# ATLANTIC-WIDE RESEARCH PROGRAMME ON BLUEFIN TUNA (ICCAT-GBYP – PHASE 4 - 2013)

# ELABORATION OF 2013 DATA FROM THE AERIAL SURVEY ON SPAWNING AGGREGATIONS

# DATA RECOVERY PLAN

## Final Report

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## Background

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

An important element of this programme is to develop fisheries independent 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.

The purpose of this work is to elaborate the Aerial Survey data, collected under Phase 4 of the GBYP in order to allow the SCRS and the Commission to fully consider the requirements and associated costs and benefits of a long-term aerial survey.

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 in much more extended areas.

## Objectives

I. update, including 2013 data, the analysis conducted in 2010 and 2011, by using the same methodological approach;

II. develop recommendations on the minimum survey design(s) for the next survey required for use within a scientific management framework, , including the advantages and disadvantages of having limited or extended survey.

## Deliverables

D1) A draft final report updating the analysis conducted in GBYP Phase 1, 2 and 3, on the effect of additional variance to be appended to a more detailed report that recommends a minimum survey design that can still meet scientific management objectives (to be delivered on **13th September 2013** at the latest).

D2) A final report report for the SCRS (to be delivered **on 20th September 2013** at the latest), updating the draft final report and including the comments by ICCAT (to be delivered on **20th September 2013** at the latest).

D3) A short PowerPoint presentation of the main results for the SCRS (to be delivered on **20th September 2013** at the latest).

## 1. Abundance estimates

# 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 (Cañadas, Vázquez & Hammond 2011) based on: the eleven defined survey areas (survey areas A to G; and sub-areas surveyed in 2010 and 2011 within blocks A, C, E and G, see Figure 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 (except in block D where 45º where chosen to keep this criterium).

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

In general, coverage of all sub-areas was comprehensive. But there were a couple of problems: The southern sections of sub-areas A and B could not be surveyed. In terms of analysis that doesn't mean any problem as being on the edge of the survey sub-areas, the "empty" sections could be extracted leaving the actual survey areas with the adequate coverage.

More problematic was the situation in sub-area E (both inside and outside sub-areas). In the outside sub-area the westernmost and easternmost sections were not surveyed (see Figure 10). In the inner sub-area the southernmost bit and the whole SW were not surveyed either. This implies that the density cannot be extrapolated to the whole area without dismissing the equal coverage probability assumption. Therefore, the not-surveyed areas were deleted, as was done with sub-areas A and B (see Figure 13).

Additionally, sub-area E-inside was more heavily surveyed in the eastern half (with three replicas, one of them strangely shifted some degrees so they cross the other ones diagonally) than in the western half (with one unique replica). Also the northern section of this sub-area was more heavily covered than the rest. Therefore, the sub-area E-inside seems to be breaking the equal coverage probability assumption with a non-homogeneous coverage (given that the heavily / non-heavily surveyed sections are not scattered over the whole sub-area but in defined sections). Hence, results for sub-area E-inside should not be considered totally reliable.

### Data provided

Draft data collection forms were proposed by Hammond, Cañadas & Vázquez (2010) and modified in 2013. 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 minor errors/inconsistencies and missing data. Missing data were checked with the survey teams, noted and corrected in most cases. Forty-nine sightings had to be discarded due to lack of information on cluster size and weight. Forty-one sightings did not have declination angles, of which 13 could be "saved" calculating the perpendicular distances from the sighting/animals positions. The accuracy of these data is unknown. But twenty-eight sightings did not have data to obtain perpendicular distances; most of them did not have cluster size and weight either, but 5 sightings had but had to be discarded due to lack of perpendicular distance data. Therefore, a total of 54 sightings had to be discarded due to lack of vital information for the analysis (49 lacking cluster size and weight data and 5 lacking perpendicular distance).

The data on school size were recorded in two ways: estimated number of animals in the school, and estimated total weight in tons of the school. Both were used as a measure of school size in analysis, performing two analysis 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.

## Data analysis

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

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

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

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

Abundance was estimated as:

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

where A is the size of the survey area.

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

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

**Fitting the detection function**

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

Detection functions were fitted to the perpendicular distance data to estimate the effective strip half-width, *esw*. Multi-Covariate Distance Sampling (MCDS) methods, within the MRDS engine, were used to allow detection probability to be modelled as a function of covariates additional to perpendicular distance from the transect line. These covariates were defined in the survey design phase and included sea state, air haziness, water turbidity, observers searching, cue and estimated weight of the school. Table 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, 5,000m 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).

# Results

Table 2 shows the area of each survey sub-area, the number and length of searched transects and the number of sightings of bluefin tuna schools used for analysis.

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

The final model selected, had two covariates (team and cluster size class) with a Hazard-rate key function. The Kolmogorov-Smirnov and the Cramer-von Mises tests performed well and overall there were no significant differences between the cdf and the edf. The q-q plot shows a good agreement between the cdf and the edf. Table 3 shows the main parameters for the detection function and the results of the diagnostics tests. Figure 14 shows the fitted detection function and Figure 15 shows the Q-Q plot.

In order to investigate the effect of Team (AirMed, AirPerigod and Unimar) on the probability of detection, an MCDS model was run in DISTANCE to visualize the curves of the detection function for each team (Figures 16 to 18).

Tables 4 and 5 shows 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 9,100 (CV = 45%) tonnes and 138,650 (CV = 35%) individuals of bluefin tuna was estimated in all the spawning sub-areas ('inside').

Table 7 shows the results for 2013, divided as 'inside' sub-areas, 'outside' sub-areas, and total.

### Comparison with 2010 and 2011 estimates

Table 6 shows a comparison between the estimates in 2010, 2011 and 2013 in terms of encounter rates of schools and of total weight and abundance in each of the subareas and their CVs.

## Discussion

### Survey logistics

The survey design generally seemed to work well. Evenly spaced north-south transects seemed to work well as a design configuration. Data collection worked much better than in 2010 and 2011.

Nevertheless, a situation like that in sub-area E (both inside and outside sections), where the homogeneous coverage is not achieved with much more effort in some areas than in others, should be strongly avoided 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.

Looking at the detection functions by team, there is an obvious undesirable effect for the team of Unimar, where there is a strong drop of detections in the first 500 meters from the line transect. This is probably due to the way the observers look… not putting too much effort to the area underneath the airplane (which is the most important section). It is advisable to correct this pattern in the future.

A handicap of this years' data was that in way too many occasions declination angle was not provided for OFF effort sightings of BFT. These data are necessary to increase sample size for the detection function allowing for a better fit. It was a real shame not being able to use all those sightings due to the lack of data on declination angle.

Another undesirable fact happened this year too. There were many sightings of other species, mainly marine mammals and sea turtles, but in most occasions declination angles were not collected, even when there were no sightings of BFT and therefore observers were not busy with the target species. It was encouraged to record these data at the pre-survey meeting at ICCAT. This is highly regrettable as it means a huge waste of resources, instead of acting in synergy with other species' research. This is the first time a global survey is carried out in the Mediterranean Sea, and a unique situation in which a huge amount of information could have been obtained for sea turtles and cetaceans, all endangered and protected species, which would have been extremely useful for their conservation and as a liaison with other research and conservation organizations such as ACCOBAMS.

### 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 48 % and 54% for the 'inside' sub-areas and 97 - 106% for 'outside' sub-areas. The precision of mean school size had a very large range, between 19 and 108% for the 'inside' sub-areas. There wasn't enough data on the 'outside' sub-areas to estimate the mean school size CV. CVs for estimates of total weight were high in all sub-areas: 40 - 96% for 'inside' sub-areas, and 96 – 117% for 'outside' sub-areas. Summing over all sub-areas surveyed, the CV of total abundance was 35% for the 'inside' subareas and 86% for the 'outside' sub-areas.

In Table 4 it is obvious that, within the 'inside' sub-areas the largest CVs correspond to the E, probably due to the heterogeneity in coverage as described above and the heterogeneity in the distribution of the sightings, i.e., the majority of the on-effort sightings occurred in the section with less effort (see Figure 10) which has probably increased greatly the variance for the encounter rate.

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 increase the number of sightings. This can be achieved partly by more efficient searching and partly by increasing the amount of searching effort (transect length).

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 much of their time beneath the surface and unavailable to be detected (so-called availability bias). Estimates of abundance from these surveys are thus underestimates (minimum estimates) even though a detection function has been fitted to correct for animals missed within the survey strip.

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

This year it was requested that observers record the time at initial sighting and time abeam of the schools of BFT, with an accuracy of the nearest second. With this data, as it was explained during the pre-survey meeting, it would be possible to calculate an estimation of availability bias. Unfortunately, data was not recorded as requested. In many cases the time abeam was not provided, and when provided, it was recorded (or at least provided to the analyst) with an accuracy of minutes, and not seconds. This is totally useless for an airplane where seconds matter given the speed. Therefore, this calculation could not be done.

**Comparison with 2010 and 2011 estimates**

The coefficients of variation have gone up in all 'inside' sub-areas in 2013 with respect to 2011, and some up and some down with respect to 2010. Variability also varies greatly among sub-areas (Table 6).

*Sub-area A-inside*

In sub-area A-inside there was slightly more effort in 2013 than in 2010 (around 7.5% more), and slightly less than in 2011 (15% less), while there was a 46% increase in number of sightings with respect to 2010 and 15% with respect to 2011, resulting in an increase of 38% in encounter rate and 65% in density of schools with respect to 2010 and 21% and 56% respectively with respect to 2011. However, the mean weight of the schools has decreased 29% in 2013 with respect to 2010 but has remained similar (only 6% larger) than in 2011. Therefore, it seems that in 2013 there were more groups but smaller (in terms of weight) than in 2010, resulting in a decrease of 13% (161 tn) in final total weight for this sub-area from 2010 to 2013, which, given the wide CVs, are no significantly different, remaining very similar than in 2011 (only 5% more weight in 2013, 50t). However, there was a strong decrease in mean cluster size (in terms of number of animals in the school) being 44% smaller in 2013 than in 2011 (no data available on cluster size in 2010), yielding a total abundance of fish in 2013 21% larger than in 2011.

In summary, with respect to 2010, there seemed to be more groups but with smaller fish resulting in a 13% less of total weight of BFT in 2013. With respect to 2011, there seemed to be also more groups, similar in weight, only 5% larger, but with fewer animals per group resulting in a very similar total weigh and a 21% more animals.

*Sub-area C-inside*

In sub-area C-inside there was much less effort in 2013 than in 2010 and 2011 (68% less in both cases), while there was a 45% increase in number of sightings with respect to 2010 and 9% with respect to 2011, resulting in an increase of 82% in encounter rate and 68% in density of schools with respect to 2010 and 72% and 78% respectively with respect to 2011. The mean weight of the schools has also largely increased with respect to 2010 (34%) and 2011 (77%). Therefore, it seems that in 2013 there were many more groups and much larger (in terms of weight) than in 2010 and 2011, resulting in an increase of 77% (5,093 tn) in final total weight for this sub-area from 2010 to 2013, and of 95% (6,269 tn) from 2011 to 2013. There was also a very strong increase in mean cluster size (in terms of number of animals in the school) being 81% larger in 2013 than in 2011 (no data available on cluster size in 2010), yielding a total abundance of fish in 2013 96% larger than in 2011.

In summary, there seemed to be a strong increase on BFT in this sub-area, both in terms of total weight and of total number of animals, in 2013 with respect to 2010 (77% more weight in 2013) and 2011 (95% more weight and 96% more animals in 2013).

*Sub-area E-inside*

Sub-area E-inside had different size in 2013 due to some changes done to the limits of the block (mainly reduction of the non-surveyed areas), resulting in an area 18,417 $km^2$ smaller than in 2011 (around 18%) and 8,742 $km^2$ smaller than in 2010 (around 10%).

In sub-area E-inside there was less effort in 2013 than in 2010 and much less than in 2011 (17% and 62% less respectively), while there was a 5% increase in number of sightings with respect to 2010 and a 43% decrease with respect to 2011, resulting in an increase of 21% in encounter rate and 84% in density of schools with respect to 2010 and a 32% increase in encounter rate and a 20% decrease in school density with respect to 2011. The mean weight of the schools has decreased extremely with respect to 2010 (92%) and 2011 (96%). Therefore, it seems that in 2013 there were more groups but extremely much smaller (in terms of weight) than in 2010 and 2011, resulting in a decrease of 60% (1,386 tn) in final total weight for this sub-area from 2010 to 2013, and of 98% (43,888 tn) from 2011 to 2013. There was also a very strong decrease in mean cluster size (in terms of number of animals in the school) being 91% smaller in 2013 than in 2011 (no data available on cluster size in 2010), yielding a total abundance of fish in 2013 95% smaller than in 2011.

In summary, it seemed that the strong increase on BFT groups in this sub-area observed in 2011 with respect to 2010 is maintained, although not as high as in 2011, but these groups were largely smaller in 2013 than the previous two years, both in terms of total weight and of total number of animals, with a very strong decrease in 2013 with respect to 2010 (60% less total weight in 2013) and 2011 (98% less total weight and 95% less animals in 2013).

*Sub-area G-inside*

Sub-area G-inside had slightly different size in 2013 due to some changes done to the limits of the block, resulting in an area 1,081 $km^2$ larger than in 2010 (around 2%). This sub-area was not surveyed in 2011.

In sub-area G-inside there was 51% less effort in 2013 than in 2010, while there was a 61% decrease in number of sightings, resulting in an increase of 21% in encounter rate and 23% in density of schools with respect to 2010. The mean weight of the schools has decreased extremely with respect to 2010 (95%). Therefore, it seems that in 2013 there were fewer groups and extremely much smaller (in terms of weight) than in 2010, resulting in a decrease of 60% (9,998 tn) in final total weight for this sub-area from 2010 to 2013.

*All 'inside' sub-areas together*

In total, as can be seen in Table 6, given that some effort was put in the 'outside' areas, the total effort allocated to these spawning areas was less than in 2010 and 2011 (and even considering that in 2011 sub-area G-inside was not surveyed. Nevertheless, considering the four sub-areas together, the encounter rate of groups was larger in 2013 and density of schools was much larger than in 2010 but only slightly smaller than in 2011. There seems to be a general increase of schools in sub-areas A and C in 2013 with respect to the two previous years, being variable in sub-area E (much larger in 2013 than in 2010 but smaller than in 2011 in terms of density), and a decrease in sub-area G with respect to 2010.

The mean weight of schools has increased in 2013 in sub-areas A and C but has decreased strongly in sub-areas E and G, resulting in a decrease of total weight in 2013. The mean cluster size in terms of number of animals has also decreased in 2013 with respect to 2011 resulting in a strong decrease of total abundance of animals in 2013. Nevertheless, the extreme value of total abundance in 2011 corresponds mainly to sub-area E-inside, where there were concerns about the results due to some doubts about the data there. Only looking at sub-areas A and C, total abundance has increased in 2013, so the strong decrease is only due to sub-area E.

An important point to consider is that in 2013 the results in sub-areas E-inside and G-inside could have been negatively affected by the extension of the survey time, if the survey this year was done not in the best time. And in any case, it was different (partially) than in previous surveys, which difficults the task of comparing results if a temporal issue is affecting.

There is obviously large variability in density of groups, mean weight and mean cluster size in all spawning areas over the years, being sub-area A the apparently more stable of all. But the usually large CVs do not allow as yet as to reliably comparing them. It is necessary to reduce these CVs in future surveys if trends in density and/or weight are expected to be assessed. To achieve this, much more effort should be allocated to these areas in future surveys allowing for the detection of more schools.

*'Outside' sub-areas*

Almost as much effort was allocated to the 'outside' sub-areas than to the 'inside' sub-areas. This was a good experiment to assess the assumption that the previously surveyed 'inside' sub-areas were truly the main density areas for BFT in the Mediterranean.

With only 15% less effort in the outside sub-areas, there was 75% less encounter rate and 82% less density of schools. The mean weight was also smaller although in the same order of magnitude than in sub-areas E and G 'inside', being similar between A 'outside' and 'inside'. It is interesting to say that there were no BFT sightings on effort in 'outside' sub-areas B, C and F and only 1-2 sightings in A, D and E. The majority were observed in G, but all of them right outside the 'inside' area (see Figure 12) north of Cyprus. Therefore, it is recommended to extend the 'inside' G sub-area slightly to the west north of Cyprus to include that section with an accumulation of sightings.

## 2. Recommendations for future survey design

The results of the power calculations performed in 2011 indicated the CVs of abundance that need to be achieved if particular objectives for management are to be met. Two particular points need to be addressed. The first is that the CV of an estimate of abundance comprises variability in a number of estimated quantities (encounter rate, average probability of detection and mean school size) and it is necessary to extract the CV of encounter rate from the overall CV. The second is that schools of tuna are not distributed randomly in space and the magnitude of encounter rate CV depends on how aggregated are the detected schools. To determine the length of transect that will generate a given CV of encounter rate therefore requires this level of aggregation to be set.

The value for total transect length to achieve the baseline CV of 0.33 established in 2011 in an area the size of that surveyed in 2010 and 2013 was closer to the transect length actually flown in 2010 if the variance multiplier for encounter rate is assumed to be 5, so these results are probably more realistic. The results of the power analysis done in 2011 showed that to survey the whole Mediterranean (2 million $km^2$) will require approximately 200,000 km of transect to achieve the selected CVs. In an area half that size, approximately 100,000 km would be required. In 2013, a total of 1,555,224 $km^2$ were surveyed with only 28,947 km of effort, clearly far too little compared to what was recommended in 2011 (which given the surveyed area would have been around 150,000 km).

As can be seen in Table 7, a reliable estimate of BFT density, abundance or weight in the ‘outside’ areas is not possible due to the small amount of effort and the very small amount of sightings.

A few recommendations for future surveys are:

a) The type or form of survey design applied in 2010, 2011 and 2013 (i.e. equally spaced parallel lines) has proven to be feasible and successful and it is recommended to design future surveys in the same way.

b) Concentrate the survey effort to only the known spawning areas (‘inside’ sub-areas) as the effort outside only serves to spread out effort and resources over areas with basically very small or no density of spawning blufin tuna. The 2013 survey has been useful to prove that the previously surveyed spawning areas remain the important areas to be surveyed in the future. It would be interesting, though, to repeat a whole basin wide survey every decade, for example, to assess that there are no important changes to be made to the spawning areas (see for example point c) below); but if surveys are going to be done annually or bi-annually, the recommendation is to concentrate on the known and previously surveyed spawning areas.

c) Concentrate the survey effort in a defined time period, the same all years, to allow a more realist comparison of the results and avoid a potential temporal (seasonal) variability.

d) Extend the G-inside sub-area slightly to the west on the north of Cyprus to cover the small area detected with concentration of BFT for future surveys (see Figure 12). Also, extend the northern border of the C-inside subarea slightly as there was a concentration of off-effort sightings right outside the sub-area (see Figure 8).

e) Allocate more effort to future surveys, to allow the reduction of the CVs

f) Strongly insist the observers teams to ALWAYS collect declination angles of BFT even when on off-effort flights to allow the increase of sample size for the detection function

g) Strongly insist the observer teams to collect proper data (including declination angle and cluster size) of sea turtles and cetacean species (when not busy collecting BFT data in BFT high density bits of transects) to make more efficient use of the resources and allow for synergies with the conservation of other marine species.

In summary, the surveys in 2010, 2011 and 2013, although impacted by political and operational difficulties, have shown that it is feasible to collect useful data on bluefin tuna abundance in the Mediterranean Sea. Operational teething problems encountered in 2010 were addressed in a Training Workshop in February 2011 and 2013. This smoothed the operation of the survey in 2011 and 2013 but some aspects remain to be improved. Nevertheless, the surveys are clearly operationally feasible. Political impacts are largely beyond control and future survey design and analysis needs to take this into account. One aspect of this is the expectation that not all sub-areas will be surveyed every year, which means that additional variance will need to be taken into account.

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## TABLES

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

| Covariate | Type | Levels |
|---|---|---|
| **Sighting related** | | |
| Cue | factor | ripples<br>shining<br>splash<br>travelling<br>other |
| Weight class | factor (tn) | 0-10<br>10.1-100<br>100.1-200<br>200.1-600 |
| School size class | factor | 1-5<br>6-50<br>51-200<br>201-1000<br>1001-3000<br>3001-12000 |
| **Effort related** | | |
| Beaufort sea state | factor | calm (glassy)<br>calm (rippled)<br>smoothed (wavelets)<br>slight<br>moderate<br>rough |
| Air haziness | factor | clear<br>slight<br>moderate<br>diffused<br>heavy |
| Water turbidity | factor | clear<br>slight<br>medium<br>heavy |
| Observer level | factor | 17 levels |
| Team | factor | Air-Med<br>Air-Perigod<br>Unimar<br>Périgord Travail Aerién |
| Glare intensity | factor | null<br>slight<br>moderate<br>strong |

**Table 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 | 62,194 | 76 | 6,807 | 13 |
| C | 54,177 | 37 | 2,791 | 11 |
| E | 82,054 | 108 | 4,371 | 20 |
| G | 56,329 | 27 | 1,700 | 12 |
| Subtotal Inside | 254,754 | 248 | 15,669 | 56 |
| **Outside** | | | | |
| A | 112,140 | 20 | 1,777 | 2 |
| B | 157,455 | 9 | 2,946 | 0 |
| C | 179,121 | 13 | 1,444 | 0 |
| D | 171,047 | 17 | 1,399 | 1 |
| E | 137,682 | 15 | 1,127 | 1 |
| F | 296,961 | 38 | 2,080 | 0 |
| G | 249,064 | 18 | 2,505 | 8 |
| Subtotal Outside | 1,303,470 | 130 | 13,278 | 12 |
| **Total** | 1,558,224 | 378 | 28,947 | 68 |

**Table 3**. Parameters and diagnostics of the detection function.

| Average probability of detection (p) | Effective strip width (esw) (km) | K-S test (p) | Cramer-von Mises test (unweighted) (p) |
|---|---|---|---|
| 0.275 | 2.3 | 0.967 | 0.969 |

**Table 4**. Mean school size, density and total weight and abundance of bluefin tuna for each "inside" subarea.

| Sub-area |
|---|

| | | A | C | E | G | TOTAL |
|---|---|---|---|---|---|---|
| **Survey area (km$^2$)** | | 62,194 | 54,177 | 82,054 | 56,329 | **254,754** |
| **Number of transects** | | 76 | 37 | 108 | 27 | **248** |
| **Transect length (km) (L)** | | 6,807 | 2,791 | 4,371 | 1,700 | **15,669** |
| **Number of sightings (n)** | | 13 | 11 | 20 | 12 | **56** |
| **Weight (tonnes)** | **Mean weight** | 90.1 | 189.0 | 4.2 | 3.3 | **22.6** |
| | **CV (%)** | 32 | 22 | 103 | 62 | **51** |
| **School size (animals)** | **Mean school size** | 439 | 1,536 | 111 | 272 | **302** |
| | **CV (%)** | 35 | 19 | 108 | 57 | **43** |
| **Density of schools (per sq km)** | **Density of schools** | 0.447 | 0.742 | 3.164 | 2.343 | **1.804** |
| | **CV (%)** | 51 | 49 | 54 | 48 | **34** |
| | **Lower 95% CL** | 0.173 | 0.293 | 1.172 | 0.918 | **0.937** |
| | **Upper 95% CL** | 1.156 | 1.880 | 8.541 | 5.978 | **3.472** |
| **Density of animals (per sq km)** | **Density of animals** | 0.196 | 1.139 | 0.351 | 0.638 | **0.544** |
| | **CV (%)** | 45 | 53 | 99 | 63 | **36** |
| | **Lower 95% CL** | 0.083 | 0.422 | 0.068 | 0.196 | **0.272** |
| | **Upper 95% CL** | 0.461 | 3.074 | 1.807 | 2.075 | **1.089** |
| **Density of weight (per sq km)** | **Density of weight** | 0.017 | 0.122 | 0.012 | 0.008 | **0.036** |
| | **CV (%)** | 40 | 59 | 96 | 68 | **45** |
| | **Lower 95% CL** | 0.008 | 0.041 | 0.002 | 0.002 | **0.015** |
| | **Upper 95% CL** | 0.037 | 0.369 | 0.057 | 0.027 | **0.084** |
| **Total weight (tonnes)** | **Total weight** | 1,083 | 6,633 | 949 | 436 | **9,100** |
| | **CV (%)** | 40 | 59 | 96 | 68 | **45** |
| | **Lower 95% CL** | 504 | 2,204 | 193 | 124 | **3,867** |
| | **Upper 95% CL** | 2,327 | 19,965 | 4,671 | 1,532 | **21,413** |
| **Total abundance (animals)** | **Total abundance** | 12,194 | 61,725 | 28,819 | 35,911 | **138,650** |
| | **CV (%)** | 45 | 53 | 99 | 63 | **35** |
| | **Lower 95% CL** | 5,191 | 22,874 | 5,603 | 11,034 | **69,270** |
| | **Upper 95% CL** | 28,647 | 166,562 | 148,238 | 116,870 | **277,517** |
| **Encounter rate of schools** | **n/L** | 0.0018 | 0.0039 | 0.0046 | 0.0071 | **0.0036** |
| | **CV (%)** | 42 | 44 | 47 | 41 | **23** |

**Table 5**. Mean school size, density and total weight and abundance of bluefin tuna for each “outside” subarea.

| | | Sub-area | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **TOTAL** |
| **Survey area** | | 112,140 | 157,455 | 179,121 | 171,047 | 137,682 | 296,961 | 249,064 | **1,303,470** |
| **Number of transects** | | 20 | 9 | 13 | 17 | 15 | 38 | 18 | **130** |
| **Transect length (km) (L)** | | 1,777 | 2,946 | 1,444 | 1,399 | 1,127 | 2,080 | 2,505 | **13,278** |
| **Number of sightings (n)** | | 2 | 0 | 0 | 1 | 1 | 0 | 8 | **12** |
| **Weight (tonnes)** | **Mean weight** | 87.5 | 0 | 0 | 20.0 | 1.5 | 0 | 4.4 | **7.5** |
| | **CV (%)** | 0 | 0 | 0 | 0 | 0 | 0 | 61 | **55** |
| **School size (animals)** | **Mean school size** | 700 | 0 | 0 | 1,500 | 6 | 0 | 418 | **432** |
| | **CV (%)** | 0 | 0 | 0 | 0 | 0 | 0 | 60 | **49** |
| **Density of schools (per sq km)** | **Density of schools** | 0.174 | 0 | 0 | 0.153 | 0.495 | 0 | 1.235 | **0.323** |
| | **CV (%)** | 97 | 0 | 0 | 103 | 106 | 0 | 100 | **76** |
| | **Lower 95% CL** | 0.032 | 0 | 0 | 0.025 | 0.078 | 0 | 0.214 | **0.079** |
| | **Upper 95% CL** | 0.956 | 0 | 0 | 0.918 | 3.123 | 0 | 7.127 | **1.320** |
| **Density of animals (per sq km)** | **Density of animals** | 0.122 | 0 | 0 | 0.229 | 0.003 | 0 | 0.517 | **0.140** |
| | **CV (%)** | 97 | 0 | 0 | 103 | 106 | 0 | 117 | **86** |
| | **Lower 95% CL** | 0.022 | 0 | 0 | 0.038 | 0.000 | 0 | 0.078 | **0.030** |
| | **Upper 95% CL** | 0.669 | 0 | 0 | 1.377 | 0.019 | 0 | 3.417 | **0.656** |
| **Density of weight (per sq km)** | **Density of weight** | 0.010 | 0 | 0 | 0.003 | 0.001 | 0 | 0.005 | **0.002** |
| | **CV (%)** | 96 | 0 | 0 | 103 | 105 | 0 | 117 | **65** |
| | **Lower 95% CL** | 0.0018 | 0 | 0 | 0.0005 | 0.0001 | 0 | 0.0008 | **0.000** |
| | **Upper 95% CL** | 0.0533 | 0 | 0 | 0.0167 | 0.0045 | 0 | 0.0350 | **0.014** |
| **Total weight (tonnes)** | **Total weight** | 1,104 | 0 | 0 | 477 | 98 | 0 | 1,309 | **2,988** |
| | **CV (%)** | 96 | 0 | 0 | 103 | 105 | 0 | 117 | **65** |
| | **Lower 95% CL** | 204 | 0 | 0 | 79 | 16 | 0 | 197 | **496** |
| | **Upper 95% CL** | 5,972 | 0 | 0 | 2,861 | 614 | 0 | 8,709 | **18,156** |
| **Total abundance (animals)** | **Total abundance** | 13,693 | 0 | 0 | 39,133 | 409 | 0 | 128,745 | **181,980** |
| | **CV (%)** | 97 | 0 | 0 | 103 | 106 | 0 | 117 | **86** |
| | **Lower 95% CL** | 2,499 | 0 | 0 | 6,503 | 65 | 0 | 19,477 | **38,751** |
| | **Upper 95% CL** | 75,039 | 0 | 0 | 235,480 | 2,580 | 0 | 851,017 | **854,603** |
| **Encounter rate of schools** | **n/L** | 0.0011 | 0 | 0 | 0.0007 | 0.0009 | 0 | 0.0032 | **0.0009** |
| | **CV (%)** | 96 | 0 | 0 | 101 | 103 | 0 | 99 | **69** |

**Table 6**. Comparison of main results on effort, encounter rates and density of schools, and mean and total weight and animal abundance in the inside subareas, between 2010, 2011 and 2013.

| **Year** | **2010** | | | | **2011** | | | **2013** | | | | **TOTAL** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sub-area** | **A inside** | **C inside** | **E inside** | **G inside** | **A inside** | **C inside** | **E inside** | **A inside** | **C inside** | **E inside** | **G inside** | **2010** | **2011** | **2013** |
| **Date** | 1-Jun / 2-Jul | 5-29-Jun | 3-Jun / 3-Aug | 5-30-Jun | 15-Jun / 11-Jul | 19-Jun / 8-Jul | 13-29-Jun | 6-Jun / 6-Jul | 18-28-Jun | 22-Jun /12-Jul | 20-Jun / 15-Jul | | | |
| **Survey area (km$^2$)** | 62,264 | 52,461 | 90,796 | 55,248 | 62,264 | 52,461 | 100,471 | 62,194 | 54,177 | 82,054 | 56,329 | 260,769 | 215,196 | 254,754 |
| **Number of transects** | 52 | 45 | 42 | 55 | 131 | 77 | 65 | 76 | 37 | 108 | 27 | 194 | 273 | 248 |
| **Transect length (km)** | 6,301 | 8,703 | 5,288 | 3,482 | 7,977 | 8,771 | 11,429 | 6,807 | 2,791 | 4,371 | 1,700 | 23,774 | 28,177 | 15,669 |
| **Effective strip width x2 (km)** | 9.66 | 2.92 | 9.66 | 2.92 | 7.03 | 7.03 | 0.66 | 4.6 | 4.6 | 4.6 | 4.6 | 2.9 / 9.7 | 0.7 / 7.0 | 4.6 |
| **% Coverage** | 97.8 | 48.4 | 56.3 | 18.4 | 90 | 118 | 7.5 | 50.3 | 23.7 | 24.5 | 13.9 | 57 | 58 | 28.3 |
| **Number of schools** | 7 | 6 | 19 | 31 | 11 | 10 | 35 | 13 | 11 | 20 | 12 | 63 | 56 | 56 |
| **Encounter rate of schools** | 0.0011 | 0.0007 | 0.0036 | 0.0089 | 0.0014 | 0.0011 | 0.0031 | 0.0018 | 0.0039 | 0.0046 | 0.0071 | 0.0027 | 0.0020 | 0.0036 |
| %CV encounter rate | 51 | 43 | 39 | 25 | 32 | 31 | 24 | 42 | 44 | 47 | 41 | 20 | 47 | 23 |
| **Density of schools (1000 km$^{-2}$)** | 0.157 | 0.237 | 0.508 | 3.05 | 0.196 | 0.162 | 3.98 | 0.447 | 0.742 | 3.164 | 2.343 | 0.909 | 1.956 | 1.804 |
| %CV density of schools | 55 | 53 | 44 | 40 | 37 | 36 | 26 | 51 | 49 | 54 | 48 | 30 | 25 | 34 |
| **Mean weight (t)** | 127.1 | 124.2 | 50.6 | 62.1 | 84.8 | 42.7 | 102.8 | 90.1 | 189.0 | 4.2 | 3.3 | 85.9 | 94.9 | 22.6 |
| %CV mean weight | 8 | 5.6 | 25 | 13 | 26 | 44 | 27 | 32 | 22 | 103 | 62 | 15 | 11 | 51 |
| **Mean cluster size (animals)** | | | | | 789 | 291 | 1,275 | 439 | 1,536 | 111 | 272 | | 1,211 | 302 |
| %CV mean cluster size | | | | | 26 | 31 | 32 | 35 | 19 | 108 | 57 | | 12 | 43 |
| **Total weight (t)** | 1,244 | 1,540 | 2,335 | 10,434 | 1,033 | 364 | 44,837 | 1,083 | 6,633 | 949 | 436 | 15,553 | 46,234 | 9,100 |
| %CV total weight | 56 | 53 | 51 | 42 | 43 | 54 | 41 | 40 | 59 | 96 | 68 | 30 | 40 | 45 |
| **Total abundance (animals)** | | | | | 9,616 | 2,477 | 549,276 | 12,194 | 61,725 | 28,819 | 35,911 | | 561,369 | 138,650 |
| %CV total abundance | | | | | 43 | 46 | 42 | 45 | 53 | 99 | 63 | | 41 | 35 |

**Table 7**. Mean school size, density and total weight and abundance of bluefin tuna for the total "inside" and "outside" subareas in 2013.

| **Sub-area** | **2013 'inside'** | **2013 'outside'** | **TOTAL** |
|---|---|---|---|
| **Survey area (km$^2$)** | 254,754 | 1,303,470 | 1,558,224 |
| **Number of transects** | 248 | 130 | 378 |
| **Transect length (km)** | 15,669 | 13,278 | 28,947 |
| **Effective strip width x2 (km)** | 4.6 | 4.6 | 4.6 |
| **% Coverage** | 28.3 | 4,7 | 8.5 |
| **Number of schools** | 56 | 12 | 68 |
| **Encounter rate of schools** | 0.0036 | 0.0009 | 0.0024 |
| %CV encounter rate | 23 | 69 | 23 |
| **Density of schools (1000 km$^{-2}$)** | 1.804 | 0.323 | 0.565 |
| %CV density of schools | 34 | 76 | 41 |
| **Mean weight (t)** | 22.6 | 5.5 | 15.0 |
| %CV mean weight | 51 | 75 | 46 |
| **Mean cluster size (animals)** | 302 | 432 | 364 |
| %CV mean cluster size | 43 | 49 | 37 |
| **Total weight (t)** | **9,100** | **2,988** | **12,088** |
| %CV total weight | 45 | 65 | 38 |
| **Total abundance (animals)** | **138,650** | **181,980** | **320,629** |
| %CV total abundance | 35 | 86 | 53 |

**FIGURES**

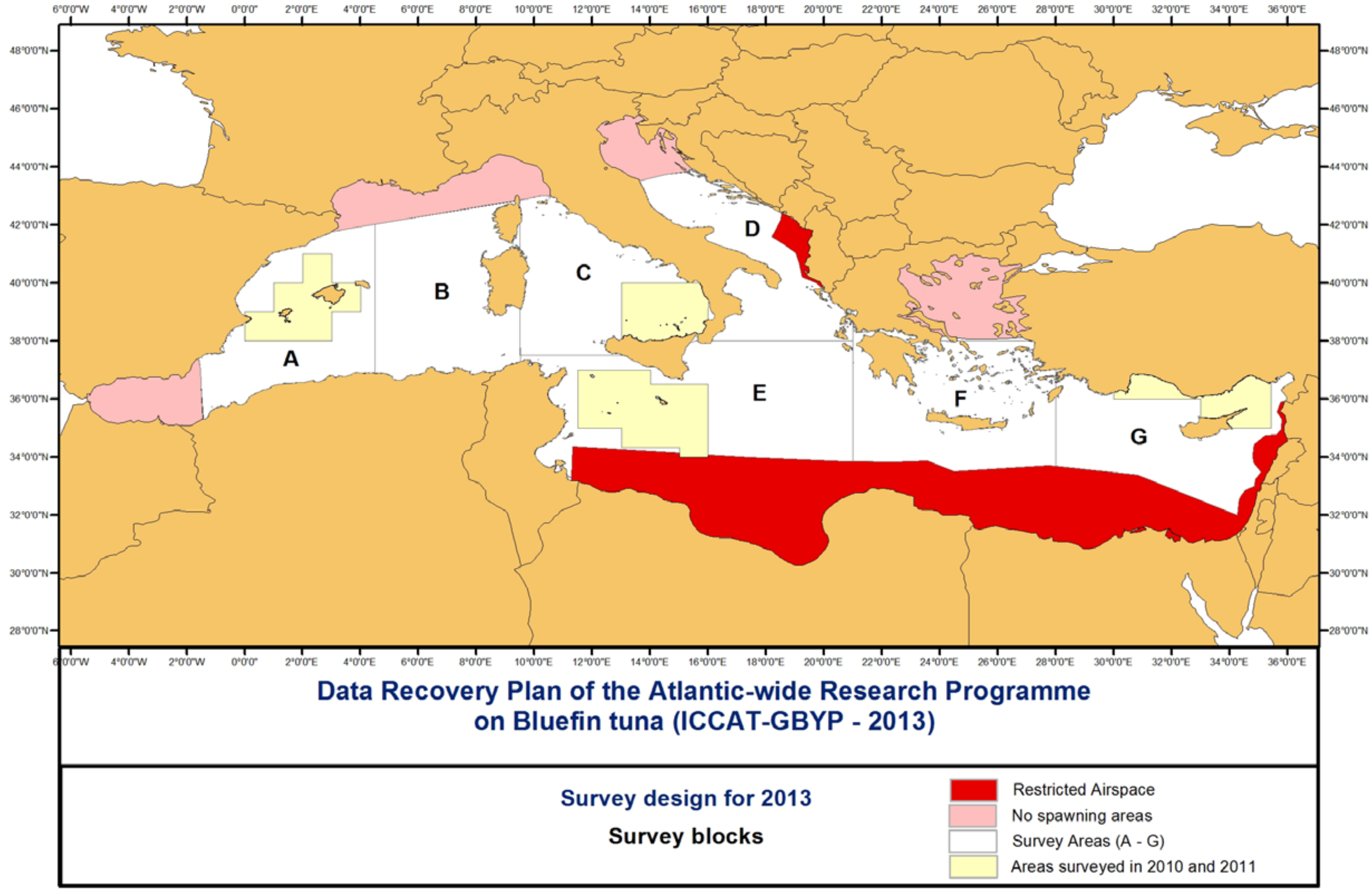



**Figure 1.** Survey blocks

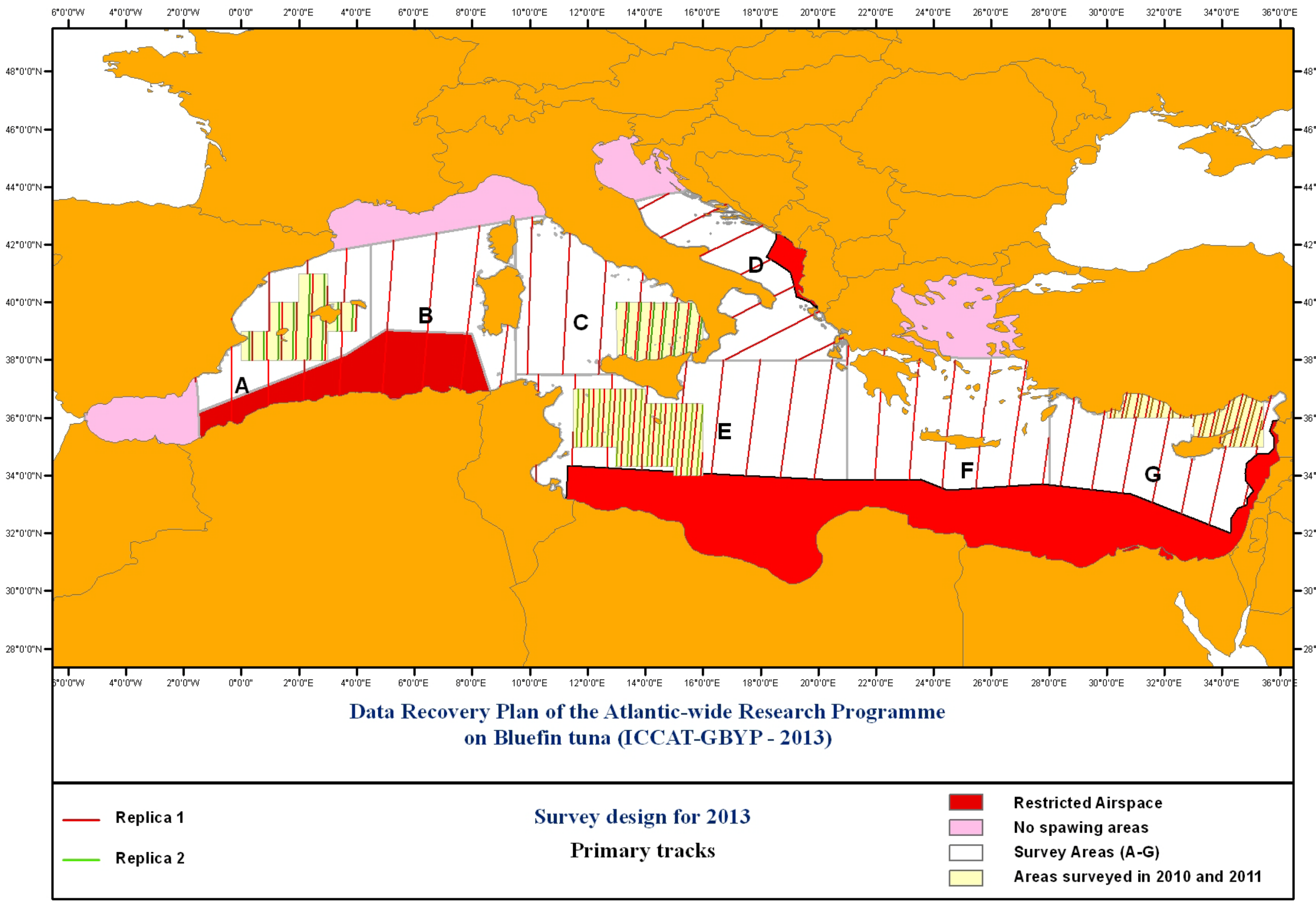



**Figure 2**. Originally designed transects.

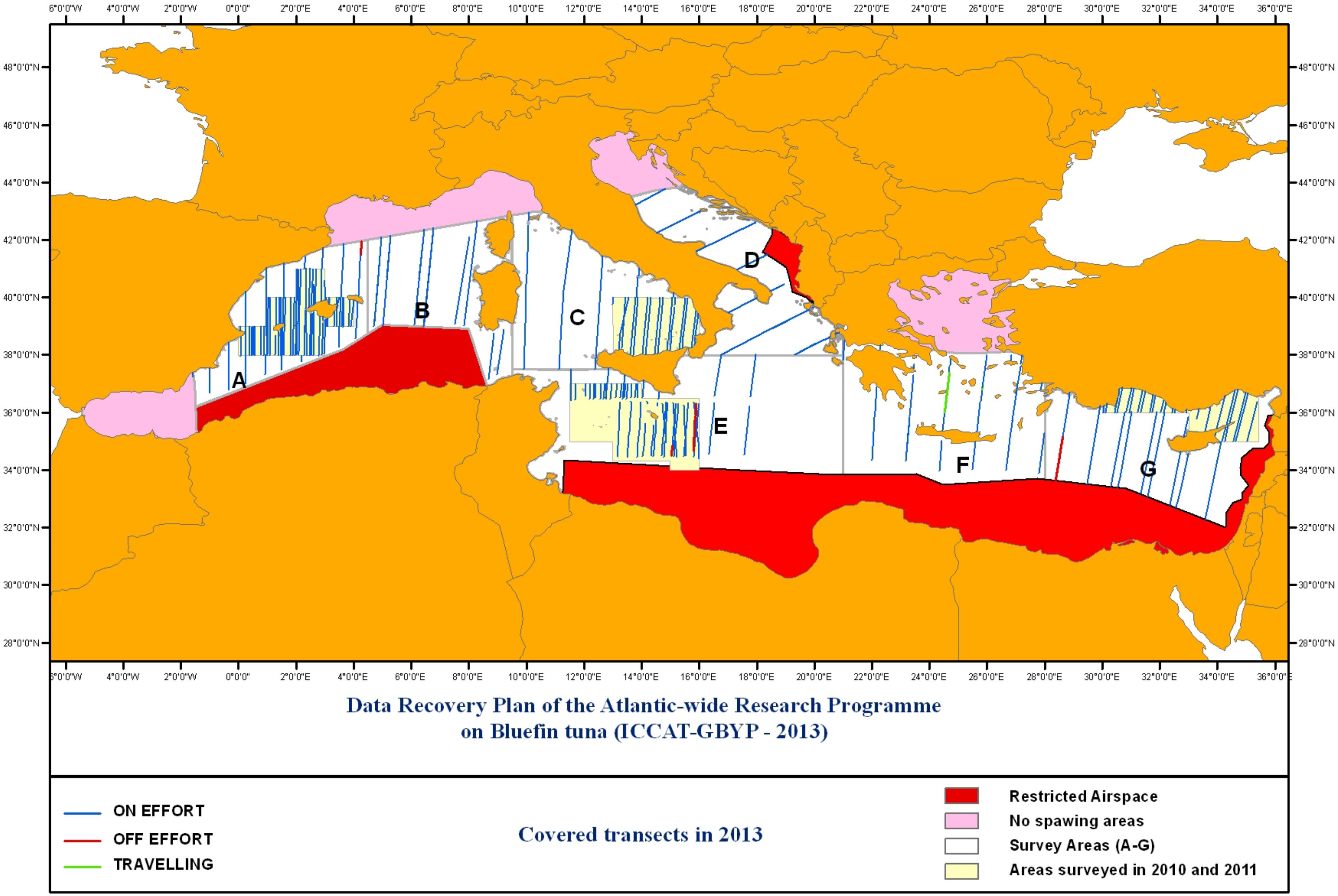



**Figure 3**. Transects flown on effort.

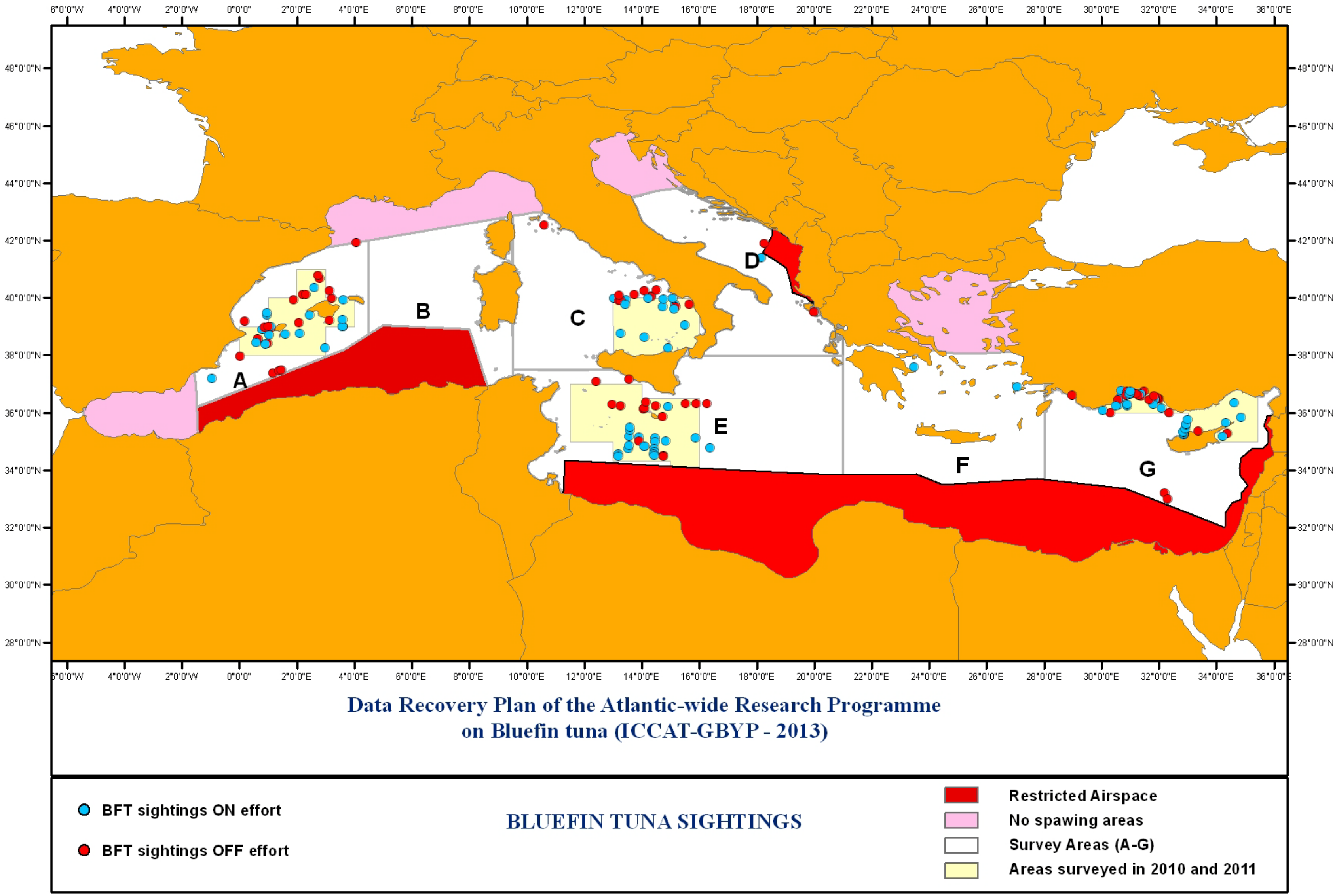



**Figure 4**. Sightings of bluefin tuna on and off effort.

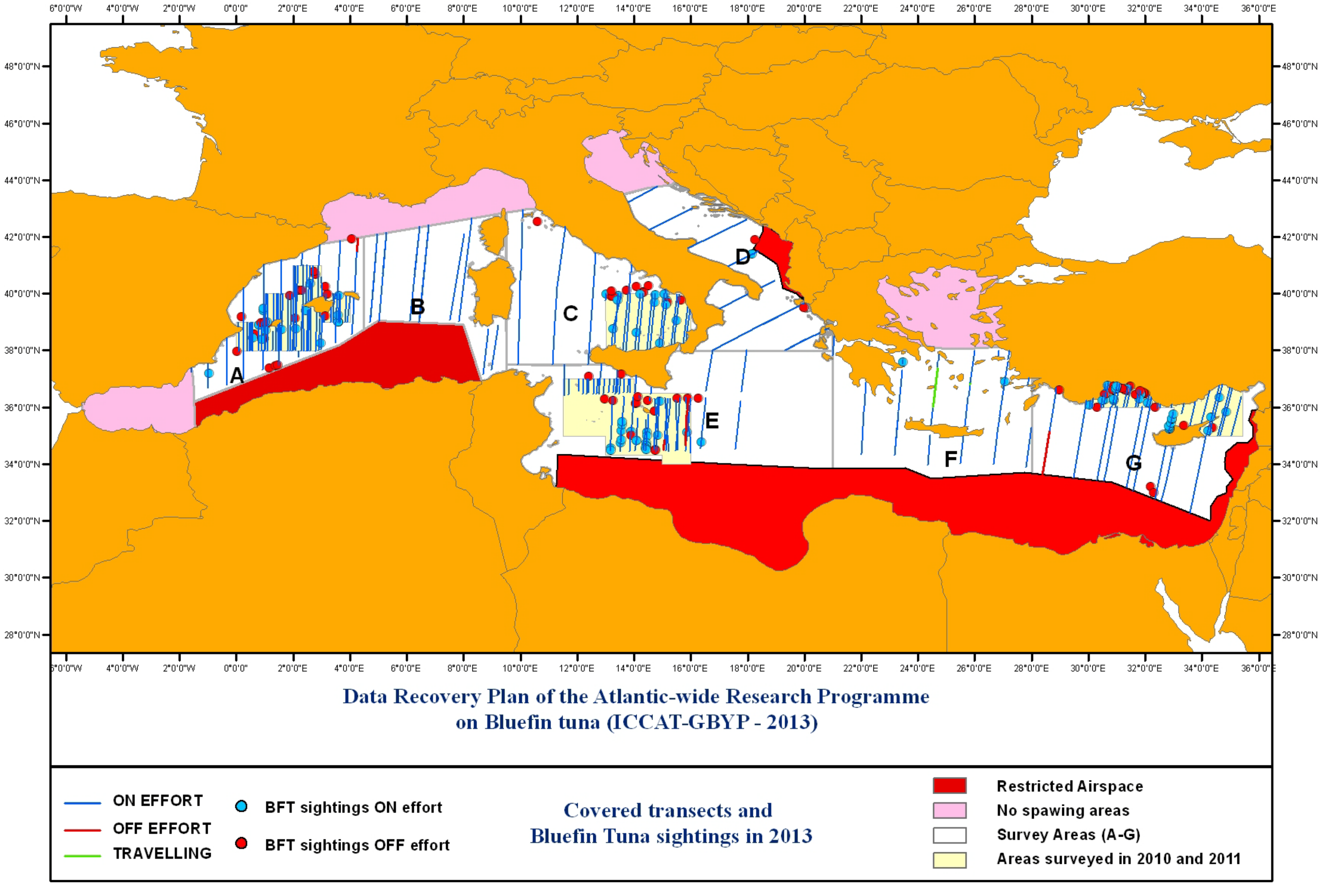



**Figure 5**. Transects flown and sightings of bluefin tuna on and off effort.

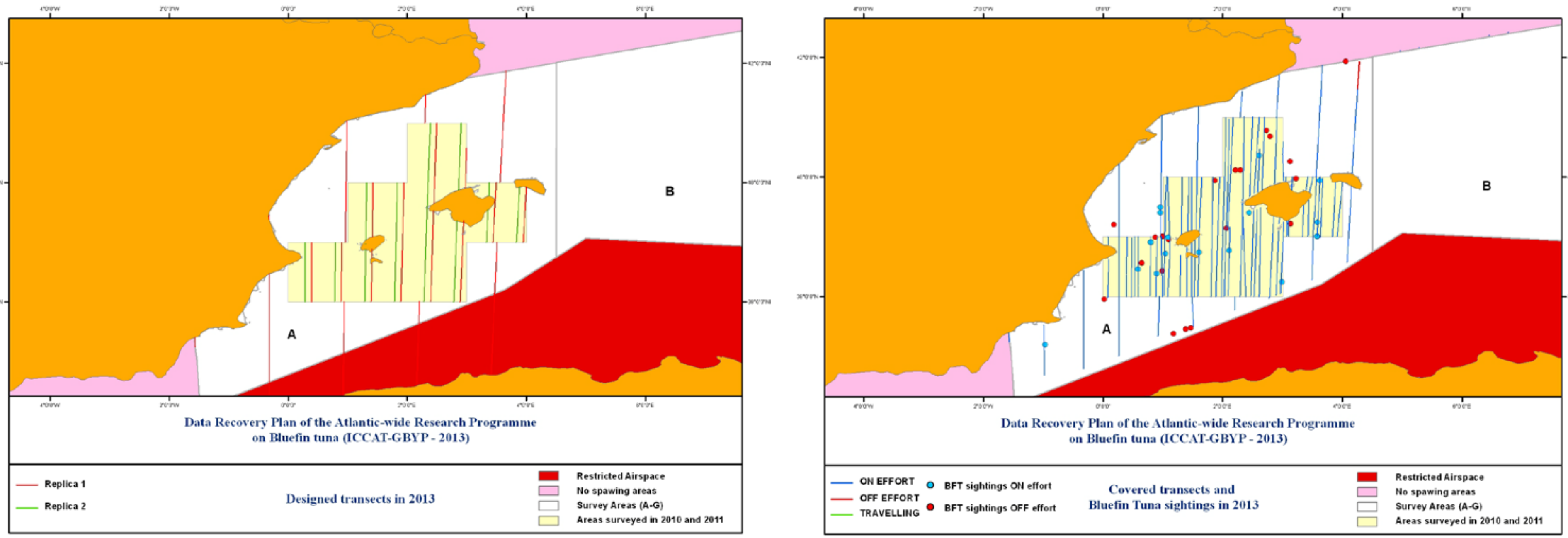



**Figure 6**. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area A.

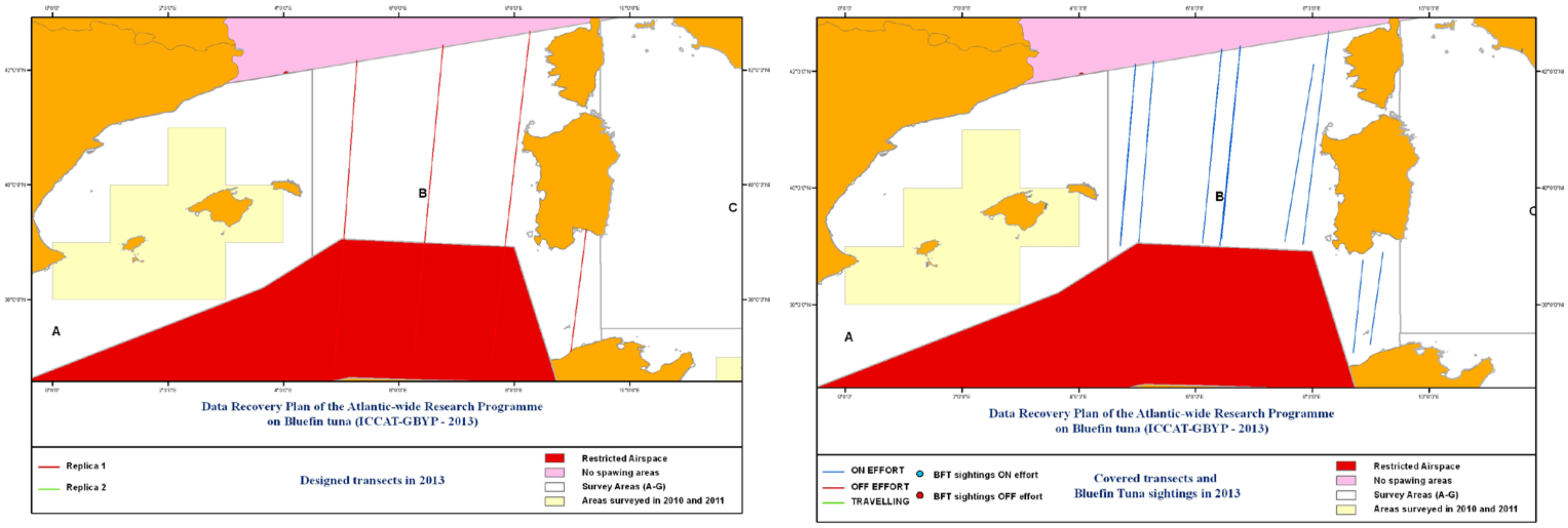



**Figure 7**. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area B.

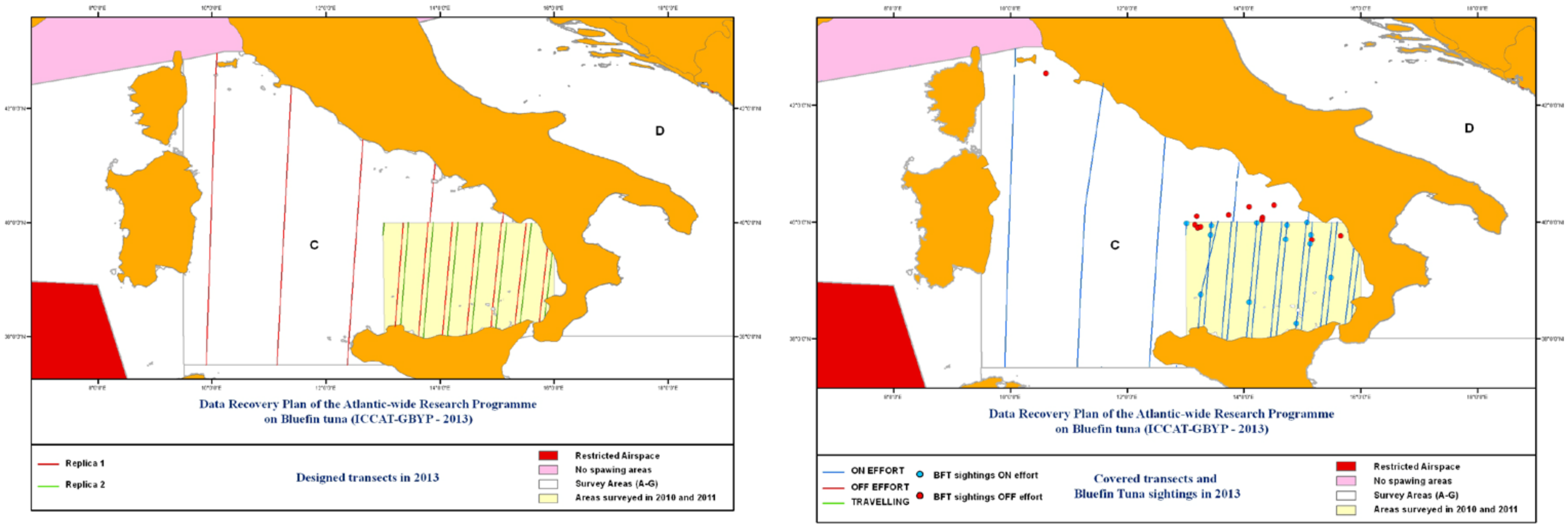



**Figure 8**. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area C.

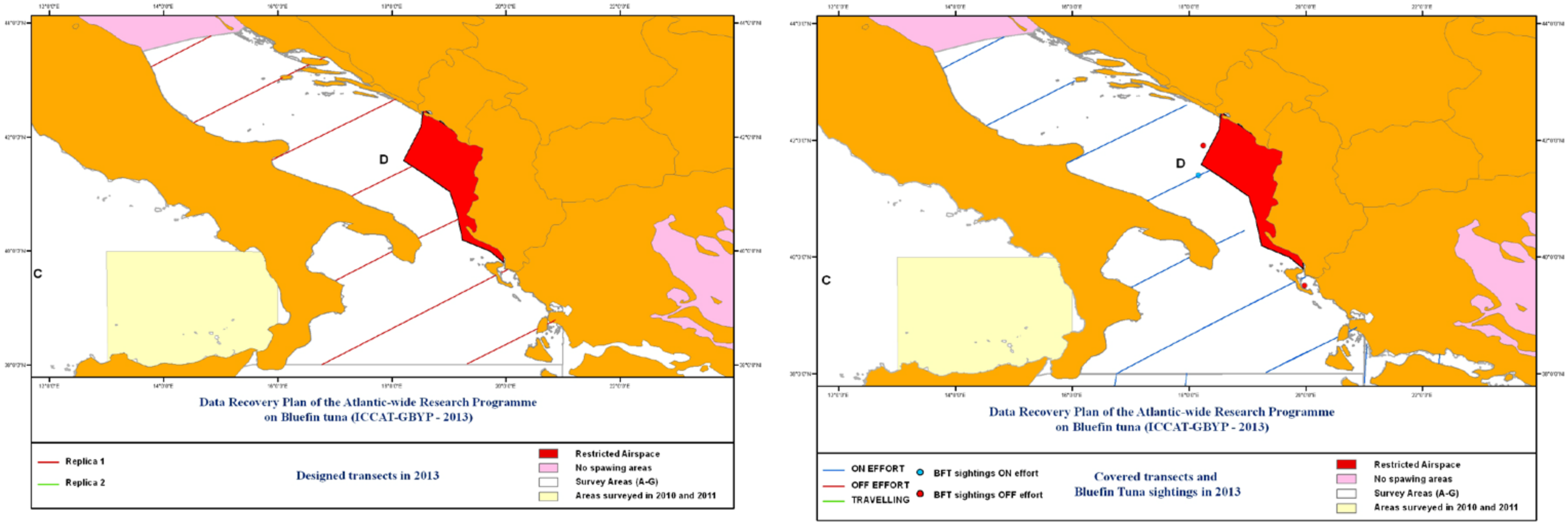



**Figure 9**. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area D.

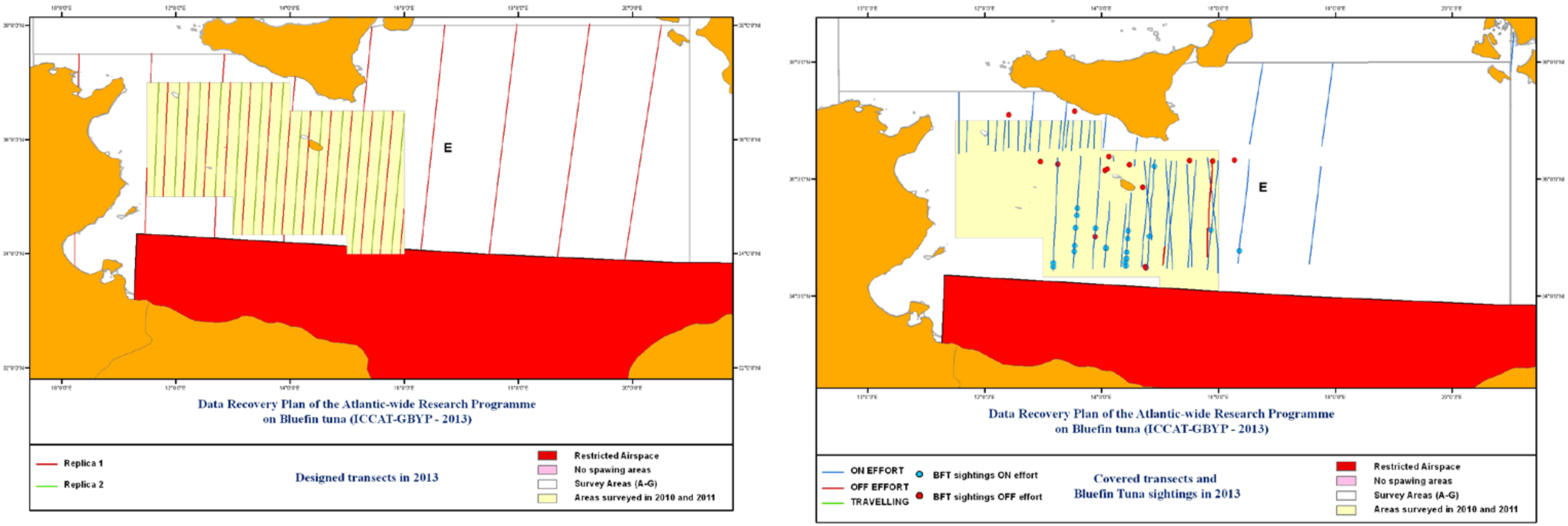
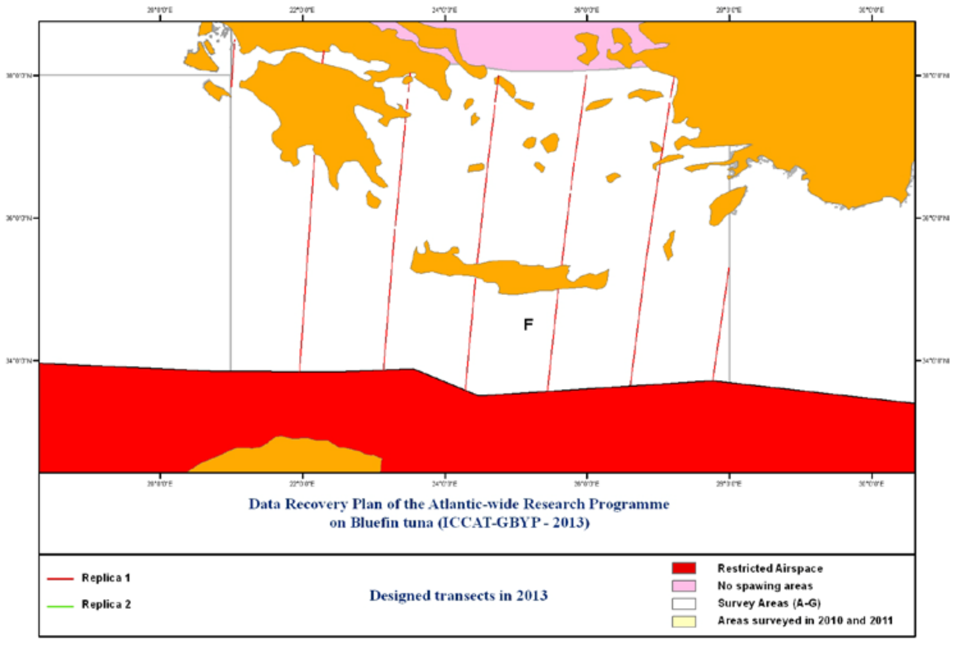



**Figure 10**. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area E.



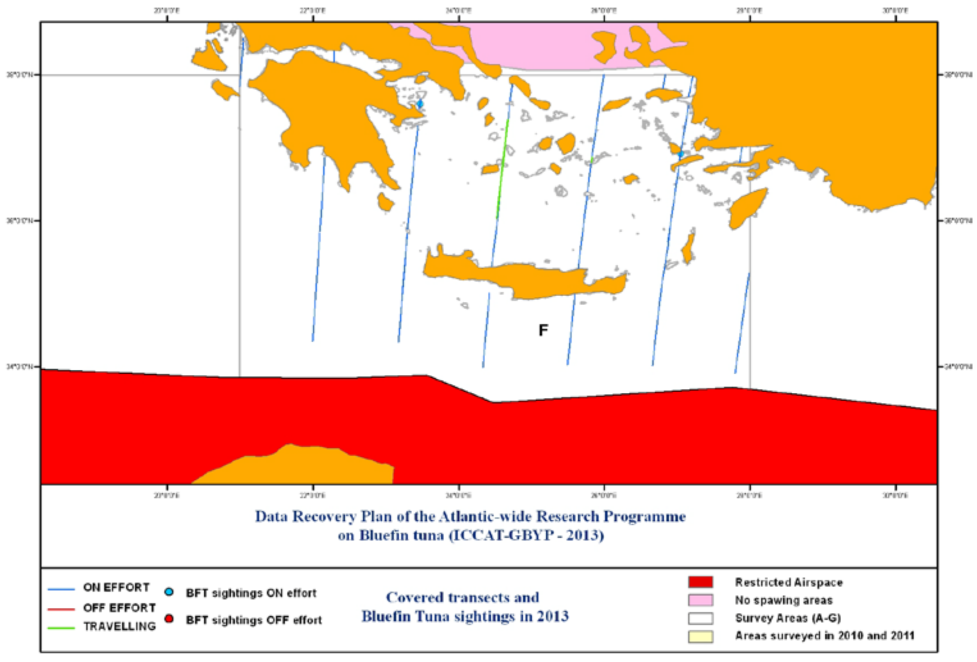




**Figure 11**. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area F.

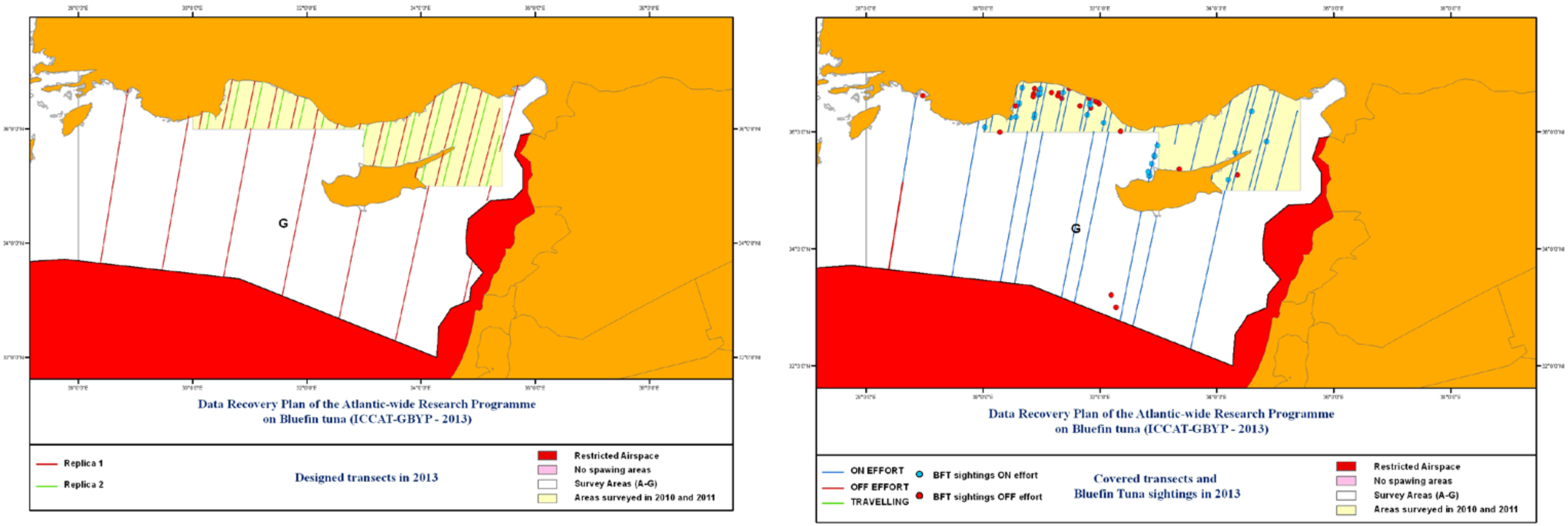
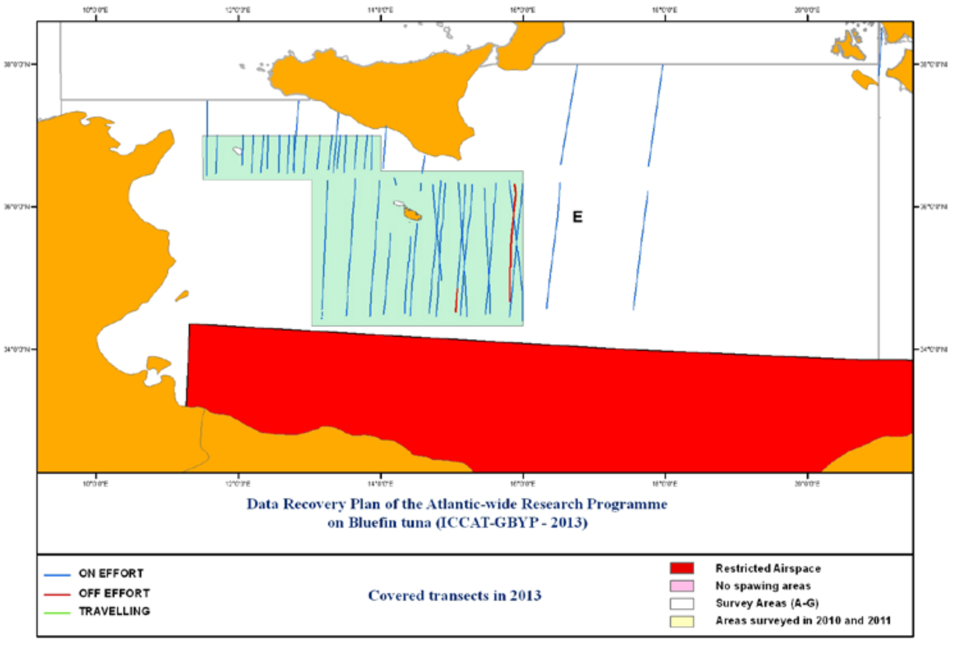



**Figure 12**. Transects designed and realized, and sightings of bluefin tuna on and off effort in sub-area G.



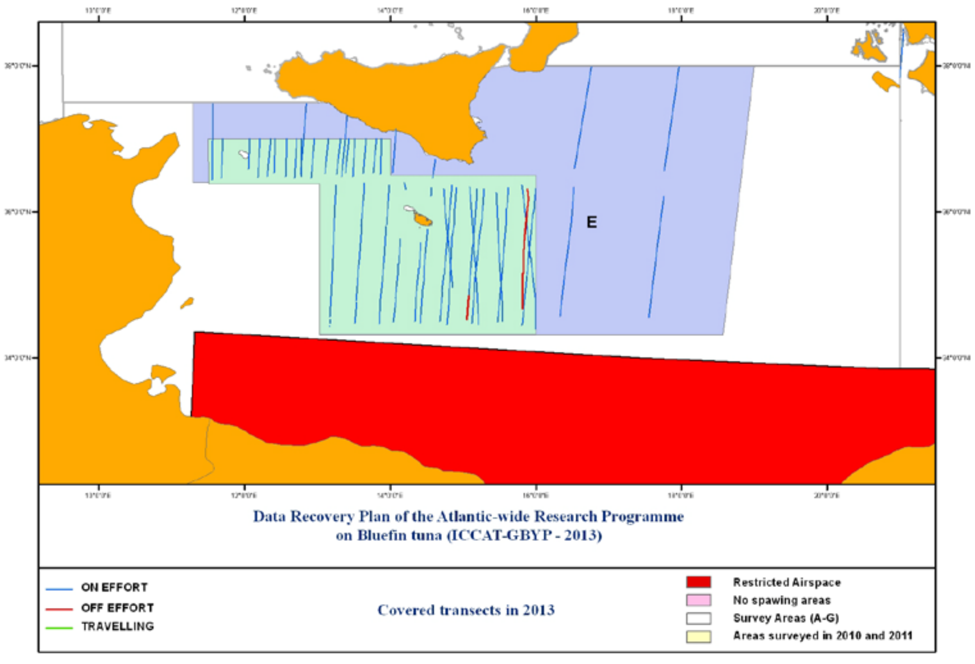




**Figure 13**. Modified sub-areas E-inside (left) and E-outside (right) deleting the not-surveyed sections, and transects realized.

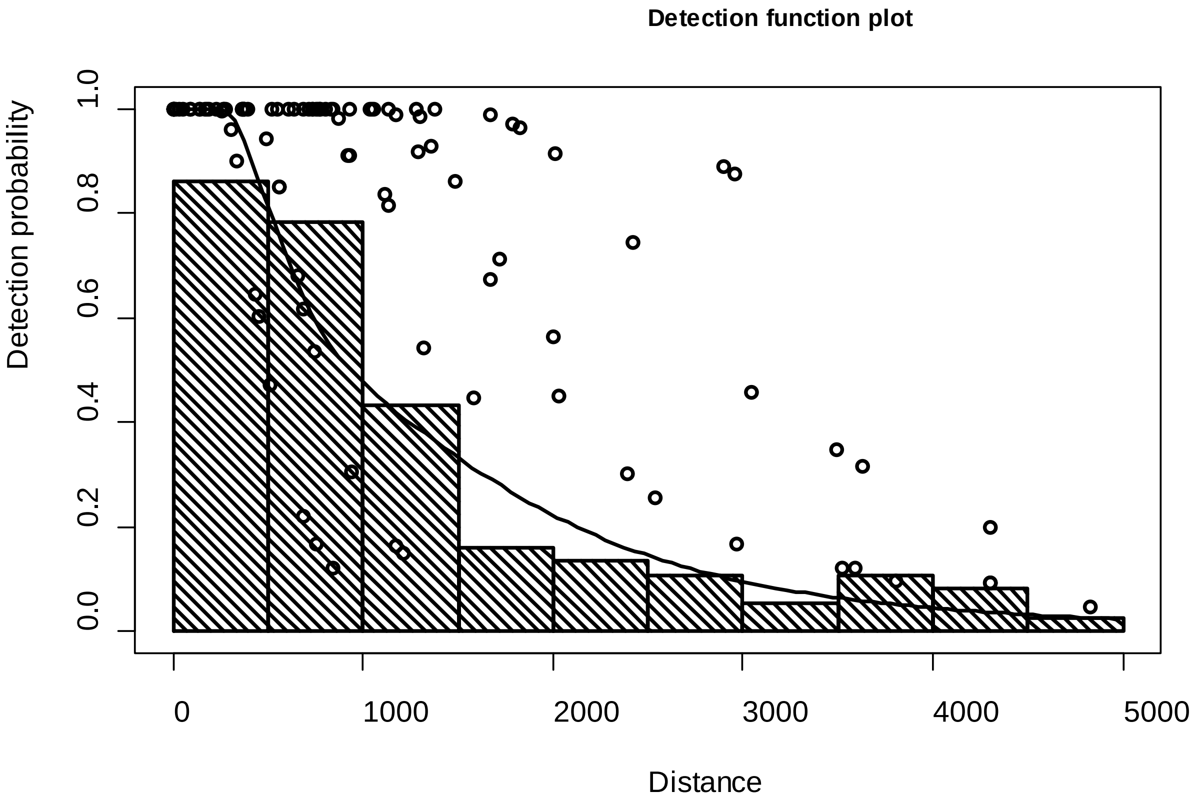



**Figure 14.** Detection function, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings.

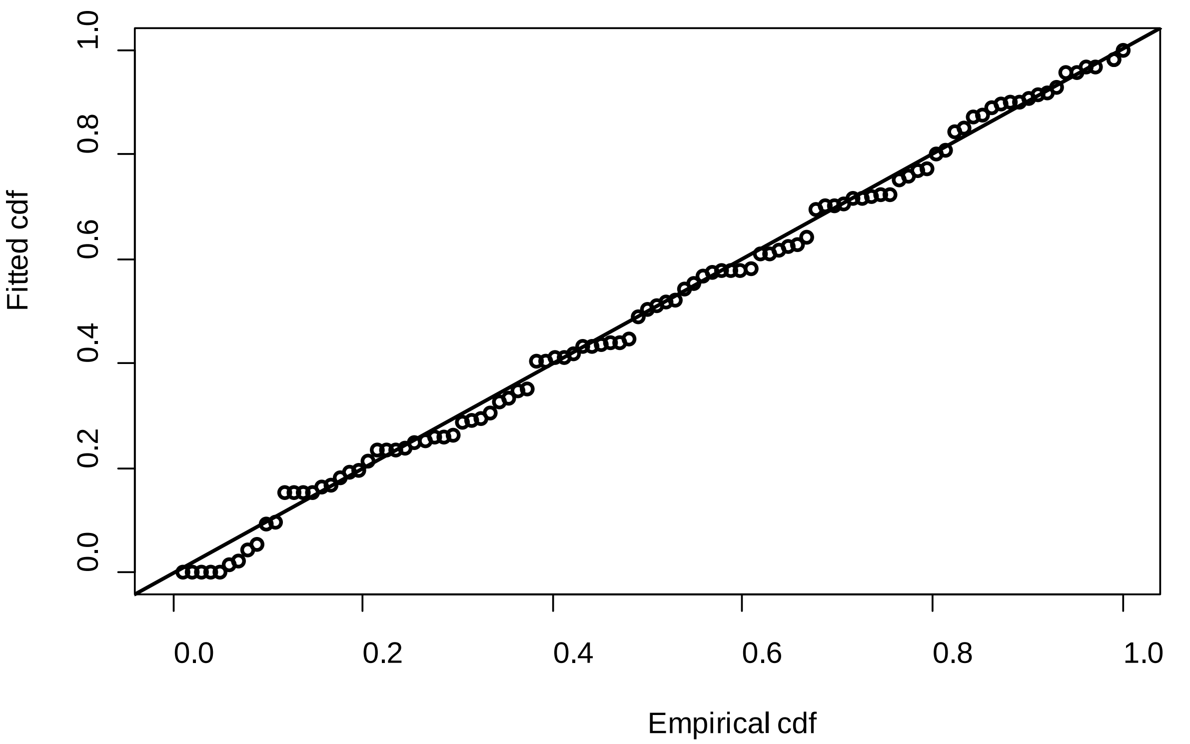



**Figure 15.** Q-Q plot.

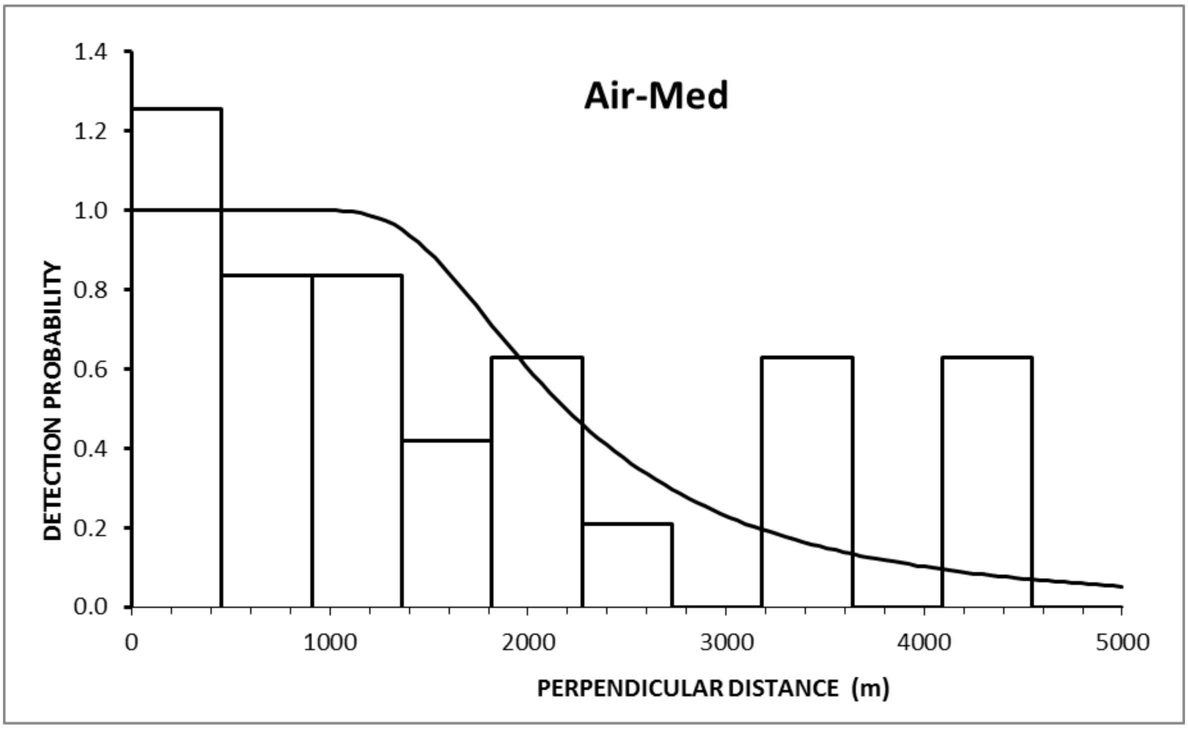



**Figure 16.** Detection function for AirMed.

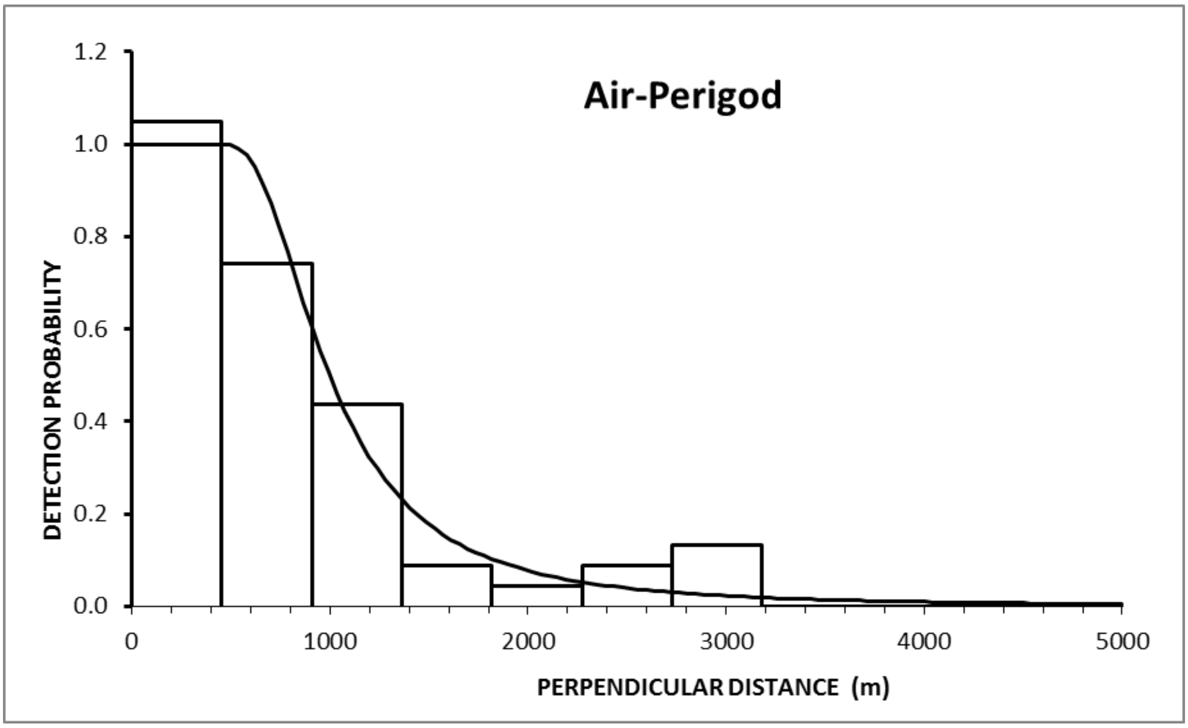



**Figure 17.** Detection function for AirPerigod.

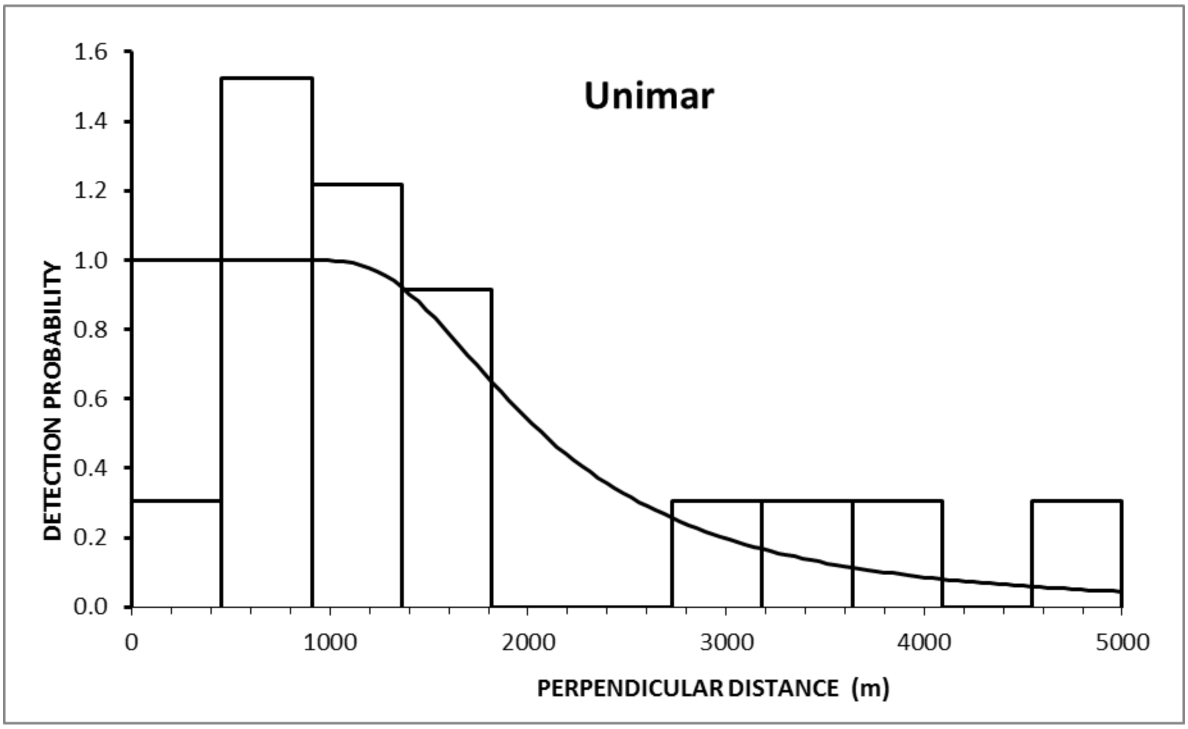



**Figure 18.** Detection function for Unimar.