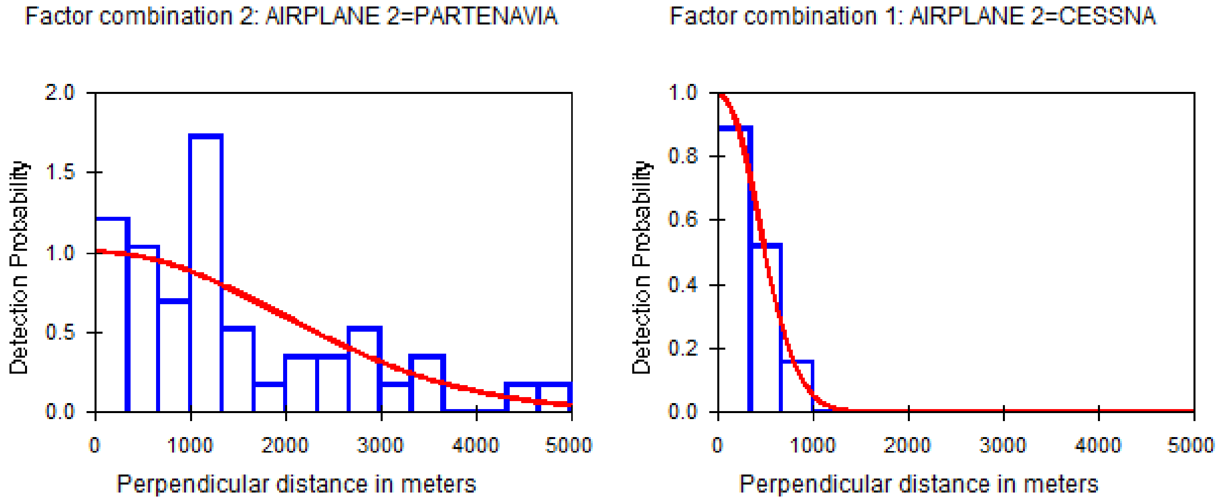

Figure II.24. 2015 detection function for each level of the covariate "airplane".