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ICCAT GBYP AERIAL SURVEY FOR BLUEFIN TUNA SPAWNING AGGREGATIONS IN 2015. PRELIMINARY REPORT

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SUMMARY

Another ICCAT GBYP aerial survey was carried out in 2015, after the previous survey done in 2010, 2011 and 2013, on 11 areas, 6 densely monitored and 7 less densely monitored. It was carried out during the peak of the bluefin tuna spawning period (mostly in June), by 3 companies which used 6 aircrafts. It was necessary to get a new survey design in 2015, always using the DISTANCE methodology, adopting a new protocol. The survey reports were provided in August and therefore the data analyses is available only partly, according to what was set by the ToRs of the contract. The preliminary elaboration provides the estimates for each area (number of schools, number of tunas and quantities), with the usual details, comparing the areas when these were surveyed in previous years. Furthermore, this paper provides a preliminary comparison for overlapping areas over the years. The preliminary results show a high interannual variability of the quantities in total and by area, but anyway a high potential SSB, taking into account that the oceanographic situation in 2015 was quite peculiar.

RÉSUMÉ

Une autre prospection aérienne de l'ICCAT-GBYP a été effectuée en 2015, après la prospection aérienne réalisée en 2010, 2011 et 2013, sur 11 zones, six ayant fait l'objet d'un suivi intense et sept à un moindre niveau. Celle-ci a été réalisée au point culminant de la période de frai du thon rouge (surtout en juin), par trois sociétés qui ont utilisé six aéronefs. Il a été nécessaire d'obtenir une nouvelle conception de la prospection en 2015, toujours à l'aide de la méthodologie DISTANCE, en adoptant un nouveau protocole. Les rapports de prospection ont été fournis au mois d'août, et c'est pourquoi les analyses des données ne sont disponibles que partiellement, selon ce qui a été défini par les termes de référence du contrat. L'élaboration préliminaire donne les estimations pour chaque zone (nombre de bancs, nombre de thons et quantités), avec les détails habituels, en comparant les zones lorsque celles-ci ont fait l'objet d'une prospection au cours des années précédentes. En outre, ce document fournit une comparaison préliminaire pour les zones de chevauchement au fil des ans. Les résultats préliminaires montrent une forte variabilité interannuelle des quantités totales et par zone, mais en tout état de cause une SSB potentiellement élevée, si l'on tient compte du fait que la situation océanographique en 2015 était assez particulière.

RESUMEN

En 2015 se llevó a cabo otra prospección aérea del ICCAT GBYP, después de las realizadas en 2010, 2011 y 2013, en 11 áreas, de las que 6 fueron objeto de intenso seguimiento y 7 fueron objeto de menos seguimiento. La llevaron a cabo durante el pico del periodo de desove del atún rojo (principalmente en junio) 3 empresas que utilizaron 6 aeronaves. En 2015 era necesario contar con un nuevo diseño de prospección, utilizando siempre la metodología de DISTANCIA, y adoptando un nuevo protocolo. Los informes de la prospección se proporcionaron en agosto y, por tanto, los análisis de los datos están disponibles solo en parte, de conformidad con lo establecido en los términos de referencia del contrato. La elaboración preliminar proporciona las estimaciones para cada área (número de bancos, número de túnidos y cantidades) con los detalles usuales, comparando las áreas cuando en años anteriores habían sido objeto de prospecciones. Además, este documento presenta una comparación preliminar para las zonas de solapamiento a lo largo de los años. Los resultados preliminares muestran una elevada variabilidad interanual en las cantidades totales y por área, pero también una elevada SSB potencial teniendo en cuenta que la situación oceanográfica de 2015 era bastante peculiar.

KEYWORDS

Bluefin tuna, ICCAT, Aerial survey, Species distribution, Mediterranean, Methodology

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1. Introduction

Aerial survey are used for obtaining fishery independent data for some marine species of for more closely study their behaviour (Heldt, 1932; Cram and Hapton, 1976; Rivas, 1978; Arena *et al*., 1979; Arena, 1980, 1981, 1982a, 1982b, 1982c, 1985, 1986a, 1986b, 1988a, 1988b, 1990; Marsh and Sinclair, 1989; Cowling *et al*., 1996; Polacheck *et al*., 1996; Lutcavage *et al*., 1997; Hiby and Lovell, 1998; Cowling and O'Reilly, 1999; Lutcavage and Newland, 1989; Buckland *et al*., 2001; Fromentin, 2001; Arena and Cefali, 2002; Hammond *et al*., 2002; Thomas *et al*., 2002; Fromentin *et al*., 2003, 2013; Nicholson and Jennings, 2004; Newlands *et al*., 2007: Bonhommeau *et al*., 2010; Farley and Bennet, 2011; Eveson *et al.*, 2011; Palka, 2011; Kessel *et al*., 2013; Basson and Farley, 2014; Bower *et al*., 2014).

The ICCAT GBYP aerial surveys for bluefin tuna spawning aggregations are a method for having fishery independent indices of the bluefin tuna spawning stock biomass over the year and, therefore, for possibly obtaining trends, taking into account the implicit variability and the additional variance due to many factors; it is implicit that estimates will be in the best case the minimum estimates, because they will reflect the quantities really encountered, which are always much less than the real fish at sea, due to many natural factors. From a management point of view, this will represents a precautionary point of view. The initial decision for carrying on the survey on spawners and not on juveniles was taken by the SCRS, confirmed by a GBYP Workshop (Anonimous, 2012) and confirmed again after a SWOT analysis (Di Natale and Idrissi, 2013b), The surveys were carried out in 2010 (Di Natale, 2011), 2011 (Di Natale and Idrissi, 2012, 2013a), 2013 (Di Natale *et al*., 2014a, 2014b) and 2015, depending on the availability of funds and the choices of the GBYP Steering Committee, the SCRS and the Commission. Furthermore, the GBYP was able to develop a first tentative spatial model for predicting density and distribution of the bluefin tuna spawning aggregation in correlation with the SST (Cañadas *et al*., 2010b, 2011). All results and reports are available on the ICCAT GBYP web pages http://www.iccat.int/GBYP/en/asurvey.htm .

The four ICCAT GBYP surveys were carried out with yearly changes, set by the GBYP Steering Committee. The plan set by the SCRS and approved by the Commission at the beginning of GBYP was to survey three areas for three years, but this plan was not sufficient for detecting any trend, as it was revealed later by a power analysis requested by the Steering Committee (Cañadas and Vázquez, 2013), where a minimum of 6 years was necessary. The total original budget set for three surveys in three areas was 1,200,000 Euros; the cost of carrying out four surveys in many more areas (four main "internal" areas and seven "external" areas) is approximately 1,619,624.24 Euros (134.97% of the original budget, but with more than twice the activities).

The first year (2010) it was planned to carry out the survey in 8 subareas all to be densely monitored, but finally, due to many security and permit problems, the survey included 3 full areas and 3 partial areas. The survey was carried out by aircrafts not equipped with bubble windows and declinometers.

The second year (2011) it was planned to carry out the survey over 6 areas, all to be densely monitored. An ICCAT GBYP workshop discussed the details (Anon., 2012), which were adopted by the Steering Committee. Finally, due to security and permits problems, the survey included only three areas. In this year, following the updated recommendation of the Steering Committee, the survey was carried out by aircrafts equipped with bubble windows and declinometers and these tools were used in all following surveys.

The third year (2013) the GBYP Steering Committee requested an extended survey, covering all possible areas in the Mediterranean Sea. It resulted in 11 different areas, 4 to be densely monitored (these 4 almost overlapping most of the areas surveyed in previous years) and 7 with less dense transects. At the end, almost all areas were surveyed, except some parts in three areas, due to security reasons or permit issues. The logistic was extremely complex, close to impossible.

The fourth year (2015) the GBYP Steering Committee requested again an extended survey, covering all possible areas in the Mediterranean Sea (about 54.35% of the total surface). It resulted in 11 different areas (partly different from the previous 11, because of the updated information available on potential bluefin tuna spawning areas), 4 to be densely monitored (almost overlapping most of the areas surveyed in previous years) and 7 with less dense transects. The shape of both types of areas was different from the ones in 2013, with limited changes for the areas to be densely monitored. Finally, all areas were surveyed, with the exception of most of the Tunisian FIR, while security and permits issues affected even this last survey. The logistic was again extremely difficult and close to impossible.

The companies, pilots and observers were only partly the same during the four survey. This was due to the administrative structure of ICCAT GBYP (each Phase is administratively independent from the following one), which implies to operate with different Call for tenders and contracts in each Phase.

Therefore, the GBYP Steering Committee requested since 2013 a calibration exercise for the spotters, with the objective to calibrate their sightings and attribute individual CVs for smoothing the additional variance when elaborating the aerial survey data, but so far it was not possible to carry out any due to serious budget or operational constraints. In 2015, after many discussions within the Steering Committee and between the Steering Committee and the GBYP Coordination for trying to find the way for carrying out even a limited calibration exercise, a SWOT analysis was done (Di Natale, in press), showing that a calibration is almost impossible for an extended survey like the ICCAT GBYP one, which includes so many pilots and spotters.

As a matter of fact, this is the first time in marine science that an aerial survey is carried out over a so large proportion of a spawning area which includes so many countries and FIRs, which is certainly an extremely difficult challenge.

The extremely short time available between the end of field activities, the necessary time for providing reports and files, the time required for checking all data in details and fix any possible error or imperfection, made it impossible for presenting a full report to SCRS in 2015. This report presents a very preliminary analyses and the output data are to be considered with caution.

2. The aerial survey in 2015

The budget originally planned for the aerial survey in 2015 was 543,000 euro, but it was increased up to 670,000 after a revision made by the Steering Committee. This figure was included in the EU Grant Agreement and was finally approved. It included the new survey design, the new protocol (Anon. 2015), the training for the pilots, the professional and the scientific spotters, the survey activities and the analyses of the aerial survey data. The final cost is to be defined, because the administrative part of several contracts is still open on 16 September 2016, and will be better defined at the end of Phase 5. According to the contracts in place, it should be around 500,000 euro.

2.1 Aerial survey design

The aerial survey design was provided by the same company which provided the previous ones (Alnilam Investigation and Conservation Ltd), following a specific recommendation provided by the GBYP Steering Committee (Cañadas and Vázquez, 2015a).

Aerial surveys for bluefin tuna in the Mediterranean Sea were designed using the software DISTANCE http://www.ruwpa.st-and.ac.uk/distance/, the "industry standard" software for line and point transect distance sampling (Cañadas & Vázquez, 2015a) 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 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) was set according to Scenario 2 of the Feasibility study carried out at the beginning of 2013 (Cañadas and Vázquez, 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 (referred 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 might be used and therefore more effort could be allocated.

2.2 Aerial survey contracts in 2015

This year, for the first time, the Call for tenders for the aerial survey (IICAT GBYP 03/2015, ICCAT Circular 1796 on 8 April 2015) was set for two different activities, as requested by the Steering Committee: "activity A" for providing aircrafts, pilots and a scientific spotter for each aircraft, and "activity B" for providing only professional and scientific spotters to be rotated among the areas. Some tenders provided offers for both components, because of the legal problems existing for taking on board crew members from other companies and for all the complex procedures linked to the flight permits. In total, ICCAT received 7 bids for "action A" and 3 bids for "action B". Therefore, after consultation with the Steering Committee, three companies were awarded the contracts for various areas, but excluding any rotation among the spotters. A Spanish company (Grup AirMed) was awarded for area A, a French company (Action Air Environnement) for areas B, E and G, and an Italian company (Consorzio Unimar) for areas C, D and F.

A training course for pilots, professional spotters and scientific observers was organised at the ICCAT Secretariat in Madrid, on 26 May 2015, attended by 21 fellows, trained by two external experts (Dr. A. Cañadas and Dr. J.A. Vásquez) and by the GBYP Coordinator. The new GBYP Protocol for Aerial Survey for Bluefin Tuna Spawning Aggregation (Anon., 2015), provided by the two contracted experts, was reviewed by GBYP and officially circulated among all the contractors.

Once awarded the contracts, the ICCAT Secretariat immediately informed all concerned CPCs and assisted all contractors in all procedures for getting the necessary permits. This work needed a continuous assistance by the GBYP Coordination, because of the many delicate aspects concerned and many daily difficulties encountered for various reasons. Tunisia, after several letters and besides of the many interventions of the ICCAT Executive Secretary, the GBYP staff and the efforts made by the Companies, provided a letter of availability for examining any permit request which arrived too late, on 3 July 2015, just two days before the final date for finalising the survey. **Figure 2** shows the map without the Tunisian FIR.

Due to the very limited number of specialist in aerial survey data analyses and following consultation with the Steering Committee, ICCAT circulated the terms of reference set by the GBYP Steering Committee to some specialists. Only one bid was received, while other specifically declined their will to carry out the work within the tight time frame available. The contract was provided to Alnilam Investigation and Conservation Ltd.

The companies contracted for carrying out the aerial survey provided the draft final reports and the necessary excel files, which required additional work for the GBYP Coordination and also the external experts in charge of data elaboration, because of the various problems found while checking all details.

2.3 Survey coverage

Figure 3 shows the original designed survey transects for the various areas; **Figure 4** shows transects that were effectively surveyed.

Coverage of all sub-areas was not comprehensive in all sub-areas. Areas A inside and C inside were well covered, as were A, C, D and F outside, although B, C, D, E and F did not reach completely the border of the areas for various reasons (including the request from the aerial authorities to keep a security distance from the Libyan air space in some cases), and B, C and E missed a marginal part for the problem linked to the lack of Tunisian permit[3]. Sub-area E inside had a very undesirable situation, very similar to 2013, as the eastern section was more heavily surveyed (with two replicas in part of it) than the western section (with only one replica and not complete). Even in the eastern section, the south-western part of it had only one replica, while the rest had two. 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 very reliable. Sub-area E outside was barely surveyed and therefore these results are not fully acceptable. The problems in area E are mostly to to a complexity of motivation: Malta airport was able to provide a limited amount of fuel per day (200 l), making difficult or limited the survey in areas far from the airport (also taking into account the logistic); it was necessary to move the base airport to Pantelleria, for covering the western side, due to the fuel limits in Malta; security problems affected some activities, caused by the situation in Libya and in Tunisia; the weather was not always .

[3] The Tunisian authorities, within the mandatory requirements for releasing a flight survey permit, required also the aircrafts to use always Tunisian airports and to take on board a national Tunisian observer.

Similar problems are found in area G. Only two thirds (the westernmost section) of the sub-area G outside were covered. Area G inside was not homogeneously covered either, missing the whole south-eastern section. Anyway, compared to previous surveys, the coverage was much more extended. The aircraft operating in this area had on board a Turkish national observer when operating in the Turkish FIR[4]. This area had very complex situations, mostly due to security problems and the aircraft had to move from one airport to others, following the indications of various authorities in different countries, facing an extremely difficult logistic.

The weather and oceanography conditions are extremely important for the aerial survey, particularly in the Mediterranean Sea, where oceanography factors are essential components of the spawning activities. The general geography of the Mediterranean area, with so many different coasts and hundreds of isles naturally creates many different meteorological situations, over the more that 2.5 million Km^2 of the Mediterranean. At the same time, the oceanography is quite complex as well, with effects on the distribution and reproductive biology and behavior of Bluefin tuna.

For this reason, the GBYP staff monitored every day SST, waves and wind[5], as it was done in the past, checking the maps available on the web by contacting several people in various sites. **Figure 5** shows the situation during the aerial survey in 2015, using three colours: red for bad weather conditions or for fully unsuitable oceanographic conditions for Bluefin tuna spawning, yellow for problematic conditions and green for good ones, always taking into account that these are average estimates for sometimes large areas having mixed situations. Of course, larger the area, greater the variability within the same area.

Figure 6 shows the average conditions by area. In general, average good conditions were present in the survey are in 48% of the days during the survey period. Negative conditions were there for 13% of the time, while problematic conditions affected 38% of the days and this means that during these days there were zones where it was possible to carry out the survey and zones where it was not possible, even within the same area. The peak of negative conditions was in area A, the Balearic one, with 22% of negative days, followed by area B (south of the infamous Gulf of Lion) with 20% of negative days, while area C never had average negative conditions. Problematic situations were noticed for more than 40% of the days in four areas (49% in areas F and G, 41% in area C and $$% in area A), while the peak of good days (68%) was in area D.

The variability of both oceanographic and meteorological conditions, along with the logistic and the many domestic regulations requirements and limitations, impose to this activity a very high and adaptive flexibility.

The sightings of bluefin tuna schools made on and off effort in all areas together are showed in **Figure 7**. It is very clear that several outside areas had very few sighting, while even some parts of inside areas had no sightings. This is an unusual situation which might be possibly related to the oceanographic conditions (see SCRS/2015/154).

The detection function in average has a more logic distribution by distance (**Figure 8**), but it is different from team to team. In this case, taking into account that the methodology was firmly clarified during the taring course and that several spotters are now quite used to the DISTACE methods and to bubble windows. The major problems, this year, seem related to two main factors: a) the fact that several schools of tunas were not often at the surface, due to peculiar oceanographic conditions, and b) that this fact reduced the "encountering possibility" (or opportunity) for the aircrafts along the transects; as a matter of fact, the bluefin tuna schools sightings in some areas were so reduced in number that even the detection function was affected by the casualty. Furthermore, the encountering rate was partly affected by the large areas to be surveyed, which reduced the number of possible replicates.

Preliminary CVs estimates for density of schools in all models varied between 40 % and 71% for the 'inside' areas (**Table 1**) and 59 - 105% for 'outside' areas (**Table 2**). The precision of mean school size had a very large range, between 19 and 67% for the 'inside' sub-areas. There were not enough data on the 'outside' areas to estimate the mean school size CV except for A outside with 33% CV and B with 41%. CVs for estimates of total weight were high in all sub-areas: 40 - 97% for 'inside' areas, and 70 – 106% for 'outside' areas. Summing over all areas surveyed, the CV of total abundance was 41% for the 'inside' areas and 52% for the 'outside' areas. The CVs of the 'outside' areas were extremely high, due to extremely small number of observations there, to the lack of replicates and the major distance between transects, making those estimates rather useless.

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[4] ICCAT GBYP acknowledges the very strong cooperation from the Turkish authorities, which worked hardly for solving various problems and which were able to provide on time the national observer. The continuous contacts have been always extremely for solving all problems in real time.

[5] Oceanographic data were obtained by http://medforecast.bo.ingv.it/ while the daily situation of waves and winds was by http://isramar.ocean.org.il/isramar2009/wave_model/default.aspx?region=coarse&model=wam

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

The main way to reduce the estimated CVs in future surveys is to increase the number of sightings (if tuna schools will be there and visible). This can be achieved partly by more efficient searching strategies (= the best possible logistic) and partly by increasing the amount of searching effort (higher total transect length equal to more replicates). Increasing searching effort will possibly 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 by Cañadas and Vázquez (2013). As a rough idea of the effect, for example, if total sample size were doubled from 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).

Table 3 shows this comparison. With only 20% less effort in the outside areas, there was 30% less encounter rate and 32% less density of schools than in the inside areas. The mean weight was much larger outside mainly due to area B[6]. The smallest weights were recorded in the easternmost areas (F and G, both inside and outside) with a very large difference with the other areas, but the sample size is so small in them that these results are most probably irrelevant[7]. 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 here but still too few to make reliable comparisons. Density of animals was, however, similar overall in the inside sub-areas (0.355 animals/km^2, 41%CV) and the outside sub-areas (0.372 animals/km^2, 52%CV).

It is interesting to note that there were no BFT sightings on effort in ‘outside’ areas D and E and only 1 sighting in C, F and G. The majority were observed in A and B (only 3 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 similarity of density of animals between the inside and outside areas in 2015 as a fact. As long as the CVs are so large, neither results not comparisons are meaningful.

3. Comparison with the results in previous surveys

3.1 Comparison of total data

Table 4 shows the results obtained in the various years in both “inside” and “outside” areas. A comparison between the estimates in 2010, 2011, 2013 and the preliminary estimates in 2015 in each of the “inside” areas is more properly discussed in point 3.2 of this paper, after re-analysing all years only for the overlapping ‘inside’ areas.

The same table 4 shows the comparison of results in the ‘outside’ sub-areas in 2013 and 2015, which are the only two extended surveys made for including also potential spawning areas which are not usually the main spawning areas. Due to the zones excluded from 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 26% less of effective effort time (line length) than in 2013: 9,835 km in 2015 *vs*. 13,278 km in 2013. The reasons for this decrease are mostly linked to the extremely complicate logistic, the reduced amount of fuel provided in some airports, the new legal constrains and also the bad weather situations in some days during the timeframe of the survey.

With 26% less effort in 2015 with respect to 2013, there was 25% less amount of observations (12 in 2013 and 9 in 2015) yielding a very similar encounter rate of schools in 2015 compared to 2013, but 17% smaller density of schools. On the other hand, both mean cluster size and mean weight are considerable larger in 2015 than in 2013. 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 areas remain that large with such small sample size, these comparisons may be meaningless.

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[6] The sightings in the outside B area included a very large school, the largest encountered in 2015.
[7] It is supposed that in the last part of the season very young adults can be seen at the Surface in both areas, but a further analysis of both sightings and photos would possibly help for better defining the average size by school.

3.2 Comparison of overlapping areas

In Phase 5, ICCAT GBYP finally got the agreement of the Steering Committee for exploratory analyse the survey data in the various years only for overlapping areas, trying to reduce at least the additional variance induced by the different shape and surface of the various areas among the surveys.

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

Given the small amount of sightings "on effort" per area and year in all cases, it was decided to follow the same process adopted for all previous data: (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 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 they were not done for each area independently because of the small sample size. Instead, they were post-stratified by sub-areas in the analysis. After the initial exploration of the data, different right truncation distances were chosen for each year, plus a left truncation of 250m in 2010, given the lack of bubble windows that year. The full details are available on the preliminary report (Cañadas and Vázquez, 2015b).

Table 5 shows the new overlapping area of each survey area, the length of searched transects and the number of sightings of bluefin tuna schools used for analysis.

The final models selected, both for cluster size and weight, for 2010 and for 2011 had "area" as covariate with a Hazard-rate key function, and for 2013 and 2015 it had the covariate "team" also with a Hazard-rate 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 6** 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). **Figure 10** shows the fitted detection functions for each year.

Table 7 shows the estimates of density of schools, number of individuals and total weight of bluefin tuna in each area and year. Previously, an estimate of fish abundance was not obtained for 2010 due to the lack of school size by some teams. However, data in areas C and E had this information (100% of the sightings in C and 80% in E) and therefore it was estimated in this new analysis for those areas. **Table 8** shows the results for all areas pooled together in each year. **Table 9** shows a comparison between the results before and after cropping the areas for obtain the overlapping areas, in each year.

After cropping the overlapping areas, comparisons are more meaningful than before. There seems to be large inter-annual variations as well as geographical variations (see **Table 2.7**). Overall, pooling all areas together, appears to be a relatively strong progressive decrease in total weight and density of animals from 2011 to 2015 (and taking into account that sub-area G was not surveyed in 2011, the difference is 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 and 2015.

It has to be taken into account that the effort deployed for surveying these areas in 2013 and 2015 was considerably lower than in 2010 and 2011, due to the effort allocated to the outside area these two last surveys. There has been also 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 32% less effort than 2013. 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 (possibly due to a different oceanography in this year), both with respect to 2013 and the first phase of 2010-2011. It is interesting to note that with a reduction of 32% effort in 2015 with respect to 2013, there was a reduction of 71% in the number of observations, yielding a 36% reduction in total abundance of number of fish in 2015 with respect to 2013. On the other hand, there has been a slight increase of weight (8%) in 2015 with respect to 2013.

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) and therefore the confidence in the observed decrease is limited. All results still need to be taken cautiously given the many problems observed during data collection each year, which may be biasing the outputs, especially for some areas. These various issues will be explored and discussed in the following step of these analyses that will be completed in February 2016.

Area A-inside seems to be the most stable in terms of density of schools and fish (either in number or weight), except for some increase in density of fish in 2011 while the weight remained fairly stable. The effort in area A remained very similar over the years, even when time was allocated to the outside areas. Only in 2015 there was a more noticeable decrease in effort.

Area C-inside had much less effort in 2013 and 2015 than in 2010 and 2011 (but fairly similar within the two blocks of years), but in 2013 there was an increase in number of sightings compared to 2010 and the same amount compared to 2011, resulting in a density of schools 5 times larger in 2013 than in 2010 and 1.4 times larger than in 2011. In 2015 there were 70% less sightings than in 2013, with an almost identical amount of effort, resulting in a density of schools 3.4 times smaller in 2015 than in 2013. Oceanographic factors may had affected the presence or “sighting availability” of fish. The total estimated weight remained very similar in 2010 and 2011, but increased by 6 and 7 times in 2013 compared to 2012 and 2010 respectively, while in 2015 the total weight was around the double than the first two years. At the same time, in terms of abundance of fish, the total estimated abundance in 2013 was much larger than in any other year. The 95%CI of the 2013 estimate do not overlap those from 2010 and 2011 but overlap those in 2015 when the CV is very large due to the very few sightings.

Area E-inside shows the largest interannual variability, possibly induced mainly by the heterogeneity of coverage, especially in 2013 and 2015. The amount of effort in this area has been decreasing progressively, with 20% less effort in 2011 than in 2010, and 33% less effort in 2015 than in 2013. Various external factors affected the amount of effort. In terms of estimated weight, 2011 had a much larger amount than in 2010, while 2015 is very similar to 2010 and 2013 and much lower than any other year (but keeping in mind that the coverage this last year in the resulting overlap area was not complete). However, in terms of fish abundance, 2010, 2013 and 2015 are similar, while it was extremely high in 2011. The encounter rate and density of schools was much larger in 2011 than 2010 and 2015 but lower than in 2013. The mean school size was also larger in 2011 than the rest of the years, especially than in 2013 (which compensates and overtakes the larger encounter rate of schools this year). Thus, an increased density of schools plus an increased mean cluster size leads to a very large increase in fish density.

This area certainly had serious coverage issues in 2013 and 2015, which may cause biases in these years. Effort in 2013 was very incomplete and heterogeneous in the overlapping area, as it was again, to a lesser extent, in 2015. Therefore, estimates of these two last years, based on extrapolation of the information from the most surveyed parts of this area to the whole overlapping E-inside (including poorly or not at all covered sectors) are not very reliable as the assumption of equal coverage probability is not met. Therefore, in 2013, the non-surveyed sector was removed for the 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 at the moment for the overlapping area, making the estimates this year still provisional.

Area G-inside has the problem of a partial and heterogeneous coverage in 2015. This fact, caused by several external factors, along with only two observations of bluefin tuna schools on effort, yields very unreliable total estimates, rather useless. Furthermore, this area was not surveyed in 2011, due to the lack of permit. This means that only 2010 and 2013 may be compared. Unfortunately, no estimate of total fish abundance is available for 2010, due to the failure in data collection that first 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 tons in 2013 *vs*. 63.6 tons in 2010. The reasons for this difference are possibly linked to a more fractioned presence of the schools. The 2 observations on effort in 2015 were estimated to be 15 and 3 tons each, and the observation off effort was of 1 ton, therefore closer to the estimates in 2013.

3.3 Comparison between previous data and overlapping areas

Table 9 shows the comparison between the full data sets for all internal areas and for the overlapping surfaces.

In 2010 the effort was reduced by about 900 km in total in the overlapping areas, compared to the full “inside” surface of the areas. The number of sightings available for the estimates was also different, 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 get smaller, which is positive. Total estimated weight increased slightly in all areas, except area A where the increase is substantial (almost 3 times), and therefore as total estimates for 2010, but this difference is not significant. Even if it was not possible to obtain an overall CV for total weight estimates with DISTANCE analysis in 2010, the point estimate was larger in the new analysis, as it was for the density of schools. The main increase is observed in area A, followed by E, probably due to the reduction of the left truncation from 1.25 km to 0.25 km. Area C shows very similar results, and in G there is an increase due to the extension of the right truncation from 4 to 6 km. These changes in truncation allowed for the inclusion of a few more sightings of tuna schools with similar effort or even less (this is the case mainly in area G). The CVs for the density of schools were reduced considerably in the overall estimate, and also in areas C and G (this is the case for the CVs of estimated weight too). CV for density of schools and for estimated weight was not available by the Distance analysis for 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 they were labelled in 2010).

In 2011 effort has been reduced in almost 2,000 km in total in the overlapping areas. The number of sightings remained the same in area C, while there is one observation less in area A. There are 20% more observations in the overlapping area E, due to a large increase in the right truncation distance and the elimination of the left truncation. These changes in truncation, together with changes in the probability of detection in the 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 areas A and C and increased in E. In 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 fish and weight increased substantially. On the other hand, in area E, with increased effective searched area but increased number of observations too, this effect did not occur and the estimates are similar to the previous ones. The overall estimates of weight and abundance are similar in the two analysis, despite the variations between areas. The CVs are smaller in area E in the overlapping area due to the largest number of observations available. In C they are similar and in A slightly larger. The overall CV in 2011 is smaller considering all areas together.

In 2013, the overlapping process reduced the on effort tracks by 800 km, and discarded 4 observations, 3 of them in area A and 1 in area C. The truncation distance was reduced from 5 km to 4.4 km. As the changes were relatively small, the effective searched area remained similar. Some changes can also be observed in mean cluster size and mean weight. The reason is because DISTANCE chose the “expected cluster size” (estimated with a regression) in previous analyses, while in the current one taken by default the actual mean cluster size given that in some cases (especially 2015) when there were too few observations for fitting a regression line. Therefore, the mean cluster size was used in all models to ensure a sort of homogeneity for estimating mean cluster size and mean weight across areas and years in the overlapping areas. A specific issue arises for area E in 2013, because the original area in the survey design (107,673 km^2) was cropped during the first analysis to 82,054 km^2 to eliminate the not-surveyed part. Therefore, the comparison this area before and after creating the overlap area is meaningless unless the overlap area is reduced accordingly to the crop done in 2013. This part of the analysis should be possibly redo in a second step, before February 2016, but further cropping the overlapping area will imply loosing many sightings in previous surveys and this fact might bias tin another manner the outputs; therefore various tests will be necessary. At the moment, due to this problem, the 2013 results for area E overlapping shall be considered with a lot of caution. Overall, the resulting estimate of abundance in 2013 in the overlapping areas is 50% times larger than in the previous analysis, and double in the case of weight. All CVs resulted much smaller with the new analysis.

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

4. Sources of additional variance

Additional variance for aerial surveys on marine animals is process error. Additional variance in this specific case 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 areas do not take into account this variability in true abundance. There is no problem if all areas are surveyed in a sufficiently short period that the surveys can be considered synoptic. But if not all areas are surveyed every year, the precision of estimates of total abundance summed across areas surveyed in different years needs to incorporate variability in true abundance in each area. If additional variance is not included in these situations, the uncertainty in estimates of total abundance will be underestimated. Document SCRS/2015/156 (Quílez Badía *et al*.,in press) provides a first methodological approach for this specific additional variance.

5. Discussion

The ICCAT GBYP aerial survey is an extremely challenging activity, not only for the many factors which can bias the observations in different ways (Di Natale, in press), but also for the many difficulties in operating in a so large area and in so many aerial spaces managed by so many countries. This activity implies also that several aircraft and spotters shall be used at the same time, because of the short time frame in a normal spawning season for the bluefin tuna. All these factors combined together were never tested in the same survey.

In addition to these factors, there are others linked to the survey methodology itself (DISTANCE), which is currently considered the best available for marine species. 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 flight speed means that some schools available to be "sampled" will inevitably not be detected (so-called perception bias). In addition, Bluefin tuna spend a variable part of its time beneath the surface and, in this case, it is unavailable to the detection (the so-called availability bias). This specific factor will be possibly corrected by using the data obtained by several electronic tags that were deployed by ICCAT GBYP and other entities, at least for having the percentage of time at surface of the fish that went into the Mediterranean spawning areas when the aerial survey was in place. Estimates of abundance from these surveys are therefore implicitly underestimates (minimum estimates) even though a detection function has been fitted to correct for fish 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 almost stable over time but knowledge of the distribution in time and space of bluefin tuna throughout the Mediterranean Sea is still incomplete and subject to variables difficult to be detected. To minimise natural variation in using survey estimates as indices of abundance over time and therefore detecting trends, surveys in future years should ideally be conducted always in the same areas and at the same time of year.

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Table 1. Provisional 2015 survey data for mean school size, density and total weight and abundance of bluefin tuna for each "inside" area (without taking into account the areas that became not available during the survey).

		Areas				
		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	3,620	1,291	**12,291**
Effective strip width x2 (km)		3.2	3.2	3.2	3.2	**3.2**
Area searched (km^2)		13,435	10,496	11,739	4,187	39,857
% coverage		21.6	16.2	10.0	6.2	12.8
Number of sightings (n)		7	3	4	2	**16**
Encounter rate of schools	**n/L**	0.0017	0.0009	0.0011	0.0015	0.0013
	CV (%)	37.9	60.5	48.3	69.5	30.5
Density of schools (km^2)	**Density of schools**	0.521	0.286	0.341	0.478	0.395
	CV (%)	40.2	61.9	50.1	70.8	30.0
Weight (tonnes)	**Mean weight**	160.7	190.0	200.0	9.0	106.0
	CV (%)	11.7	19.9	77.1	66.7	22.5
School size (animals)	**Mean school size**	708	1,533	1,005	600	**818**
	CV (%)	19.8	19.0	60.6	66.7	19.1
Density of animals (per km^2)	**Density of animals**	0.369	0.438	0.343	0.287	**0.355**
	CV (%)	44.8	64.8	78.7	97.2	40.9
Total weight (tonnes)	**Total weight**	**5,419**	**3,654**	**8,354**	**304**	**17,731**
	CV (%)	40.4	65.2	92.0	97.3	
	Lower 95% CL	2,449	1,099	1,235	34	
	Upper 95% CL	11,991	12,150	56,520	2,718	
Total abundance (animals)	**Total abundance**	**22,912**	**28,317**	**40,324**	**19,491**	**111,044**
	CV (%)	44.8	64.8	78.7	97.2	40.9
	Lower 95% CL	9,814	8,569	8,231	2,181	
	Upper 95% CL	53,491	93,569	197,530	174,170	

Table 2. Provisional 2015 survey data for mean school size, density and total weight and abundance of bluefin tuna for each "outside" area (without taking into account the areas that became not available during the survey).

		Areas							
		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	213	1,171	2,068	**9,835**
Effective strip width x2 (km)		3.2	3.2	3.2	3.2	3.2	3.2	3.2	**3.2**
Area searched (km2)		4,889	2,880	6,051	6,881	690	3,797	6,705	31,892
% coverage		4.0	3.3	4.0	4.7	0.7	2.9	2.8	3.3
Number of sightings (n)		3	3	1	0	0	1	1	9
Encounter rate of schools	**n/L**	0.0020	0.0034	0.0005			0.0009	0.0005	0.0009
	CV (%)	59.4	62.7	105.2			105.0	104.0	44.8
Density of schools (per sq km)	**Density of schools**	0.614	1.042	0.165			0.263	0.149	0.269
	CV (%)	60.9	64.1	106.0			105.9	104.9	39.0
Weight (tonnes)	**Mean weight**	213.3	1250.0	300.0			2.0	20.0	130.0
	CV (%)	34.8	70.8						49.3
School size (animals)	**Mean school size**	1,200	1,700	2,500				1,333	**1,154**
	CV (%)	33.3	41.2						23.3
Density of animals (per sq km)	**Density of animals**	0.736	1.771	0.413			0.053	0.199	**0.372**
	CV (%)	69.4	76.2	106.0			105.9	104.9	51.9
Total weight (tonnes)	**Total weight**	**16,813**	**118,410**	**7,723**			**72**	**750**	**143,768**
	CV (%)	70.3	95.6	106.1			105.9	105.0	
	Lower 95% CL	4,571	16,019	1,296			12	130	
	Upper 95% CL	61,849	875,320	46,032			431	4,320	
Total abundance (animals)	**Total abundance**	**90,827**	**154,660**	**61,811**			**6,876**	**48,002**	**362,176**
	CV (%)	69.4	76.2	106.0			105.9	104.9	51.9
	Lower 95% CL	25,126	33,690	10,376			1,142	8,337	
	Upper 95% CL	328,330	710,040	368,210			41,379	276,370	

Table 3. Provisional data about mean school size, density and total weight and abundance of bluefin tuna for the total "inside" and "outside" areas in 2015, showing a comparison of both effort and sightings.

Total areas	*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)	12,291	9,835	**22,126**
Effective strip width x2 (km)	3.2	3.2	**3.2**
Area searched (km2)	39,857	31,892	**71,749**
% Coverage	12.8	3.3	**5.6**
Number of schools	16	9	**25**
Encounter rate of schools	0.0013	0.0009	0.0011
%CV encounter rate	30.5	44.8	25,2
Density of schools (1000 km^{-2})	0.395	0.269	0.265
%CV density of schools	30.0	39.0	30.3
Mean weight (t)	106.0	130.0	107.5
%CV mean weight	22.5	49.3	12.8
Mean cluster size (animals)	**818**	**1,154**	**807**
%CV mean cluster size	19.1	23.3	16.9
Density of animals	**0.355**	**0.372**	**0.368**
%CV density of animals	40.9	51.9	38.2
Total weight (t)	**17,731**	**143,768**	**161,499**
%CV total weight			71.4
Total abundance (animals)	**111,044**	**362,176**	**473,220**
%CV total abundance	40.9	51.9	38.2

Table 4. Provisional data about mean school size, density and total weight and abundance of bluefin tuna for the total "inside" and "outside" areas in the various ICCAT GBYP aerial surveys.

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	12,291	13,278	9,835	28,947	22,126
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	39,857	61,079	31,892	133,155	71,749
% coverage	25.2	57.1	28.3	12.8	4.7	3.3	8.5	5.6
Number of schools ON effort	72	56	56	16	12	9	68	25
Abundance of schools	256	424	460	123	421	262	881	385
% CV abundance of schools	29.9	24.7	34		75	39.0		46
Encounter rate of schools	0.0023	0.0020	0.00357	0.0013	0.0009	0.0009	0.0023	0.0011
% CV encounter rate	20.0	46.9	23		69	44.8		
Density of schools (1000 km^{-2})	0.805	1.917	1.804		0.323	0.269	0.001	0.153
% CV density of schools	30.0	25.0	34		76	39.0		46
Mean weight (t)			22.6	106.0	5.5	130.0		107.5
%CV weight			51	23	75	49.3		13
Mean cluster size (animals)			302	**652**	432	**1,154**		**920**
%CV abundance			43	23	49	23.3		9
Density of animals (km^{-2})		**2.6086**	0.544	0.355	0.140	**0.372**	0.206	**0.368**
% CV density of schools		41.0	35	60	86	51.9	0	46
Total weight (t)	**22,157**	**48,287**	**9,100**	**17,731**	**2,988**	**143,768**	**12,088**	**161,499**
% CV total weight		40.0	45		65			55
Total abundance (animals)		**582,307**	**138,650**	**111,044**	**181,980**	**362,176**	**320,629**	**473,220**
% CV total abundance		41.0	35	60	86	51.9		46

Table 5. Areas, total length of transects and number of sightings of bluefin tuna for each survey and year.

Inside Area	*Area (km^2)*	*Year*	*Length of transects (km)*	*Number of observations (after truncation)*
A	62,150	2010	6,118	8
		2011	7,838	6
		2013	6,807	29
		2015	4,109	33
C	64,610	2010	8,487	6
		2011	8,826	10
		2013	2,791	10
		2015	2,739	3
E	117,718	2010	13,137	29
		2011	10,192	45
		2013	4,381	20
		2015	2,566	3
G	68,013	2010	3,790	33
		2011		
		2013	2,081	12
		2015	859	2
Total	265,627	2010	31,532	76
	209,416	2011	26,856	65
	265,627	2013	16,060	52
	265,627	2015	10,272	14

Table 6. Parameters and diagnostics of the detection functions for overlapping areas in the various years.

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	Area	6.0 (0.25)	0.247	1.48	0.912	1.000
2011	Area	4.3	0.158	0.68	0.018	0.025
2013	Team	4.4	0.341	1.50	0.871	0.800
2015	Team	5.0	0.304	1.52	0.925	1.000

Table 7. Recalculation of all data by overlapping "inside" areas by 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	0.396
%CV density of animals		45.5	44.5	44.9
Total weight (t)	**3,496**	**4,296**	**3,572**	**5,432**
%CV total weight	56.6	46.2	40.6	42.0
L 95% CI total weight	1,218	1,775	1,640	2,455
U 95% CI total weight	10,037	10,398	7,780	12,019
Total abundance (animals)		**38,720**	**18,717**	**24,527**
%CV total abundance		45.5	44.5	44.9
L 95% CI total abundance		16,249	7,990	10,551
U 95% CI total abundance		92,266	43,845	57,020

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	0.570
%CV density of animals	59.2	45.3	38.3	65.7
Total weight (t)	**1,658**	**1,999**	**11,830**	**3,709**
%CV total weight	46.9	54.9	40.9	65.9
L 95% CI total weight	678	689	5,365	1,103
U 95% CI total weight	4,056	5,794	26,081	12,467
Total abundance (animals)	**9,797**	**13,614**	**86,114**	**30,717**
%CV total abundance	59.2	45.3	38.3	65.7
L 95% CI total abundance	3,187	5,677	40,959	9,173
U 95% CI total abundance	30,016	32,649	181,040	102,860

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	2,470
Effective strip width x2 (km)	2.96	1.36	3.00	3.03
Area searched (km^2)	37,401	13,336	11,149	7,495
% coverage	40.0	14.2	11.9	8.0
Number of schools ON effort	29	45	20	4
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	0.0016
%CV encounter rate	29.9	21.0	32.9	48.7
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	200.1
%CV weight	33.9	19.2	66.0	77.0
Mean cluster size (animals)	1015	1,715	361	1,005
%CV abundance	19.0	21.5	67.3	60.6
Density of animals (km^{-2})	0.787	5.786	0.647	0.537
%CV density of animals	37.8	32.3	75.4	79.1
Total weight (t)	**7,995**	**39,344**	**1,882**	**9,743**
%CV total weight	47.1	32.2	74.3	92.2
L 95% CI total weight	3,284	21,147	486	1,443
U 95% CI total weight	19,464	73,198	7,284	65,767
Total abundance (animals)	**73,676**	**541,634**	**60,614**	**50,225**
%CV total abundance	37.8	32.3	75.4	79.1
L 95% CI total abundance	35,741	290,700	15,391	10,239
U 95% CI total abundance	151,880	1,009,200	238,710	246,360

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	0.504
%CV density of animals			54.8	95.9
Total weight (t)	**13,733**		**534**	**414**
%CV total weight	32.1		57.2	95.9
L 95% CI total weight	7,387		181	45
U 95% CI total weight	25,532		1,574	3,771
Total abundance (animals)			**44,041**	**28,319**
%CV total abundance			54.8	95.9
L 95% CI total abundance			15,587	3,112
U 95% CI total abundance			124,440	257,740

Table 8. Results for the re-analysis of the data for all overlapping areas (A+C+E+G) for the various years. Area G was not surveyed in 2011.

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	10,032
Effective strip width x2 (km)	2.96	1.36	3.00	3.03
Area searched (km^2)	88,803	35,697	44,539	30,443
% coverage	33.4	17.0	16.8	11.5
Number of schools ON effort	76	65	52	15
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	0.0015
%CV encounter rate				
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	136.2
%CV weight	1.7	2.8	1.8	5.9
Mean cluster size (fish)		1,275	582	888
%CV abundance		37.3	18.5	40.8
Density of animals (km^{-2})		**2.8363**	**0.789**	**0.504**
%CV density of animals		30.0	30.4	41.7
Total weight (t)	**26,882**	**45,639**	**17,818**	**19,298**
%CV total weight	25.6	28.7	30.1	50.9
L 95% CI total weight	14,243	26,133	9,902	6,484
U 95% CI total weight	38,347	79,703	32,061	57,435
Total abundance (no. fish)		**593,968**	**209,486**	**133,788**
%CV total abundance		30.0	30.4	41.7
L 95% CI total abundance		332,640	116,000	5,886
U 95% CI total abundance		1,060,600	378,330	306,570

Table 9. Comparison between the results before and after cropping the areas to obtain the overlapping ones for the 4 years.

	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 (km²)	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 (km²)	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. fish (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		

	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 (km²)	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 (km²)	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. fish (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

	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 (km²)	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 (km²)	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. fish (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

	Previous					Overlapping				
Year	2015					2015				
Sub-area	A inside	C inside	A inside	C inside	A inside	C inside	A inside	C inside	A inside	C inside
Survey area (km²)	62,150	64,610	62,150	64,610	62,150	64,610	62,150	64,610	62,150	64,610
Transect length (km)	4,143	3,237	4,143	3,237	4,143	3,237	4,143	3,237	4,143	3,237
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)										
Prob. 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 (km²)	12,572	9,822	12,572	9,822	12,572	9,822	12,572	9,822	12,572	9,822
% coverage	20.2	15.2	20.2	15.2	20.2	15.2	20.2	15.2	20.2	15.2
N. of schools ON effort	7	3	7	3	7	3	7	3	7	3
Abundance of schools	32	18	32	18	32	18	32	18	32	18
%CV Ab. of schools	40.2	61.9	40.2	61.9	40.2	61.9	40.2	61.9	40.2	61.9
Enc. rate of schools	0.0017	0.0009	0.0017	0.0009	0.0017	0.0009	0.0017	0.0009	0.0017	0.0009
%CV encounter rate	37.9	60.5	37.9	60.5	37.9	60.5	37.9	60.5	37.9	60.5
D. schools (1000 km⁻²)	0.521	0.286	0.521	0.286	0.521	0.286	0.521	0.286	0.521	0.286
%CV density of schools	40.2	61.9	40.2	61.9	40.2	61.9	40.2	61.9	40.2	61.9
Mean weight (t)	160.7	190.0	160.7	190.0	160.7	190.0	160.7	190.0	160.7	190.0
%CV weight	11.7	19.9	11.7	19.9	11.7	19.9	11.7	19.9	11.7	19.9
Mean cluster size	708	1,533	708	1,533	708	1,533	708	1,533	708	1,533
%CV cluster size	19.8	19.0	19.8	19.0	19.8	19.0	19.8	19.0	19.8	19.0
Dens. fish (km⁻²)	0.369	0.438	0.369	0.438	0.369	0.438	0.369	0.438	0.369	0.438
%CV density of animals	44.8	64.8	44.8	64.8	44.8	64.8	44.8	64.8	44.8	64.8
Total weight (t)	**5,419**	**3,654**	**5,419**	**3,654**	**5,419**	**3,654**	**5,419**	**3,654**	**5,419**	**3,654**
%CV total weight	40.4	65.2	40.4	65.2	40.4	65.2	40.4	65.2	40.4	65.2
L 95% CI total weight	2,449	1,099	2,449	1,099	2,449	1,099	2,449	1,099	2,449	1,099
U 95% CI total weight	11,991	12,150	11,991	12,150	11,991	12,150	11,991	12,150	11,991	12,150
Total abundance	**22,912**	**28,317**	**22,912**	**28,317**	**22,912**	**28,317**	**22,912**	**28,317**	**22,912**	**28,317**
%CV abundance	44.8	64.8	44.8	64.8	44.8	64.8	44.8	64.8	44.8	64.8
L 95% CI abundance	9,814	8,569	9,814	8,569	9,814	8,569	9,814	8,569	9,814	8,569
U 95% CI abundance	53,491	93,569	53,491	93,569	53,491	93,569	53,491	93,569	53,491	93,569

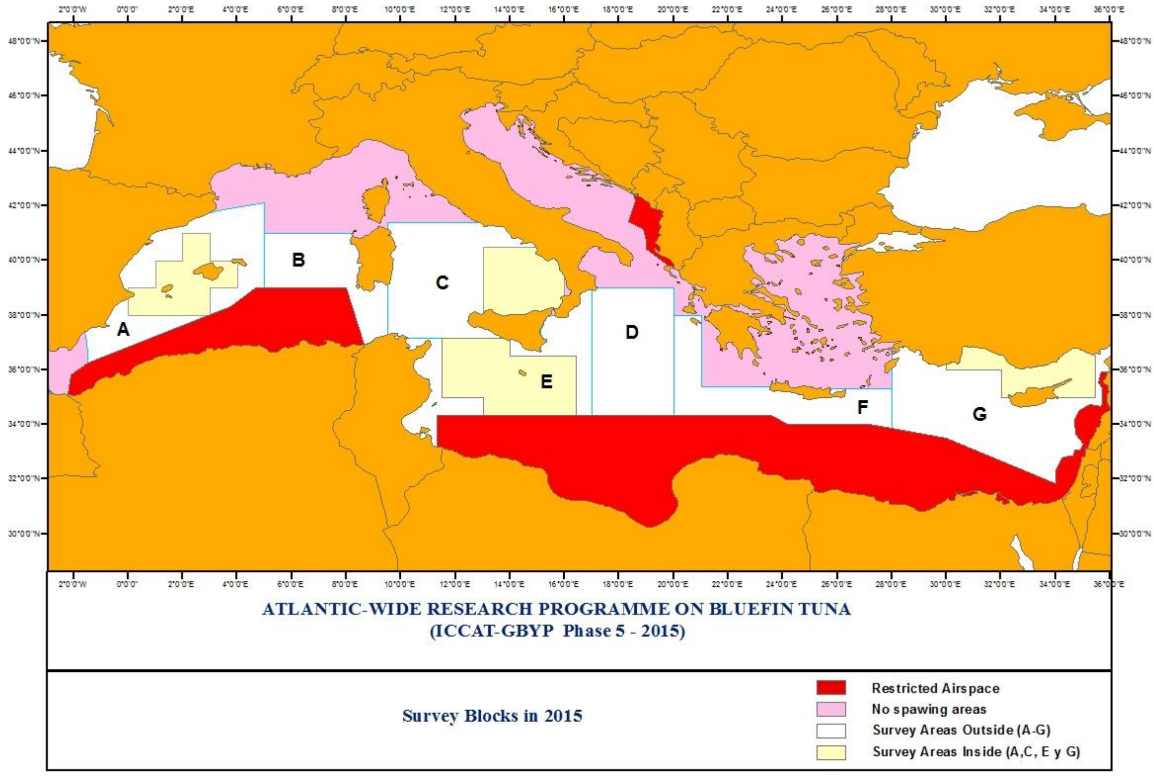


Figure 1. Areas identified for the aerial survey in 2015. The areas in light yellow are the most densely surveyed and they are similar to previous surveyed areas (called "inside"). The areas in white are less densely surveyed and called "outside".

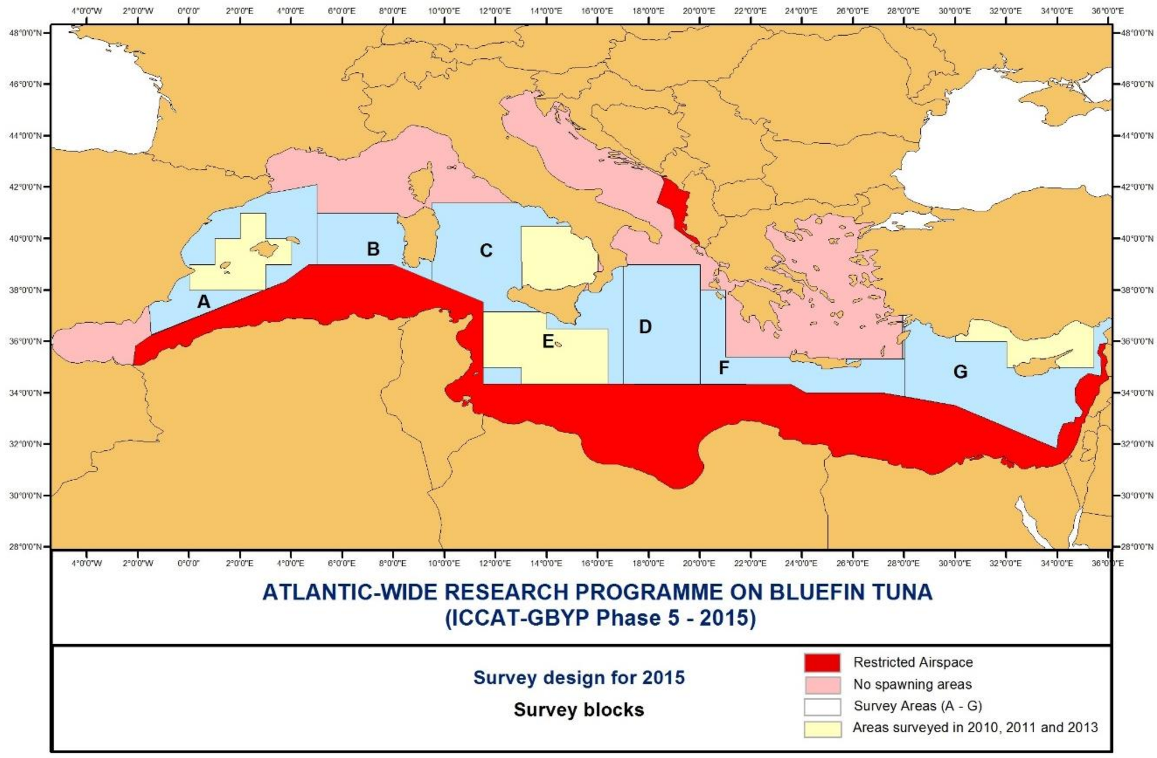


Figure 2. Areas identified for the aerial survey in 2015, after the lack of permit for the Tunisian FIR.

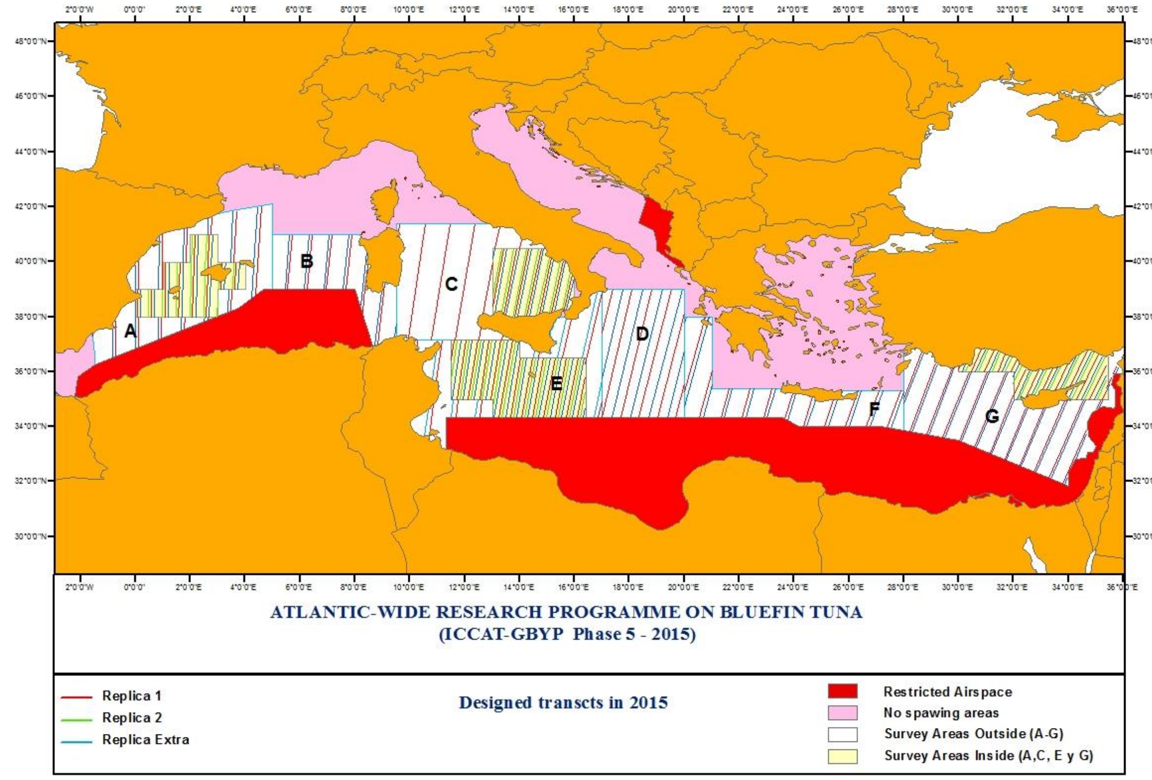


Figure 3. ICCAT GBYP Aerial survey design in 2015, showing the different density of the transects in the various areas, including replicates. The design included the Tunisian FIR that was not available later.

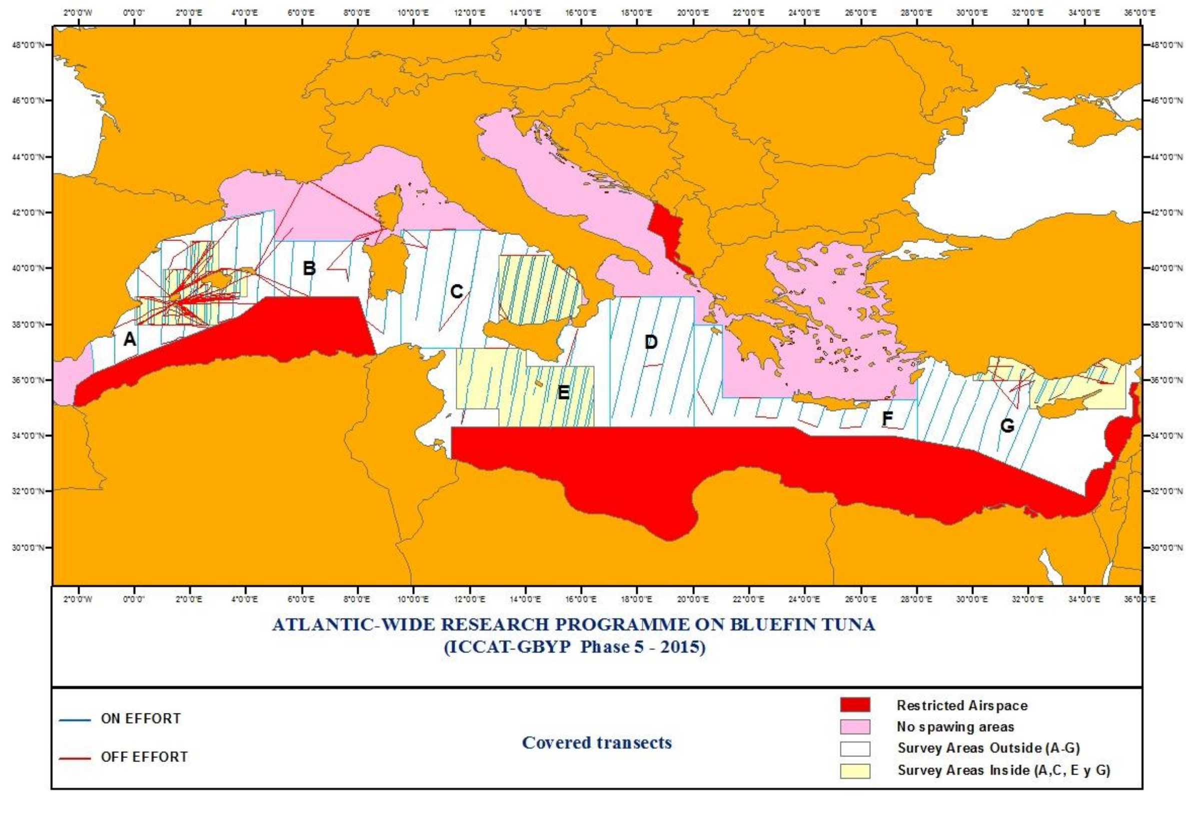


Figure 4. Covered transects on and off effort in 2015.

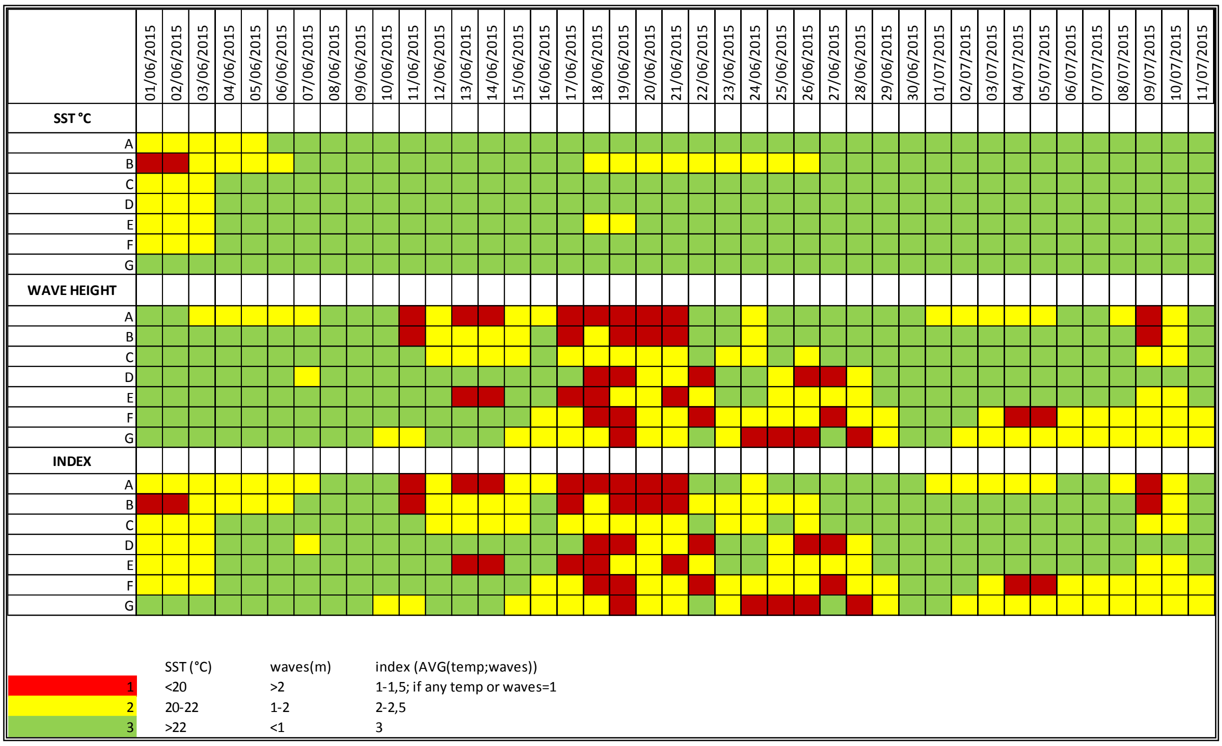
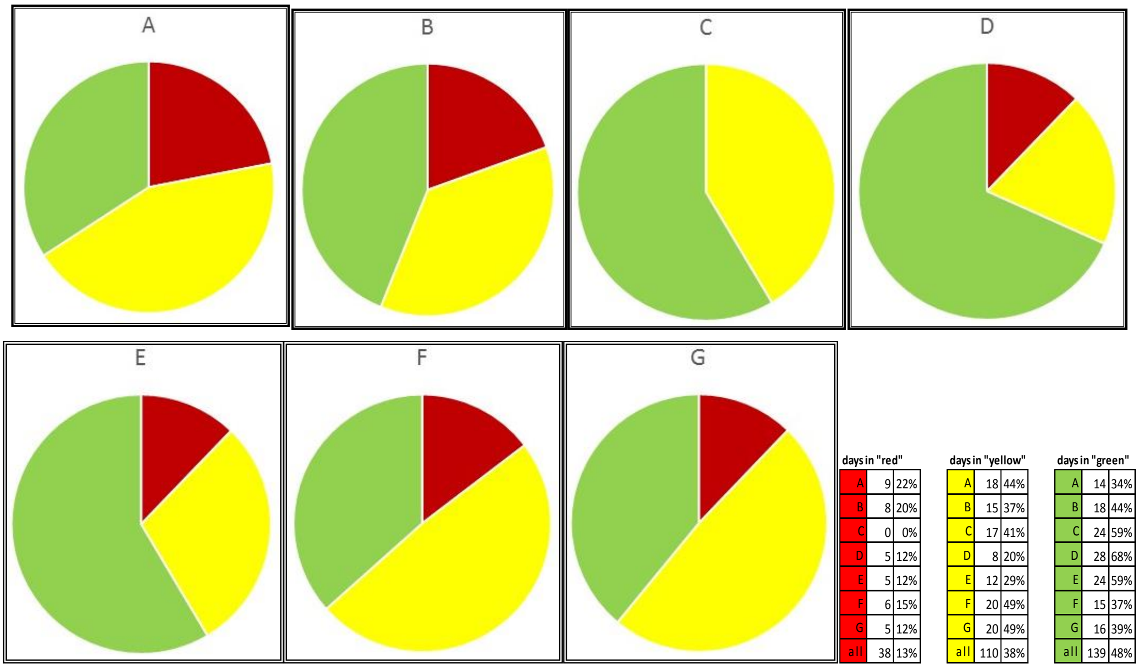


Figure 5. Graphic representation of potential SST and waves high conditions, in correlation with suitable situations for Bluefin tuna spawning and the aerial survey. Combined data are showed by the "index".



days in "red"			days in "yellow"			days in "green"		
A	9	22%	A	18	44%	A	14	34%
B	8	20%	B	15	37%	B	18	44%
C	0	0%	C	17	41%	C	24	59%
D	5	12%	D	8	20%	D	28	68%
E	5	12%	E	12	29%	E	24	59%
F	6	15%	F	20	49%	F	15	37%
G	5	12%	G	20	49%	G	16	39%
all	38	13%	all	110	38%	all	139	48%

Figure 6. Graphic representation of potential positive, problematic or positive meteo-marine conditions in the various areas and corresponding percentages.

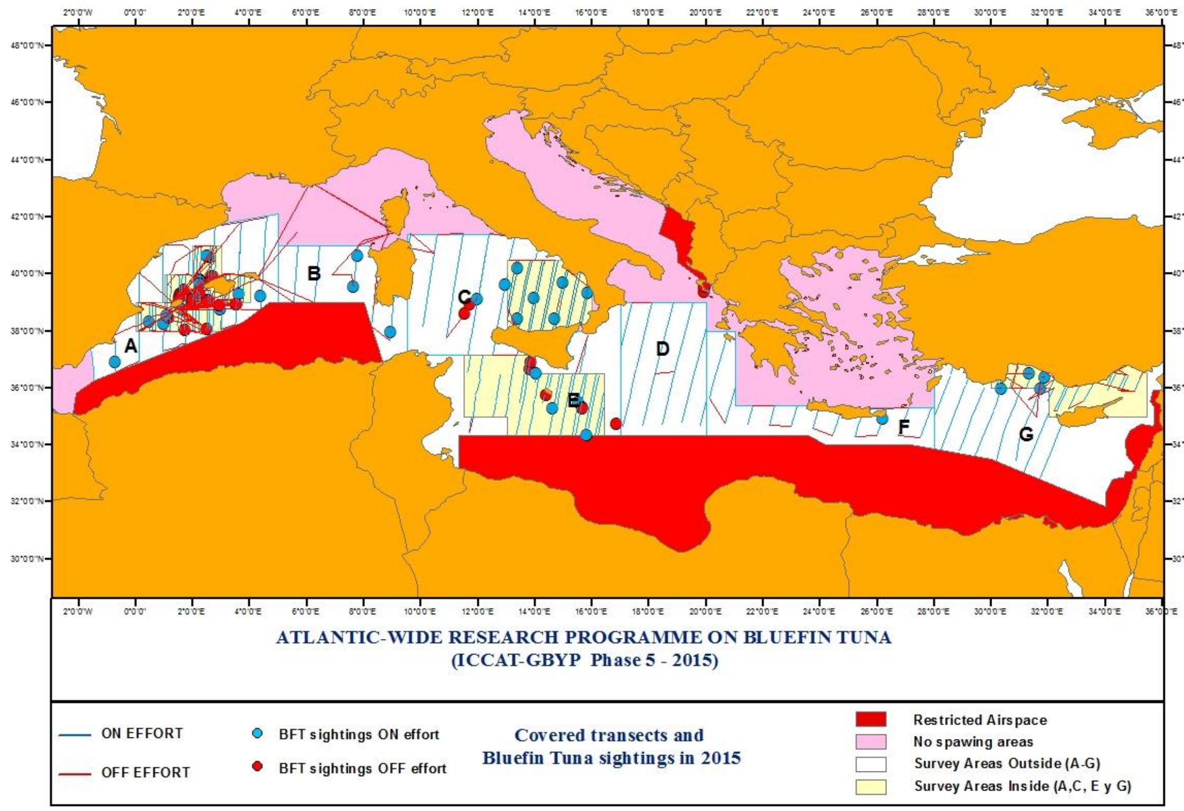


Figure 7. Transects and sightings of bluefin tuna on and off effort in 2015.

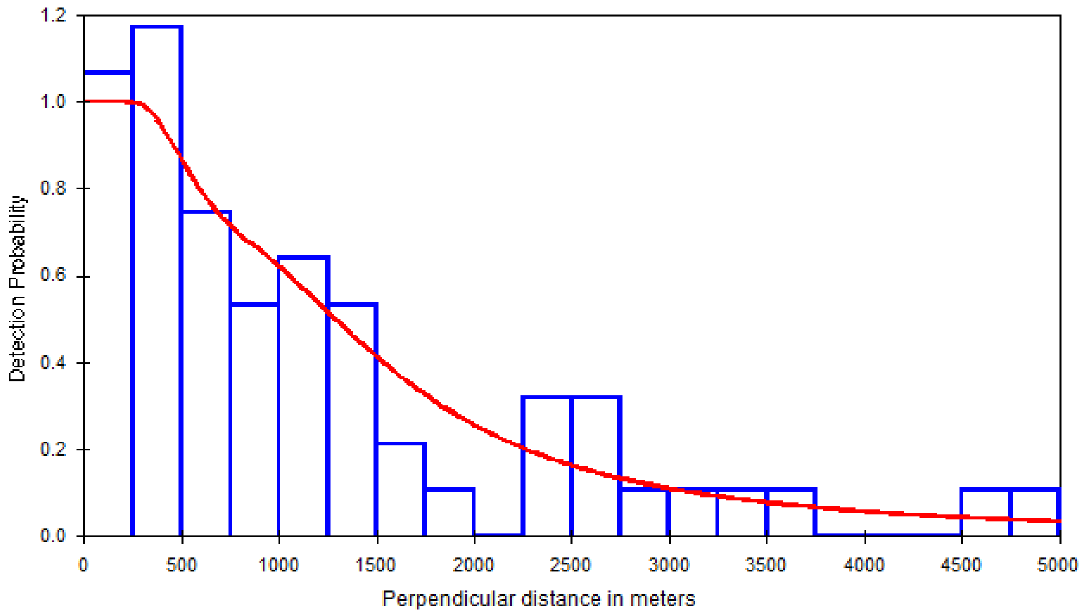


Figure 8. Detection function for cluster size, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings in 2015.

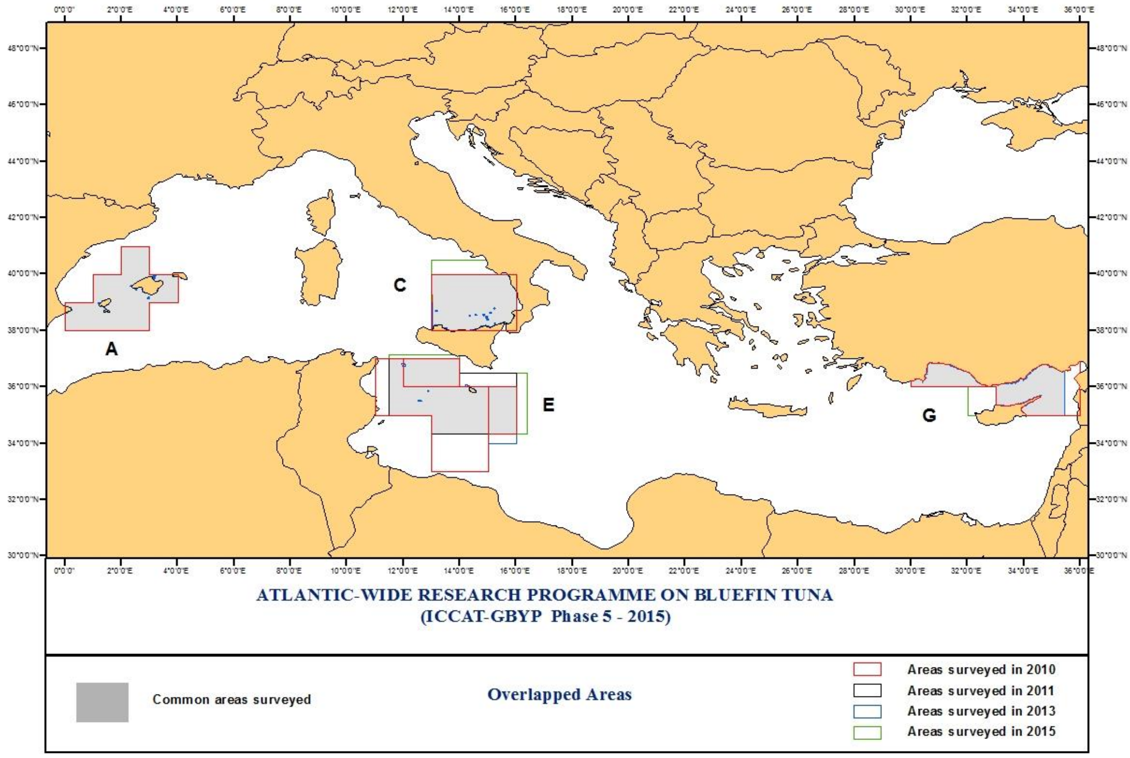


Figure 9. Overlapping survey blocks used for the tentative analyses of multi-year GBYP survey data.

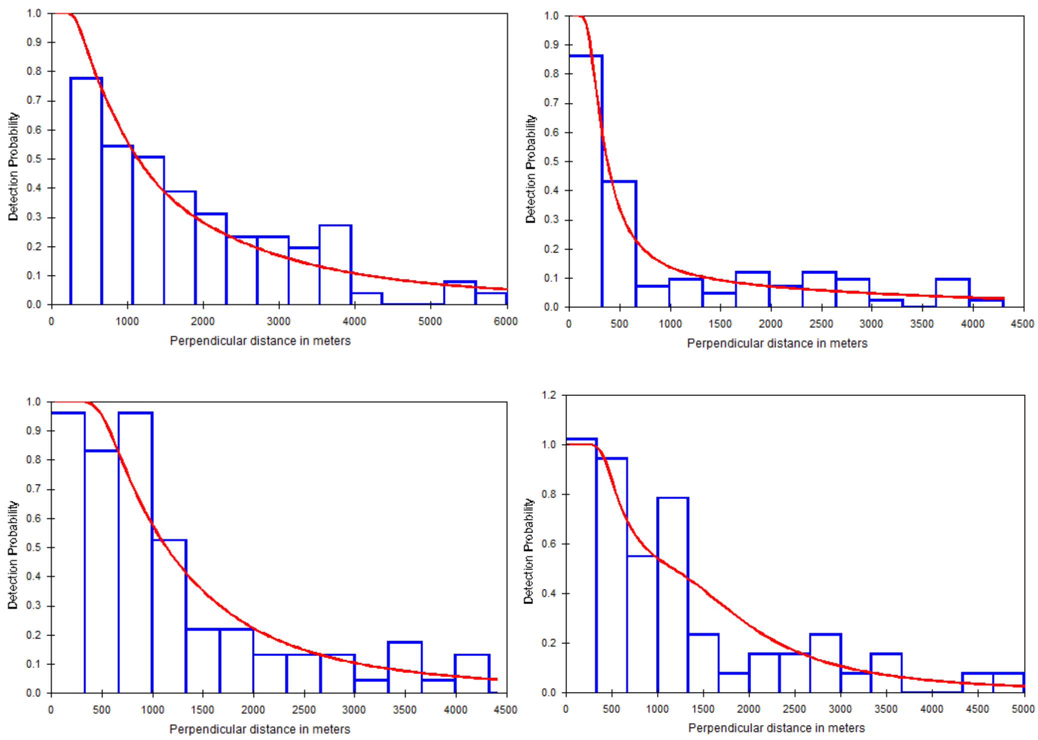


Figure 10. Detection function for 2010, 2011, 2013 and 2015, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings.