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REPORT OF THE ICCAT GBYP AERIAL SURVEY FOR BLUEFIN SPAWNING AGGREGATIONS IN 2017

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SUMMARY

The fifth ICCAT GBYP aerial survey was carried out in 2017, over 4 areas, overlapping with the corresponding areas in previous surveys. It was carried out during the peak of the Bluefin tuna spawning period (mostly in June), by 3 companies and 4 aircrafts. A new survey design was available in 2017, always using the DISTANCE methodology, adopting an updated protocol. The survey reports were provided in real-time and the survey ended on the 3rd July and therefore the data analyses have been available for the first year in real time, according to what was set by the ToRs of the contract. The elaboration provides the estimates for each area (number of schools, number of tunas and quantities), with the usual details, comparing the results with those obtained in previous years in the same areas. The results show a high interannual variability and a high potential SSB. We detected in real-time an important shifting in the abundance between areas. It is again evident that a reliable trend can be obtained only when considering various areas together.

RÉSUMÉ

La cinquième prospection aérienne de l'ICCAT-GBYP a été réalisée en 2017, sur quatre zones, couverture chevauchant avec les zones correspondantes des prospections antérieures. 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 quatre aéronefs. Une nouvelle conception de la prospection a été disponible en 2017, utilisant toujours la méthodologie DISTANCE, adoptant un protocole mis à jour. Les rapports de prospection ont été fournis en temps réel et la prospection a pris fin le 3 juillet et les analyses des données ont par conséquent été disponibles pour la première année en temps réel, conformément à ce qui avait été établi dans les termes de référence du contrat. L'élaboration donne les estimations pour chaque zone (nombre de bancs, nombre de thons et quantités), avec les détails habituels, en comparant les résultats avec ceux obtenus au cours des années précédentes dans les mêmes zones. Les résultats montrent une forte variabilité interannuelle et une SSB potentielle élevée. Nous avons détecté en temps réel un changement important dans l'abondance entre les zones. Il est une fois de plus manifeste qu'une tendance fiable peut être obtenue uniquement si l'on tient conjointement compte de diverses zones.

RESUMEN

La quinta prospección aérea del ICCAT-GBYP se llevó a cabo en 2017 sobre cuatro zonas, solapándose con las zonas correspondientes a prospecciones anteriores. Fue llevada a cabo durante el pico del periodo de desove del atún rojo (principalmente en junio) por tres empresas que utilizaron cuatro aeronaves. En 2017 se dispuso de un nuevo diseño de la prospección, se siguió utilizando la metodología DISTANCE y se adoptó un protocolo actualizado. Los informes de la prospección se proporcionaron en tiempo real, y la prospección finalizó el 3 de julio y, por lo tanto, es el primer año en el que los análisis están disponibles en tiempo real, de conformidad con lo que se estableció en los términos de referencia del contrato. La elaboración proporciona las estimaciones para cada área (número de bancos, número de túnidos y cantidades) con los detalles habituales, comparando los resultados con los obtenidos en años anteriores en las mismas áreas. Los resultados muestran una elevada variabilidad interanual y una SSB potencialmente alta. Se detectó en tiempo real un cambio importante en la abundancia entre las zonas. Una vez más resulta evidente que puede obtenerse una tendencia fiable solo si se consideran varias zonas juntas.

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KEYWORDS

Bluefin tuna, ICCAT, aerial survey, species distribution, Mediterranean, methodology

1. Foreword

Aerial survey are used for obtaining fishery independent data for some marine species or for more closely studying their behaviour (Heldt, 1932; Grierson, 1949; 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, 1999; 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; Everson *et al.*, 2011; Farley and Bennet, 2011; Fortuna *et al*., 2011, 2014; Lauriano *et al*., 2011, 2017; Palka, 2011; Panigada *et al*., 2011, 2017; Kessel *et al*., 2013; Basson and Farley, 2014; Bower *et al*., 2014; Bauer *et al*., 2015a, 2015b; Rouyer 2016, in press), not in all cases appropriately using this technique or not always providing the necessary details.

The ICCAT GBYP aerial survey for Bluefin tuna spawning aggregations is a method for obtaining fishery independent indices of the Bluefin tuna spawning stock biomass over the years 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 from the aerial survey are in the best case the minimum estimates, because they reflect the quantities really encountered, which are always much less than the real quantity of fish, due to many natural factors (mostly for the vertical distribution of the schools). From a management point of view, this represents a sort of precautionary point of view. The initial decision for carrying on the survey on spawners and not on juveniles was taken by the SCRS and confirmed by a SWOT analysis (Di Natale and Idrissi, 2013b). The previous 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 (Di Natale and Tensek, 2016; Di Natale *et al*., 2016), depending on the availability of funds and the choices of the GBYP Steering Committee, the SCRS and the Commission. All results and reports are available on the ICCAT GBYP web pages http://www.iccat.int/GBYP/en/asurvey.htm .

The previous 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 the previous four surveys in many more areas (four main "internal" areas and seven "external" areas) was approximately 1,619,600 Euros (134.97% of the original budget, but with much more than twice the activities); the aerial survey workshop, the survey design, the protocols, the training courses, the power analyses, the development of the prevision model and the analyses were all not included in the original budget.

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 partly 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 airspace, 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 new Phase is administratively independent from the previous one), which implies to operate with different Call for tenders and contracts in each Phase; the suspensions in 2012, 2014 and 1016 certainly didn't help.

Therefore, the GBYP Steering Committee has 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, 2016), showing that a calibration is almost impossible for an extended survey like the ICCAT GBYP one, which includes so many pilots and spotters, while a comprehensive calibration considering all possible variables is certainly impossible. For this reason, not a single aerial survey for marine animals had so far a comprehensive one.

As a matter of fact, this is the first time in marine science that an aerial survey is carried out over such a large proportion of a spawning area which includes so many countries and airspaces, but also a high number of aircrafts, pilots, professional spotters and scientific spotters, which is certainly an extremely difficult challenge.

At the very end of Phase 5, the Steering Committee requested a new power analyses, which confirmed the results obtained with the previous two studies, and an extremely detailed analysis of all possible variables included in the various surveys, including the so-called additional variance (http://www.iccat.int/GBYP/Documents/ASURVEY/PHASE%205/AERIAL_SURVEY_PHASE5_ANALYSIS_FINAL_REPORT_1.pdf and http://www.iccat.int/GBYP/Documents/ASURVEY/PHASE%205/AERIAL_SURVEY_PHASE5_ANALYSIS_FINAL_REPORT_2.pdf). Again, the GBYP Steering Committee decided to suspend the survey in 2016.

In 2016 the full GBYP activity has been analysed by two external and independent reviewers (Sissenwine and Pearce, 2017), including the aerial survey. In the recommendations they stated "A reliable abundance measure for the Eastern Atlantic Bluefin tuna remains a difficult challenge. It is time to select the method with the best chance of success and apply enough resources to make it work. Aerial surveys and close kin mark and recapture are the leading candidates."

The very short time available between the end of field activities and the SCRS meetings, the necessary time for providing reports and files, the time required for checking all data in details and fixing any possible error or imperfection, made it impossible to present a full report to SCRS in previous years, while full reports were presented in the following years.

In 2017 we fully changed the strategy for all reporting issues and for the first time the final report is available for the SCRS Bluefin Tuna Assessment Session.

2. The aerial survey in 2017

In the very first version of the budget proposed by the GBYP Steering Committee for Phase 7, the aerial survey was not included, because it was initially decided to suspend it again, against the opinion of the external reviewers. For the first time, after a specific request by the main funder of the GBYP, the EU (which also considered the strategy approved by the Commission since the beginning of the GBYP, confirmed again by the Commission in 2014), the aerial survey was specifically requested in Phase 7. Therefore, the GBYP Steering Committee reconsidered the activities and the aerial survey was included. The budget originally planned for the aerial survey in 2017 was only 388,000 euro, well below the usual necessary level, due to a general budget restriction for Phase 7. This figure was included in the EU Grant Agreement and was finally approved. This amount included the new survey design, the new protocol, the training course, the survey activities and the analyses of the aerial survey data.

The final cost is to be defined in details, because the administrative part of several contracts is still open on 17 September 2017, and will be better defined after that date. According to the contracts in place, it should be around 406,000 euro, within the flexibility margins of the budget. The survey was carried out having the specific condition and objective to provide the results to the SCRS Bluefin Tuna Assessment Session, in July 2017.

2.1 Aerial Survey Strategy in 2017

For responding in the necessary manner to the challenge set by the extremely strict schedule for providing the report, the GBYP Coordination studied and enforced a strategy that was completely different from the one used so far in all previous survey. At first, the areas for the survey have been set for just the four overlapping areas, so as to make all data perfectly comparable with those already collected and selected for the same areas. This coverage was anyway ensuring about 265,625 km2, equivalent to about 10.6% of the full surface of the Mediterranean Sea, to about 15.15% of both the documented and potential spawning areas and about 46.25% of the documented Bluefin tuna spawning areas[3] (Piccinetti *et al*., 2013).

Once decided the areas, it was also decided to accelerate as much as possible all the process, setting a precise schedule for all activities in order to ensure the delivery of the report on time and then going back for each step, including also some very limited buffer times.

For the very first time, it was decided also to fully change the reporting system, imposing a weekly schedule to both the companies engaged in the field activities and the team in charge of the analyses, with a further support by the GBYP coordination team. Even if the schedule has been very tight, it seems that this was a winning strategy.

2.2 Aerial survey design

Even if the GBYP Steering Committee recommended not to change the team in charge of the aerial survey design, it was considered fair to go for an open Call for tenders, comprehensive of the survey design, the revision of both the protocol and the sighting forms, the assistance to the training course and the survey data analyses, which was released on 2 March 2017 (ICCAT GBYP Call for tenders 01/2017, prot. 362/2017). The Call received one bid that, after the opinion of the Evaluation Committee, was awarded on 15 March 2017 to the same company which provided the previous survey designs (Alnilam Investigation and Conservation Ltd), including the last one (Cañadas and Vázquez, 2015a). The contract was issued on 28/03/2017.

The aerial surveys for bluefin tuna in the Mediterranean Sea were all designed using the software DISTANCE http://www.ruwpa.st-and.ac.uk/distance/ (Buckland *et al*., 2001), the “industry standard” software for line and point transect distance sampling based on: the four defined survey areas (survey areas A, C, E and G, see **Figure 1**), target survey time available (equivalent to about 32,000 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 mostly in a north-south direction to be approximately perpendicular to the coast in most blocks (**Figure 2**); according to the design, each area has four replicates, while extra additional replicates were included in the design in case of time or budget availability. The comprehensive ICCAT GBYP aerial survey design for 2017 (Cañadas and Vázquez, 2017a) is available on line
http://www.iccat.int/GBYP/Documents/ASURVEY/PHASE%207/Aerial_Survey_Design_2017.pdf .

2.3 Aerial survey protocol and sighting forms

The GBYP Protocol for the Aerial Survey on Bluefin Spawning aggregations was issued for the first time in 2015 (http://www.iccat.int/GBYP/Documents/ASURVEY/PHASE%205/AERIAL%20SURVEY%20PROTOCOL%20GBYP%202015.pdf) (Anon., 2015). Due to the various practical issues and situations that were noticed over the years and particularly those aspects linked to the practical technical part of the survey, it was decided to revise and update the protocol. The revision work was done in cooperation with the GBYP Coordination Team, checking every issue and taking into account many improvements; few extreme situations noticed in previous surveys were deeply discussed and then not included, because of the very high difficulty to face them; it was decided, for all cases not included in the protocol, to discuss them in real time with the team working on field. The updated protocol

[3] The total surface of the Mediterranean Sea is about 2,500,000 km2; the areas where Bluefin tuna spawning is considered extremely unlikely to occur have been estimated by GBYP in 2014 at about 746,505 km^2; therefore, the main documented spawning areas and those where Bluefin tuna spawning may potentially and occasionally occur were estimated at about 1,753,495 km^2, while the most documented Bluefin tuna spawning areas only are about 574,378 km^2 only.

was finally accepted on 16/05/2017 and it is now available on the web (http://www.iccat.int/GBYP/Documents/ASURVEY/PHASE%207/Aerial_Survey_Protocol_2017.pdf).

This revision work was also an opportunity for revising and updating the sighting forms used on the aircrafts for reporting the field activities. The updated form now has 51 field, with a total of 172 entries and it is considered possibly the most complete available among all aerial surveys for marine animals. The sighting forms is available on the web (http://www.iccat.int/GBYP/Documents/ASURVEY/PHASE%207/Aerial_Survey_Form_2017.xlsx).

2.4 Aerial survey contracts in 2017

Thanks to the dedicated planning, this year the Call for tender (ICCAT GBYP 02/2017) for carrying out the aerial survey was issued on 20 March 2017 (prot. 436/2017) and, after the selection process, the contracts were all issued on 10 May 2017. Three companies were awarded the contracts for various areas: a Spanish company (Grup AirMed) was awarded for area A (Balearic Sea) and area E (central southern Mediterranean Sea), two Italian companies (Unimar and Aerial Banners) for areas C and a French company (Action Air Environment/Action Communication) for area G.

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. All companies received the necessary permits, even if some permits had to follow a complex procedure, due to some peculiar situations[4].

2.5 Aerial survey training course

A training course for pilots, professional spotters and scientific observers was organised at the ICCAT Secretariat in Madrid, on 15 May 2017; it was attended by 22 fellows (for the first time, including the Turkish national observer), trained by an external expert (Dr. J.A. Vázquez) and by the GBYP Coordinator. During the training course, the GBYP Coordination carried out an independent assessment of the estimation and identification capacities of each participant, using a visual tool specifically developed by GBYP. The updated ICCAT GBYP Protocol for Aerial Survey for Bluefin Tuna Spawning Aggregation (Anon., 2017), the details for filling the sighting forms and the instructions for the administrative parts were circulated among the contractors immediately after the course.

Each crew member received a formal ICCAT Identification Card, reporting his/her role in the ICCAT GBYP Aerial Survey.

2.6 The aerial survey activities in 2017

In 2017, as reported in point 2.1, the reporting strategy was fully changed compared to previous surveys, making it stricter and much faster. This new approach, which was decided by the GBYP Coordination as the best solution for facing the extremely strict schedule for providing the aerial survey data for the SCRS Bluefin tuna stock assessment session in mid-July, was clearly defined in the Call for tenders, linking the deliverables to the weekly reports and providing the same schedule, shifted by one day, to the team in charge of checking and elaborating the data. This new approach revealed to be a win-win one, because it allowed to check immediately the reports provided by each company and team, fix any possible problem in real time and include the verified data into the system for the final elaboration each week, making the final elaboration and analysis much faster than in the past.

All teams and companies provided the necessary weekly reports on time (in some special cases, the GBYP Coordination granted one extra day for providing the weekly report).

This year, due to the reduced budget, it was necessary to fit the survey effort with the available budget. Therefore, the transect length was initially set at 32,000 km, potentially allowing a maximum of four replicates in each area; according to the previous experience, this could have resulted either in more replicates if the stand-by days are nil or in less replicates if the stand-by days are higher than the forecast. This design transect length was much higher than the effective average of the previous surveys (2010, 2011, 2013, 2015) of 21,180 km.

[4] ICCAT GBYP acknowledges the very strong cooperation from the Turkish Authorities, which worked hardly for solving various problems (also linked to the official situation derived to the “emergency status”) and which were able to provide on time the national observer. The permits for the Turkish area were provided split in several individual permits.

The schedule for beginning the aerial survey was set on 29 May 2017 and the 1st of July was set as the limit for concluding the field activities. As a matter of fact, the aerial survey field activities initiated on 29 May in area E, on 30 May in areas A and C, and on June 6 in area G, due to the complexity of the permit procedures and the travel days. The survey ended on June 14 in area C, on June 26 in areas A and G and on July 2 in area E (both the initial and ending dates do not include the days needed for reaching the base airport in each area and those for returning to the home airport). Therefore, the total number of days for effectively carrying out the survey were different in each area: 29 in area A, 16 in area C, 34 in area E and 21 area G.

The aircrafts were a Partenavia P68V (GBYP ID: ICCAT 1) in area A, a Partenavia P68V (ICCAT ID: ICCAT 2), and a Partenavia P68C-TC (GBYP ID: ICCAT 6) in area C, a Partenavia P68C (GBYP ID: ICCAT 3)[5] in area E and a CESSNA 337 Sky-master push-pull (GBYP ID: ICCAT 4) in area G. Therefore, we had three areas A, C and E) covered by high-wings twin side engines aircrafts and one area (G) covered by a high-wings push-pull engines aircraft. All aircrafts have been equipped with bubble windows, two additional GPS connected to the computer and declinometers. Each crew had a professional pilot who was also a professional observer, a professional observer and two scientific observers (except in area G where a scientific observer was substituted by the Turkish national observer).

The factors affecting the survey in each area were different and **Table 1** graphically shows the activities in each area, including the days on stand-by and the motivations. In total, over 101 days of activities (29 in area A, 16 in area C, 35 in area E and 21 in area G), the number of days in stand-by was 35, equal to 34.6% against a preliminary estimation of 25%; including the days with partial activity, then the total reaches 37.5 days, equal to 37.1%. The percentage of stand-by days by area was 41% in area A, 19% in area C, 41% in area E and 29% in area G. This high number of days in stand-by was caused by many factors but mostly by the wind (30% in total), that affected several areas during this period (mostly the Balearic area and the central-southern Mediterranean Sea). This problem affected also the stabilisation of the thermocline in some parts of these areas, particularly when the wind continued over several days. Other motivations for the stand-by have been the lack of fuel in area E (a well-known recurrent problem in Malta over the years which is difficult to solve, due to the lack of Avgas in several airports close to the area or to the need of a higher rank pilot licence to land in Pantelleria, another airport where Avgas is available), accounting for 4%, the military activities in area G and some problem to the aircraft in area C (both accounting for 1% each). As a matter of fact, there was another motivation that only partly appears in **Table 1**, and this was the poor visibility in area G, which induced also to adopt a different approach for the strip size; this limited visibility, generated by a peculiar environmental situation, caused 19% of days of limited operational activity in the survey in area G.

In previous ICCAT GBYP aerial surveys, the data analyses were available usually at the end of the year (Cañadas et al., 2010a, 2010b; Cañadas and Vázquez, 2013, 2015b). For the very first time and thanks to the new strategy, it was possible to get the data elaboration report in real time (Cañadas and Vazquez, 2017b), therefore allowing for this paper to be presented to the SCRS Bluefin tuna Group two weeks after the conclusion of the field activities. **Figure 3** shows the transects that were effectively surveyed on effort and the tracks off efforts, including the logistic flights linked to the transects.

In general, in 2017, the aerial survey worked much better than in all previous years, from all points of view and besides the usual problems. At the beginning it was necessary to discuss and solve the problems with the national authorities concerned; the problems were related to the permits in three FIRs, the potential security risks in three areas, the potential problems linked to possible interferences with rescue of migrants in one area and with military activities and operations in two areas, but at the end everything was solved by the GBYP Coordination working together side-by-side with the contracted companies concerned. The problems during the field activities were discussed and solved in real time.

The coverage was very good in all areas (**Table 2**), for a total of 265,626 km^2, even if it was not possible to reach the total length of the transects set at the beginning, due to several motivations. As a matter of fact, at the end the final effective transect length was 21,178 km, equal to the average in previous surveys. This evidence confirms again the right choice of limiting the survey to the four overlapping areas for getting comparable and standardised results. In 2017, according to the parameters and diagnostics of the detection function, the effective strip width was defined at 1.4 km in all areas.

[5] Due to a problem in the fuel reservoir at the first part of the survey in area C, it was necessary to substitute the aircraft with the reserve one.

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

To explore the effects of both the environmental and the survey factors on the probability of detection function and therefore on the estimates of abundance, an analysis of each level of the variables was performed and the results were compared. The final model of the detection function selected was the null model with a Hazard-rate key function. There was a model with the lowest AIC which had two covariates (subarea and glare30) with a Hazard-rate key function. However, all diagnostics were better for the null model, the CV of the estimate was lower and the point estimate was very similar. Therefore, the simplest model was chosen. The Kolmogorov-Smirnov and the Cramer-von Mises tests performed very well and overall there were no significant differences between the cumulative distribution function (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.

The map showing the distribution of the Bluefin tuna sightings by area, on effort and off effort, during the survey in 2017, is provided by **Figure 4**.

The weather and oceanography conditions are extremely important for the aerial survey, particularly in the Mediterranean Sea, where oceanography factors are essential components for 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; these conditions may clearly affect the operational side of the survey. At the same time, the oceanography is quite complex as well, with effects on the distribution and reproductive biology and behaviour of the Bluefin tuna, and this year it revealed a further interesting change in the distribution and concentration of the Bluefin tuna schools.

For this reason, the GBYP staff monitored every day SST, waves and wind[6], but also salinity, currents and anomalies, as it was done in the past, quite often checking in real time the maps available on the web by contacting several people in various sites. **Figure 5** shows the situation during the aerial survey in 2017, using three colours: red for bad weather conditions or for fully unsuitable oceanographic conditions for Bluefin tuna spawning Piccinetti *el al*., 2013), 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 44.6% of the days during the full extension of the aerial survey period (28 May – 3 July). Negative conditions were there for 23.6% of the time, while problematic conditions affected 31.8% of the days, meaning that during these days there were zones where it was possible to carry out the survey and zones where it was not possible, sometimes within the same area. When we take into account the effective days in which the aerial survey was carried out in each area, then average good conditions were present in 53% of the days during the effective aerial survey period. Negative conditions were there for 12% of the time, while problematic conditions affected 37% of the days. Potentially, during the full period the best conditions were in both area C and area G, while taking into account the effective days, the best conditions were surely in area C, with no negative or problematic days.

Here following there are some observations about the survey activity in each area.

Area A (Balearic Sea)

The aerial survey in area A was initially considered as one of the easiest, due to the fact that the area is well-known and that the team was almost the same one that was already engaged in all previous surveys. As a matter of fact, this year the situation was different and much more problematic.

For the first time, we have been notified about some preliminary problems with the permits, even if the aircraft was Spanish and the airspace is Spanish as well. Possibly, these problems were linked to new security requirements and controls, but luckily the problems were solved.

[6] 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 major problem which limited the survey in the area was the wind, which affected in various ways the survey in various parts of the area, fully preventing the survey during 12 days (41% of stand-by days against a prevision of max 25%) (**Table 1**). Looking in details at the conditions in Area A (**Figure 5**), it is evident that the waves were present (at least in some parts of the Balearic area) during many days, while the temperature was also colder than usual up to June 10, then reaching unusual high temperatures (28°C) on June 22; in both cases, theoretically the low and high temperatures were not suitable for the Bluefin tuna spawning. According to the data showed on **Figure 6**, good conditions were present in Area A just in 29% of the days during the effective aerial survey period; negative conditions were there for 10% of the time, while problematic conditions affected 69% of the days. Considering the full extended period (28 May to 3 July), the situation was potentially even worse, with 62% of problematic conditions, 14% of negative conditions and only 24% days of favourable conditions. Due to the complex environment, to the above mentioned situations and the presence of the islands (with the implicit complex oceanography and climate), it is reasonable that the Bluefin tuna spawning season in the Balearic area was much more concentrated during this part of the season, possibly delayed by a couple of weeks in some areas of the Balearic Sea, but at the same time quite good, due also to the low presence of jellyfish aggregations.

As concerns the survey activity, besides the unfavourable conditions during several days, it was possible to cover the full area, even if the adverse conditions and the high number of stand-by days prevented to carry out all replicas included in the design (**Figure 7**). Therefore, the total transect length on effort (4,981 km) was lower than the average in previous surveys but anyway higher than the last survey in 2015 (**Table 4**). The effective strip width (1.4 km) was quite reduced, due to the unfavourable conditions and the limited visibility in some days, and this resulted also in a reduced surface of effective area surveyed (7,017 km^2), equal to 11.3% of the total area surface, the lowest percentage so far. Besides these constraints, the abundance of Bluefin tuna schools in the area was very high (95), almost the double than the average, and the encounter rate of schools was the highest so far, along with the density of schools, that are in both cases more than the double of the average. The density of Bluefin tuna was also very high. Several additional sightings of Bluefin tuna schools were noticed off-effort. The total weight of Bluefin tuna in area A resulted in 12,693 tons, the highest value so far for this area, about three times than in 2015, as well as the total abundance of individuals, assessed in 71,520. The CVs of some data were affected by the great variability of the sightings, sometimes unusually related to single individuals.

The fact that the encounter rates and final estimates are much higher in 2017 than in all previous surveys, even if with less effort than in most of the previous surveys, indicates that there was a real increase of Bluefin tuna in area A in 2017 respect the previous 4 surveys.

Area C (southern Tyrrhenian Sea)

The aerial survey in area C was initially considered as one of the easiest, due to the fact that the area is well-known (possibly the most surveyed in the last three decades) and that the team was almost the same one that has already been engaged in all previous surveys. As a matter of fact, the forecast was correct. There were no problems with the flight permit, also because this airspace is fully Italian and the aircrafts were Italian as well.

The only problem that was noticed during the survey happened to the first aircraft and it was a technical problem in the fuel system, but which caused one day of limited activity, one day in stand-by and the need to substitute the aircraft with the reserve one, of the same type (it was just a slightly different version). In two other days, the wind forecast was negative and it was decided not to take-off, finally accounting for a total of 3 stand-by days (18.7% days of stand-by days against a prevision of max 25%, but the total reach 3.5 days when considering one day of limited activity, therefore reaching 21.9%) (**Table 1**). Looking in details at the conditions in Area C (**Figure 5**), it seems that even in the two days when the local wind forecast was negative, the sea conditions have been good, therefore the conditions for the effective period were potentially 100% good (**Figure 6**). Just after the end of the aerial survey in area C, we noticed a huge hot water mass in all the southern Tyrrhenian Sea, with very high temperatures in the SE part, reaching a SST of over 27°C on 17 and 18 June and a peak of 29°C on June 30 and July 1; these temperatures are sometimes present in the southern Tyrrhenian Sea, but usually in the last part of July and they are considered too high for allowing the Bluefin tuna spawning. According to the data showed on **Figure 6** and considering the full extended period (28 May to 3 July), area C potentially 35% of negative conditions, 11% of problematic conditions and 54% days of favourable conditions. Therefore, we have been lucky that the survey in this area has been completed in a very short time, before the negative conditions arrived. Due to the high temperatures from the second part of June, it is possible that the Bluefin tuna spawning season was between mid-May to about mid-June. Even in this area, there are no reports of any concentration of jellyfish during the spawning season.

As concerns the survey activity, due to the good conditions, it was possible to fully complete all transects and replicas included in the design, and then cover the full area (**Figure 8**). Therefore, the total transect length on effort (4,911 km) was higher than in the previous last two surveys, but slightly lower than the average in previous surveys, due to the higher number of replicas in the first two surveys (**Table 5**), allowed by a higher budget at that time. The effective strip width (1.4 km) was quite reduced, due to the parameters used in the detection function and this resulted in a reduced surface of effective area surveyed (6,918 km^2), equal to 12.8% of the total area surface, the lowest percentage so far. Besides these constraints, the abundance of Bluefin tuna schools in the area was very high (15), almost the double than the average, and the encounter rate of schools was the second highest so far, along with the density of schools, that are in both cases about the double of the average. The density of Bluefin tuna was the highest so far. The total weight of Bluefin tuna in area C resulted in 11,547 tons, the highest value so far for this area, about three times the average and more than 4 times than the value in 2015, as well as the total abundance of individuals, assessed in 82,886, which was the double of the average and more than 4 times than the value in 2015. The spotting of Bluefin tuna schools off-effort was limited to one single school. The CVs in 2017 have been in general the lowest for the large majority of the data sets obtained by the survey. The increased presence in area C in 2017 is remarkable, and only comparable with the data obtained in 2013. The high presence of Bluefin tuna in the southern Tyrrhenian Sea has been also confirmed by the concentration of purse-seines fleets of several CPCs in this area in the fishing season 2017.

Area E (central-southern Mediterranean Sea)

The aerial survey in area E was always considered a challenge for various reasons: the complex meteorology of the area, which is subject to rapid changes, the oceanography, which is showing a remarkable variability in the last decade, the very difficult emergencies of various types in the southern part of the area, the impossibility to access some airspaces, the potential interferences with military or rescue operations, the low availability of fuel and the lack of the proper fuel in several airports which can be used for the survey, etc. As a matter of fact, in 2017 we faced again most of the challenges, but finally it was possible to carry out the survey. At the early beginning, there was a problem with the flight permit in one airspace, but then it was rapidly solved, thanks to the real-time intervention of the GBYP Coordination.

The major problem which limited the survey in the area was the wind, which affected in various ways the survey in various parts of the area, fully preventing the survey during 10 days. Another major problem was the lack of fuel (Avgas) at the airport in Malta; the late information did not allow to move the aircraft to another airport and therefore it remained for 4 days in stand-by. In total, even in area E, we had 40% days of stand-by against a prevision of max 25% (**Table 1**). Looking in details at the conditions in Area E (**Figure 5**), it is evident that the waves were present (at least in some parts of the central-southern Mediterranean Sea) during many days, while the temperature was also colder than usual up to June 9. It is very possible that the combination of temperatures colder than usual and winds in some parts of area E prevented the formation of a stable and suitable thermocline, therefore possibly affecting the suitable spawning conditions for Bluefin tuna in parts of area E. According to the data showed on **Figure 6**, good conditions were present in Area E in 50% of the days during the effective aerial survey period; negative conditions were there for 9% of the time, while problematic conditions affected 41% of the days. Considering the full extended period (28 May to 3 July) which, in this area, was very close to the effective period, the situation was potentially even worse, with 43% of problematic conditions, 11% of negative conditions and 46% days of favourable conditions.

As concerns the survey activity, it was possible to cover the full area, but not with the full number of replicas included in the design (**Figure 9**), due to the above mentioned constraints, which also forced to use the full available period of time and even to apply for a short extension. Therefore, the total transect length on effort (6,705 km) was higher that the two last surveys, but slightly lower than the average (**Table 6**). The effective strip width (1.4 km) was quite reduced, due to the parameters used in the detection function and this resulted in a reduced surface of effective area surveyed (9,466 km^2) was the lowest of all surveys, equal to 10.1% of the total area surface, the lowest percentage so far. The abundance of Bluefin tuna schools in the area was very low (9), even if it was three times the one reported in 2015, but it was anyway about 42% of the average; is mirroring this, as well as the density of schools. The density of Bluefin tuna was the second lowest so far, even if about four times higher than in 2015. The estimated total weight of Bluefin tuna in area E resulted in 4,457 tons, higher than in the last two surveys, but about 42% of the average. The total abundance of individuals, assessed in 36,927, was about just 27% of the average, even if it was more than three times higher than the last survey in 2015. The CVs in 2017 have been variable, depending on the type of parameter taken into account, but they have been all much lower than in 2015. The observations of Bluefin tuna in off-efforts conditions in area E have been minimal. The low availability of Bluefin tuna in several parts of area E in 2017 was also confirmed by the movements of various purse-seiners fleets, which had left the area after the first days of unsuccessful searching.

Area G (Levantine Sea)

The aerial survey in area G, again, was always considered a challenge for various reasons: the oceanography, which is usually characterised by an early increase of the SST and even in the water masses, which usually induce an early spawning activity for the Bluefin tuna in this area, the weather conditions, because the wind can affect some areas in several days, the complex procedures to get some flight authorisations, the impossibility to access some airspaces, the uncertain definition of some areas where bilateral agreements are lacking, the potential interferences with military operations, etc. As a matter of fact, in 2017 we faced again all the challenges, but finally it was possible to carry out the survey, with the exception of two small areas for security motivations (this exclusion was discussed before initiating the survey and it was decided that the survey would not be too much affected). At the early beginning, there was a problem with the flight permits, but then it was rapidly solved, thanks to the real-time intervention of the GBYP Coordination and the strong cooperation of the Turkish authorities and the EU authorities. Furthermore, for the first time, and thanks again to the support of the Turkish authorities, it was possible to have all spotters on board duly trained by the GBYP, including the national observer. Even is some operational problems happened during the survey, the survey in this area in 2017 should be regarded as a positive one.

The major problems which limited the survey in the area were the meteorological conditions, because not only there were 5 days of wind which prevented the flights, but there was also a peculiar situation, which affected many days of survey: the very limited visibility at sea due to the brumes. This anomalous situation was induced by the high temperatures, the lack of wind and the very high humidity, all combined together; even if the visibility communicated by the control towers in the various airports was more than 10 km, at sea the real visibility was usually close to 1.2 km. After discussing in real time with the team in charge of the analyses, it was decided to go on, accurately noting the real visibility on the sighting forms. Anyway, this specific situation caused four days of limited survey activity. The military activities in the area resulted in one day of stand-by. In total, in area G, we had 28.6% of stand-by days against a prevision of max 25% (**Table 1**), but without considering the other 19% of days with reduced activity. Looking in details at the conditions in Area G (**Figure 5**), it is evident that the waves were present (at least in some parts of the Levantine Sea) during just 4 days, while the temperature was also slightly colder than usual at the beginning of the season, but then it went over >27°C on June 16 for several days for then reaching higher temperatures at the very end of June and in the first days of July. According to the data showed on **Figure 6**, good conditions were present in Area G in 57% of the days during the effective aerial survey period; negative conditions were there for 29% of the time, while problematic conditions affected 14% of the days. Considering the full extended period (28 May to 3 July), the situation was potentially slightly worse, with 54% of favourable conditions, 11% of problematic conditions and 35% of negative conditions.

As concerns the survey activity, it was possible to cover almost the full area included in the design (**Figure 10**), except the two small areas excluded by the permit and one transect for logistic problems. Therefore, the total transect length on effort (4,581 km) was the highest so far, about the double of the average (**Table 7**). The effective strip width (1.4 km) was quite reduced, due very low visibility in several days (as described above) and to the parameters used in the detection function, and this resulted in a reduced surface of effective area surveyed (6,453 km^2), which was anyway the second highest and in the average. The abundance of Bluefin tuna schools in the area was the highest so far (191), about the double of the average and more than 8 times higher than the results in 2015, as mirrored also by the density of schools. The density of Bluefin tuna was also the highest so far, eleven times higher than in 2015 and more than the double of the average (but data are not available for the first two years). The estimated total weight of Bluefin tuna in area G resulted in 3,157 tons, much higher than in the last two surveys, and close to the average. The total abundance of individuals, assessed in 159,939, was again the highest so far and more than the double of the average. The CVs in 2017 are quite low compared with the previous ones, except for some in 2010. The observations of Bluefin tuna in off-efforts conditions in area G have been many, further confirming the abundance of the species in this area in 2017.

3. Discussion

As reported in the previous paragraphs, the relevant improvements in the survey and data reporting and analysis strategy in 2017 resulted in much more coherent and better estimates. As said before, the exclusive use of overlapping areas for carrying out the survey, the mandatory weekly reporting, the weekly check of the data, the improved training course, the improved and updated protocol resulted all together in the easier elaboration of the data and in a very short time for getting the final results.

The combined data for the four areas surveyed in 2017 are shown on **Table 8** and it is very clear that the aerial survey in 2017 worked very well, even taking into account the reduced budget availability, which imposed a reduced number of replicas compared to years when the budget was much higher, and considering also the unfavourable weather conditions in some areas, which limited both the operations and the effective strip width. Besides the practical problems, most of which are unpredictable but always within the usual *alea* of a wide field activity, the activity this year has been a win-win one.

The results show that the total survey area was equal to 265,627 km^2, for a final effective transect length of 21,178 km and a total effective area searched of 29,834 km2. This last number is just the result of the reduced effective strip width (1.4 km, imposed mostly by the reduced visibility in one area), because, as a matter of fact, the searched area was much larger. The number of Bluefin tuna schools detected on effort (91) has been the highest so far, confirming a good presence of the species.

The abundance of schools (387) was one of the highest so far, almost the same than the highest value (388) registered in 2011 and much higher than the average. The encounter rate of schools (0.0043) was the highest so far, about the double than the average. The density of schools (1.457/1000 km^2) has been the second highest so far, well over the average. The mean weight of the schools was 82.3 tons, below the average, for a high presence of young spawners. The density of animals (1.304 km2) has been the second highest, even in this case over the average. The main parameters, the total weight (31,855 tons) and the total abundance of fish (n=346,272) have been both the second highest so far, well over the average (**Figure 11** graphically shows the results in all surveys for the density of fish and schools, the total abundance and the total weight).

As described in the previous chapter, a shifting of presence was noticed in 2017, about the opposite of what it was noticed in 2006 (Di Natale, 2008) and, at that time, the anomaly was motivated with a drastic change in the Eastern Mediterranean Transient (EMS). As a matter of fact, the presence in the central-southern Mediterranean Sea decreased in a remarkable manner, while a parallel increase was noticed in the southern Tyrrhenian Sea (but also in the other areas) (**Table 9**). This fact was noticed not only by the ICCAT GBYP aerial survey, but it was confirmed also by the adaptation of the fishing strategy of the purse-seiner fleets in the same days. What are the conditions which caused this shifting of presence? We cannot provide a response at the moment, even if many oceanographers have been contacted, because the analyses of the data collected in 2017 will be available at the end of the year. At the same time, as mentioned in chapter 2.6, some important anomalies have been noticed in real time in 2017. The SST showed anomalous high data in several parts of the central and western Mediterranean Sea, while the Levantine Sea and the Gulf of Sirte did not show hot temperatures (**Figures 12** and **13**). This is a fact, but if this was one of the causes which induced a different concentration of Bluefin tunas during the spawning season in 2017 is not defined.

Was this shifting in presence someway linked to the about two-weeks anticipated arrival of Bluefin tunas in all traps (both in the eastern Atlantic Ocean or in the Mediterranean Sea) in 2017? Even in this case, besides the fact that the western and central areas of the Mediterranean had some high temperature anomalies in mid-April, we don’t have any answer at the moment.

In general, 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, 2016), but also for the many difficulties for operating in a so large area and so many aerial spaces managed by so many countries. This activity implies also that several aircraft and spotters have to 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 a 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, while, in the reality, the random factor plays a very important role, which is not fitted in the function. In this last survey, the situation was better than most of the previous ones and therefore the fitted detection function, combining all areas, fitted much better than in the past (**Figure 14** shows the fitted detection function in 2017 and **Figure 15** shows the Q-Q plot; **Figure 16** shows the fitted detection function in 2010, 2011, 2013 and 2015).

For the aerial surveys, in general and in the reality, it is not possible to assume that the detection function is certain, 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 spends a variable part of its time beneath the surface and, in this case, it is unavailable for the detection (the so-called availability bias) (Quilez Badía *et al*., 2016). This latter 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. **Table 10** and **Figure 17** show the average percentage of time spent by the Bluefin tuna between 0 and 10 meters[7] depth during the various months. the data are obtained from the PSATs deployed by ICCAT GBYP between 2011 and 2015 (Tensek *et al*., 2017), updated with the data obtained from the electronic tags deployed in 2016 and up to 2017; the data taken into account are only those related to the Mediterranean Sea. Applying these percentages (accounting for the average May-June-July, equal to 60.03, which correspond to an increasing factor of about 160%) to the two main parameters, the total weight and the total number of fish, then the estimated values should be 50,968 tons and 554,035 fish in just the four areas taken into account. The trend is the same but the levels are different. 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 (should be usual the same), areas surveyed (now we are working only on standardised overlapping areas), and stability of availability and perception biases. Availability and perception bias can be reasonably assumed as almost stable over time, but the knowledge of the distribution in time and space of the Bluefin tuna throughout the Mediterranean Sea is still incomplete and subject to variables which are 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.

Again, it is very clear that, due to the high interannual variability between the four main spawning areas in the Mediterranean Sea, any type of fishery-independent trend cannot be based on one single area, because the bias could be huge and fully undefined, while it should be based on at least the four main areas.

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[7] Even in this case, the limits are very prudential, because with a good water transparency, the spotters are quite used to estimate the schools of Bluefin tunas at greater depths.

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Table 1. General overview of the field activities by area, including the motivations for stand-by.

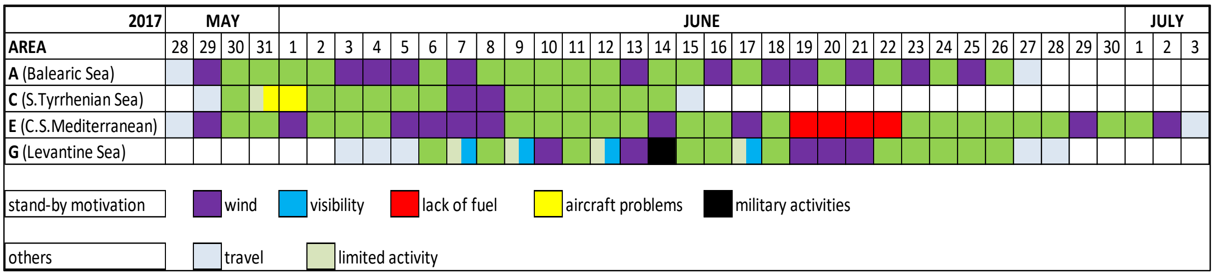


Table 2. Areas, number and total length of transects and number of sightings of Bluefin tuna for each surveyed sub-area.

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

Table 3. Parameters and diagnostics of the detection function for the ICCAT GBYP Aerial Survey in 2017.

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

Table 4. Survey details for the surveys carried out so far in Area A (Balearic Sea). All data are only related to the same overlapping surface and to on-effort results, excluding the off-effort data.

Year	2010	2011	2013	2015	2017	Total (sum)	Total (mean)
Survey area (km^2)	61,933	61,933	61,933	61,933	61,933	309,665	61,933
Transect length (km)	6,118	7,838	6,807	4,109	4,981	29,852	5,970
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	1.4		2.52
Area searched (km^2)	18,130	10,660	20,398	15,961	7,017	72,166	14,433
% coverage	29.3	17.2	32.9	25.8	11.3		23.3
Number of schools ON effort	8	10	10	6	22	56	11.2
Abundance of schools	25	58	30	23	95	231	46
%CV abundance of schools	55.4	35.9	36.1	43.4	30.8		
Encounter rate of schools	0.0013	0.0013	0.0015	0.0014	0.0044		0.00198
%CV encounter rate	54.5	33.8	35.1	41.1	25.9		
Density of schools (1000 km^{-2})	0.402	0.938	0.490	0.372	1.531		0.747
%CV density of schools	55.4	35.9	36.1	43.4	30.8		
Mean weight (t)	131.25	122.43	194.1	160.7	133.9		148.462
%CV weight	6.2	19.2	23.8	11.7	34.9		
Mean cluster size (animals)		678.1	611	825	754		717
%CV abundance		27.9	26.0	11.0	33.6		
Density of animals (km^{-2})		0.636	0.299	0.307	1.155		0.599
%CV density of animals		45.4	44.5	44.7	39.7		
Total weight (t)	**3,587**	**4,371**	**3,539**	**4,712**	**12,693**		**5,780**
%CV total weight	56.5	46.2	40.6	42.0	40.9		
L 95% CI total weight	1,251	1,807	1,624	2,132	5,848		
U 95% CI total weight	10,285	10,577	7,710	10,414	27,551		
Total abundance (animals)		**39,399**	**18,542**	**19,002**	**71,520**		**37,116**
%CV total abundance		45.4	44.5	44.7	39.7		
L 95% CI total abundance		16,540	7,913	8,195	33,620		
U 95% CI total abundance		93,850	43,445	44,060	152,141		

Table 5. Survey details for the surveys carried out so far in Area C (southern Tyrrhenian Sea). All data are only related to the same overlapping surface and to on-effort results, excluding the off-effort data.

Year	**2010**	**2011**	**2013**	**2015**	**2017**	**Total (sum)**	**Total (mean)**
Survey area (km^2)	53,868	53,868	53,868	53,868	53,868	269,340	53,868
Transect length (km)	8,487	8,826	2,791	2,739	4,911	27,754	5,550
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	1.4		2.52
Area searched (km^2)	25,150	12,004	8,364	10,640	6,918	63,076	12,615
% coverage	46.7	22.3	15.5	19.8	12.8		23.4
Number of schools ON effort	6	10	10	3	15	44	8.8
Abundance of schools	12	45	64	13	57		38
%CV abundance of schools	45.7	33.4	34.3	62.0	28.8		
Encounter rate of schools	0.0007	0.0011	0.0036	0.0009	0.0031		0.0016
%CV encounter rate	44.6	31.2	33.1	60.5	23.6		
Density of schools (1000 km^{-2})	0.217	0.833	1.196	0.239	1.058		0.709
%CV density of schools	45.7	33.4	34.3	62.0	28.8		
Mean weight (t)	124.17	38.87	173.5	190.0	202.5		145.808
%CV weight	5.6	44.4	22.1	19.9	21.9		
Mean cluster size (animals)	733	291	1,285	1,533	1,453		1,059
%CV abundance	36.5	30.7	17.0	19.0	17.2		
Density of animals (km^{-2})	0.182	0.242	1.536	0.366	1.539		0.773
%CV density of animals	59.2	45.3	38.3	64.9	33.3		
Total weight (t)	**1,596**	**1,917**	**11,370**	**2,665**	**11,547**		**4,387**
%CV total weight	46.9	54.9	40.8	65.1	35.5		
L 95% CI total weight	652	661	5,161	802	5,829		
U 95% CI total weight	3,904	5,557	25,049	8,856	22,874		
Total abundance (animals)	**9,797**	**13,059**	**82,763**	**19,708**	**82,886**		**41,643**
%CV total abundance	59.2	45.3	38.3	64.9	33.3		
L 95% CI total abundance	3,187	5,446	39,399	5,958	43,597		
U 95% CI total abundance	30,016	31,317	173,860	65,192	157,580		

Table 6. Survey details for the surveys carried out so far in Area E (central-southern Mediterranean Sea). All data are only related to the same overlapping surface and to on-effort results, excluding the off-effort data.

Year	**2010**	**2011**	**2013**	**2015**	**2017**	**Total (sum)**	**Total (mean)**
Survey area (km^2)	93,614	93,614	93,614	93,614	93,614	468,070	93,614
Transect length (km)	13,137	10,192	4,381	2,566	6,705	36,981	7,396
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	1.4		2.52
Area searched (km^2)	38,930	13,862	13,129	9,969	9,446	85,335	17,067
% coverage	41.6	14.8	14.0	10.6	10.1		18.2
Number of schools ON effort	29	45	20	3	9	106	21.2
Abundance of schools	63	304	135	20	44		113
%CV abundance of schools	31.5	24.1	34.8	58.0	36.4		
Encounter rate of schools	0.0022	0.0044	0.0046	0.0008	0.0013		0.0029
%CV encounter rate	29.9	21.0	33.6	56.3	32.4		
Density of schools (1000 km^{-2})	0.678	3.246	1.447	0.213	0.466		1.210
%CV density of schools	31.5	24.1	34.8	58.0	36.4		
Mean weight (t)	110.14	118.05	11.0	50.2	102.3		78.338
%CV weight	33.9	19.2	66.0	99.5	51.2		
Mean cluster size (animals)	1,015	1,715	361	507	848		889
%CV abundance	19.0	21.5	67.3	97.9	33.2		
Density of animals (km^{-2})	0.787	5.566	0.522	0.108	0.395		1.476
%CV density of animals	37.8	32.3	75.7	113.8	49.9		
Total weight (t)	**7,681**	**37,851**	**1,517**	**1,093**	**4,457**		**10,520**
%CV total weight	47.1	32.2	74.6	115.2	63.4		
L 95% CI total weight	3,155	20,342	390	75	1,413		
U 95% CI total weight	18,698	70,432	5,899	15,857	14,062		
Total abundance (animals)	**73,676**	**521,085**	**48,884**	**10,126**	**36,927**		**138,140**
%CV total abundance	37.8	32.3	75.7	113.8	49.9		
L 95% CI total abundance	35,741	279,620	12,363	727	14,559		
U 95% CI total abundance	151,880	971,060	193,280	141,020	93,662		

Table 7. Survey details for the surveys carried out so far in Area G (Levantine Sea). All data are only related to the same overlapping surface and to on-effort results, excluding the off-effort data.

Year	**2010**	**2011**	**2013**	**2015**	**2017**	**Total (sum)**	**Total (mean)**
Survey area (km²)	56,211		56,211	56,211	56,211	224,844	56,211
Transect length (km)	3,790		2,081	859	4,581	11,311	2,827
Effective strip width x2 (km)	2.96		3.00	3.9	1.4		2.81
Area searched (km²)	11,231		6,236	3,335	6,453	27,256	6,814
% coverage	20.0		11.1	5.9	11.5		12.1
Number of schools ON effort	33		12	2	45	92	23
Abundance of schools	150		108	22	191		118
%CV abundance of schools	28.1		39.7	70.9	23.5		
Encounter rate of schools	0.0087		0.0058	0.0015	0.0098		0.0081
%CV encounter rate	26.3		38.7	69.5	16.6		
Density of schools (1000 km⁻²)	2.674		1.924	0.399	3.398		2.099
%CV density of schools	28.1		39.7	70.9	23.5		
Mean weight (t)	63.621		4.0	9.0	16.5		23.280
%CV weight	12.7		40.2	66.7	31.5		
Mean cluster size (animals)			336	600	809		582
%CV abundance			36.7	66.7	31.9		
Density of animals (km⁻²)			0.646	0.239	2.756		1.214
%CV density of animals			54.1	97.3	40.1		
Total weight (t)	**10,507**		**440**	**220**	**3,157**		**3,581**
%CV total weight	32.1		56.5	97.3	39.3		
L 95% CI total weight	5,643		151	25	1,495		
U 95% CI total weight	19,561		1,285	1,965	6,669		
Total abundance (animals)			**36,316**	**13,448**	**154,939**		**68,234**
%CV total abundance			54.1	97.3	40.1		
L 95% CI total abundance			12,995	1,506	72,366		
U 95% CI total abundance			101,490	120,070	331,731		

Table 8. Results for all ICCAT GBYP aerial surveys in all overlapping areas combined.

Year	**2010**	**2011**	**2013**	**2015**	**2017**	**Total (sum)**	**Total (mean)**
Survey area (km^2)	265,627	209,416	265,627	265,627	265,627	1,288,135	265,627
Transect length (km)	31,532	26,856	16,060	10,272	21,178	105,898	21,173
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	1.4		2.52
Area searched (km^2)	93,442	36,525	48,127	39,904	29,834	166,041	33,208
% coverage	35.2	17.4	18.1	15.0	11.2		12.89
Number of schools ON effort	76	65	52	14	91	298	59.6
Abundance of schools	250	388	338	78	387		288
%CV abundance of schools	22.8	19.9	21.5	38.9	20.2		
Encounter rate of schools	0.0024	0.0024	0.0032	0.0014	0.0043		0.0028
%CV encounter rate				20.2	11.6		
Density of schools (1000 km^{-2})	0.942	1.852	1.274	0.295	1.457		1.086
%CV density of schools	22.8	19.9	21.5	38.9	23.4		
Mean weight (t)	87.9	101.1	22.6	272.2	82.3		113.212
%CV weight	16.8	27.5	51.0	41.4	19.2		
Mean cluster size (animals)	791	1,275	582	1,548	895		1018
%CV abundance	18.6	37.3	18.5	40.5	17.0		
Density of animals (km^{-2})		**2.7388**	**0.702**	**0.234**	**1.304**		**1.245**
%CV density of animals		29.9	29.4	39.1	25.9		
Total weight (t)	**23,371**	**44,139**	**16,866**	**8,690**	**31,855**		**24,984**
%CV total weight	25.6	28.7	30.3	35.3	26.7		
L 95% CI total weight	14,243	25,315	9,343	4,398	19,018		
U 95% CI total weight	38,347	76,964	30,447	17,169	53,355		
Total abundance (animals)		**573,543**	**186,505**	**62,284**	**346,272**		**292,151**
%CV total abundance		29.9	29.4	39.1	25.9		
L 95% CI total abundance		321,620	105,320	28,766	209,816		
U 95% CI total abundance		1,022,800	330,270	134,860	571,473		

Table 9. Results for all ICCAT GBYP aerial surveys in all overlapping areas and in total in 2017.

Year	A	C	E	G	Total (sum)	Total (mean)
Survey area (km^2)	61,933	53,868	93,614	56,211	265,627	
Transect length (km)	4,981	4,911	6,705	4,581	21,178	
Effective strip width x2 (km)	1.4	1.4	1.4	1.4		1.4
Area searched (km^2)	7,017	6,918	9,446	6,453	29,834	
% coverage	11.3	12.8	10.1	11.5	11.2	
Number of schools ON effort	22	15	9	45	91	22.8
Abundance of schools	95	57	44	191	387	96.8
%CV abundance of schools	30.8	28.8	36.4	23.5	20.2	
Encounter rate of schools	0.0044	0.0031	0.0013	0.0098		0.0043
%CV encounter rate	25.9	23.6	32.4	16.6		11.6
Density of schools (1000 km^{-2})	1.531	1.058	0.466	3.398		1.457
%CV density of schools	30.8	28.8	36.4	23.5		23.4
Mean weight (t)	133.9	202.5	102.3	16.5		82.3
%CV weight	34.9	21.9	51.2	31.5		19.2
Mean cluster size (animals)	754	1,453	848	809		895
%CV abundance	33.6	17.2	33.2	31.9		17.0
Density of animals (km^{-2})	1.155	1.539	0.395	2.756		**1.304**
%CV density of animals	39.7	33.3	49.9	40.1		25.9
Total weight (t)	**12,693**	**11,547**	**4,457**	**3,157**	**31,855**	
%CV total weight	40.9	35.5	63.4	39.3	26.7	
L 95% CI total weight	5,848	5,829	1,413	1,495	19,018	
U 95% CI total weight	27,551	22,874	14,062	6,669	53,355	
Total abundance (animals)	**71,520**	**82,886**	**36,927**	**154,939**	**346,272**	
%CV total abundance	39.7	33.3	49.9	40.1	25.9	
L 95% CI total abundance	33,620	43,597	14,559	72,366	209,816	
U 95% CI total abundance	152,141	157,580	93,662	331,731	571,473	

Table 10. Mean percentage of time spent in the Mediterranean Sea between the sea surface 10 meters depth, of all Bluefin tuna that were tagged by GBYP between 2011 and 2016 (data up to 2017), by month (from: Tensek *et al*., 2017, updated).

Month	Mean time spent at 0-10 m depth (%)
January	42,33%
February	38,59%
March	41,78%
April	50,12%
May	63,03%
June	56,02%
July	61,05%
August	54,03%
September	49,30%
October	47,41%
November	43,21%
December	40,72%
Total	53,02%

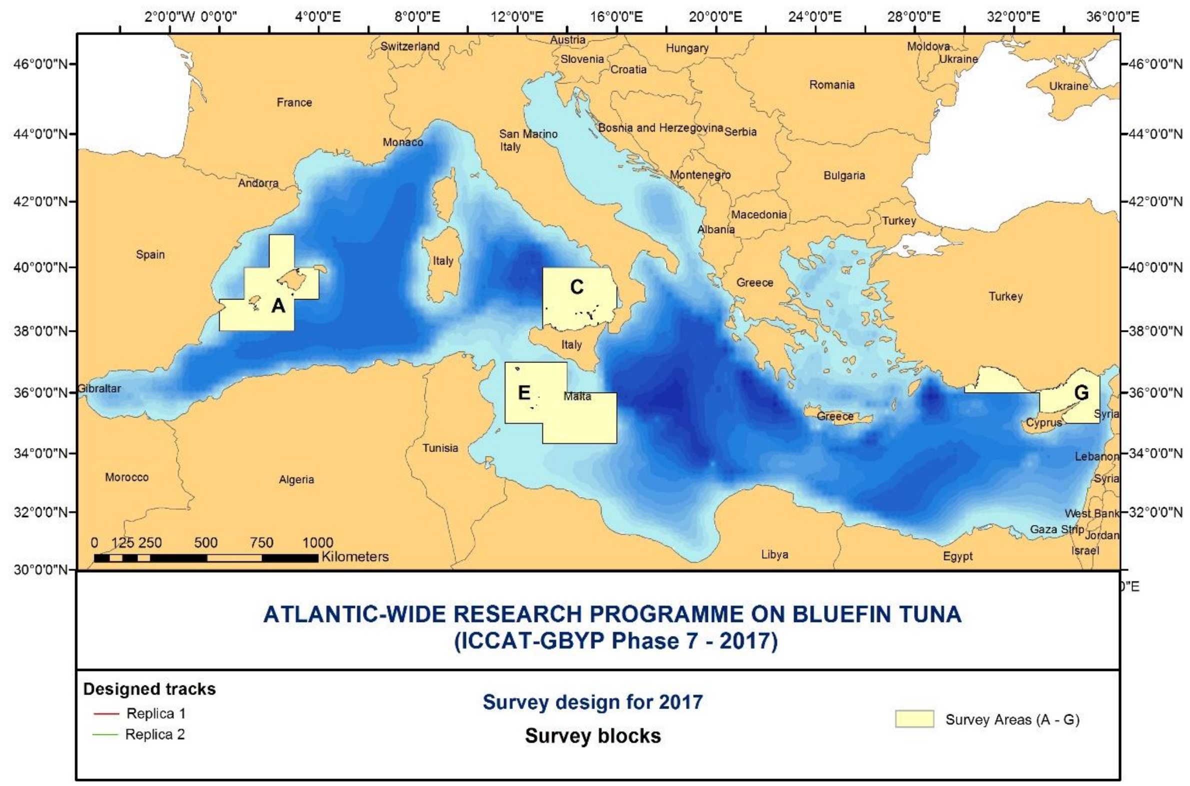


Figure 1. The four areas identified for the aerial survey in 2017. They correspond to the overlapping areas in all previous surveys and to the most important Bluefin tuna spawning areas in the Mediterranean Sea.

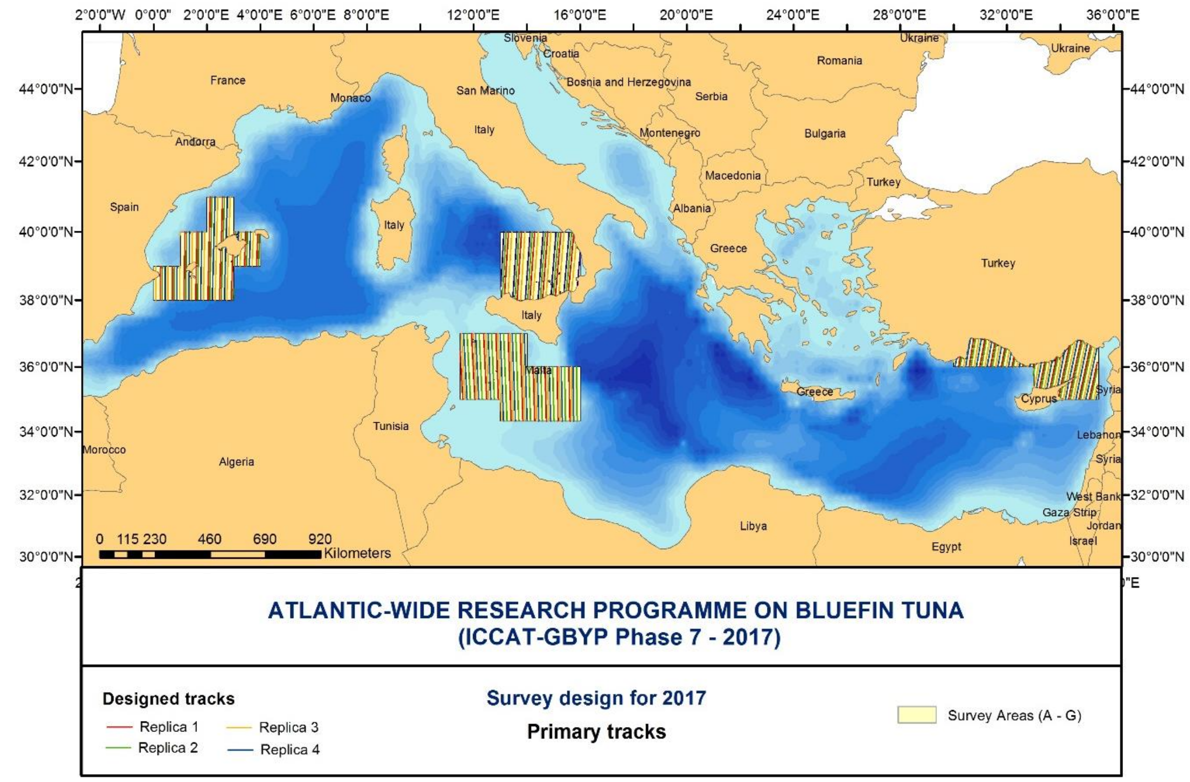


Figure 2. The transect design for the four areas to be surveyed by GBYP in 2017. Each area has four replicates, while extra replicates are not showed on this figure.

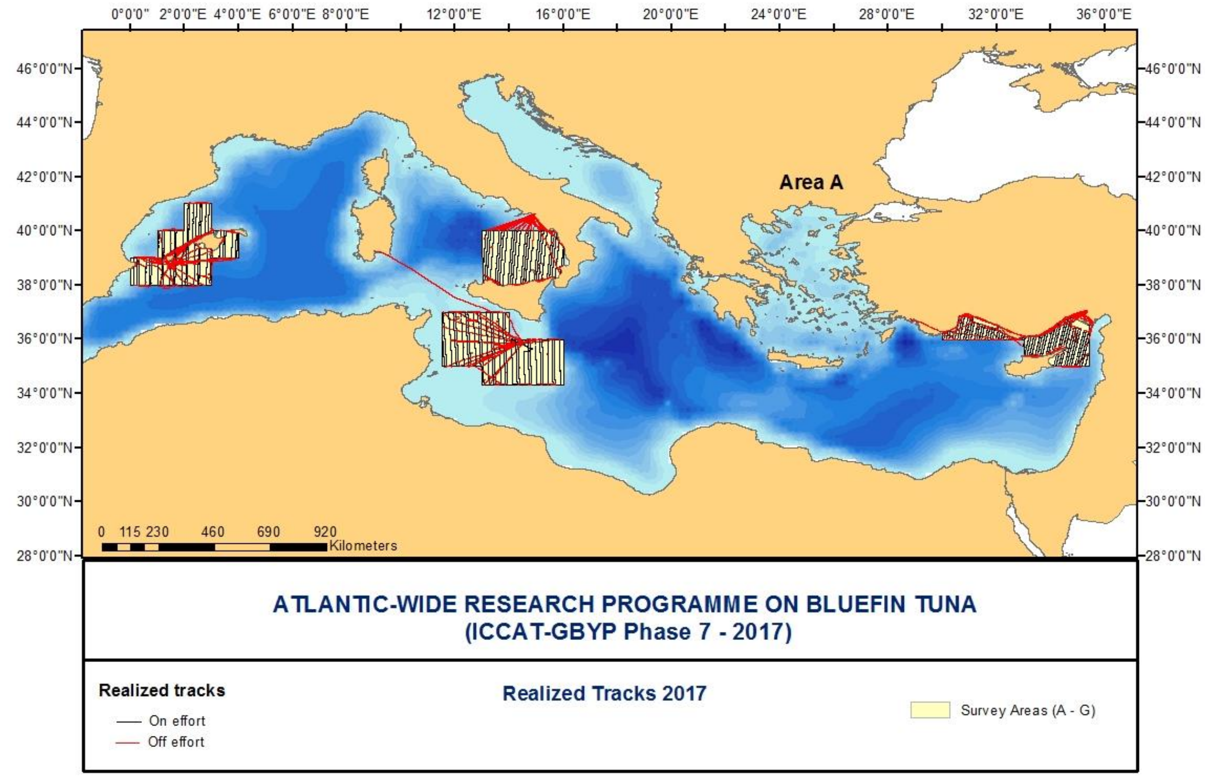


Figure 3. ICCAT GBYP transects flown on effort and off efforts, including logistics flights, in 2017.

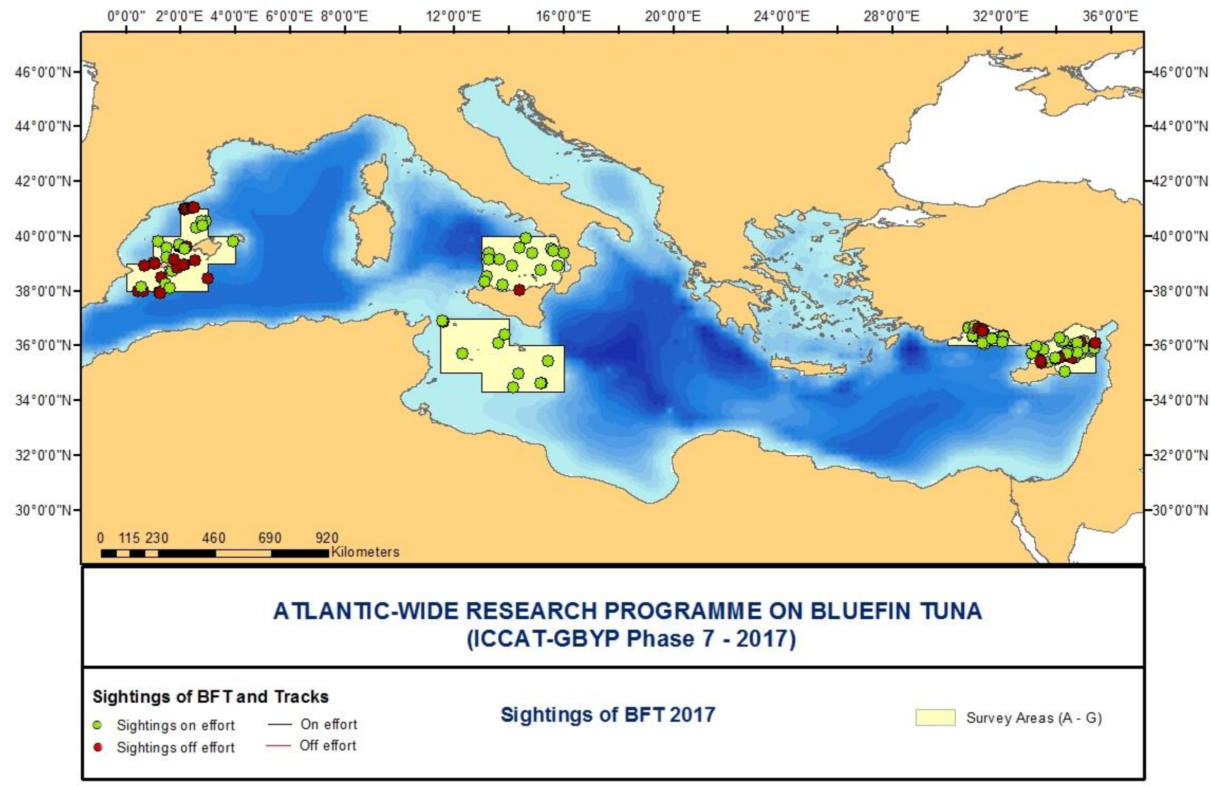


Figure 4. Distribution of the sightings of Bluefin tuna on and off effort during the ICCAT GBYP Aerial Survey for spawning aggregations in 2017.

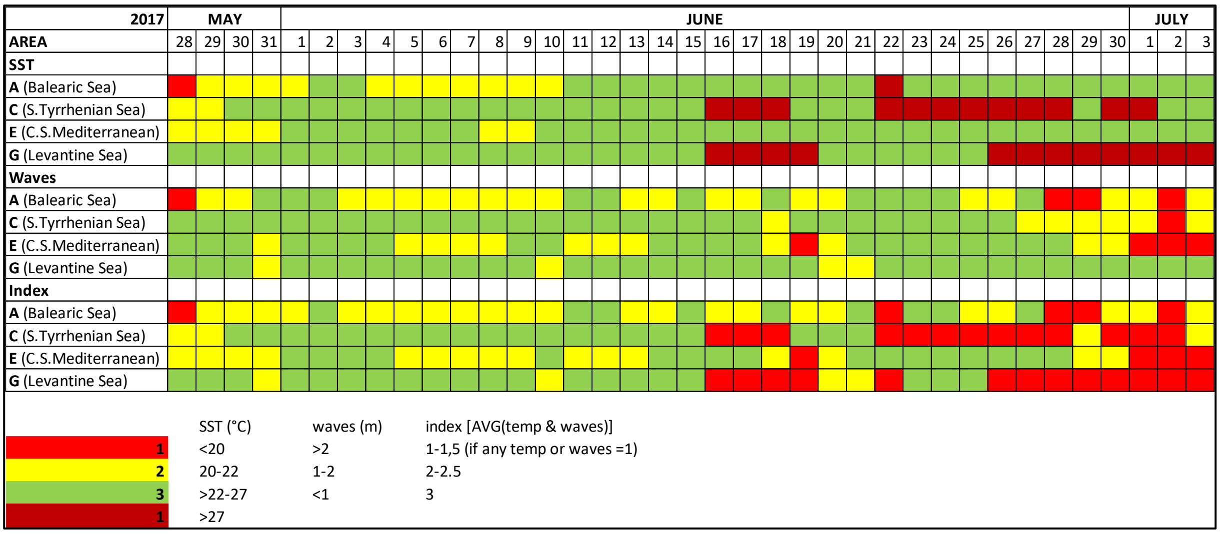
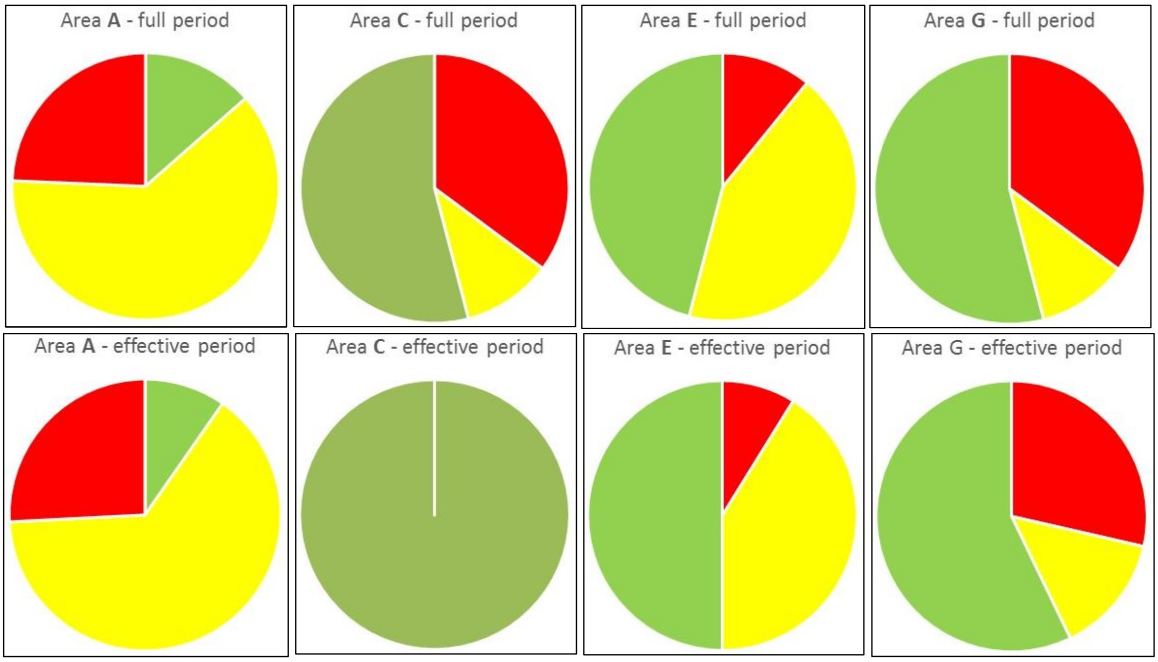


Figure 5. Graphic representation of potential SST and waves high conditions during the aerial survey activity in 2017, in correlation with suitable situations for Bluefin tuna spawning and the aerial survey. Combined data are shown by the "index".



full period

days in red		
A	5	14%
C	13	35%
E	4	11%
G	13	35%

days in yellow		
A	23	62%
C	4	11%
E	16	43%
G	4	11%

days in green		
A	9	24%
C	20	54%
E	17	46%
G	20	54%

effective period

days in red		
A	3	10%
C	0	0%
E	3	9%
G	6	29%

days in yellow		
A	20	69%
C	0	0%
E	14	41%
G	3	14%

days in green		
A	8	28%
C	16	100%
E	17	50%
G	12	57%

Figure 6. Graphic representation of potential positive, problematic or positive meteo-marine conditions in the various areas and corresponding percentages, for both the full period of the survey and the effective survey period in each area.

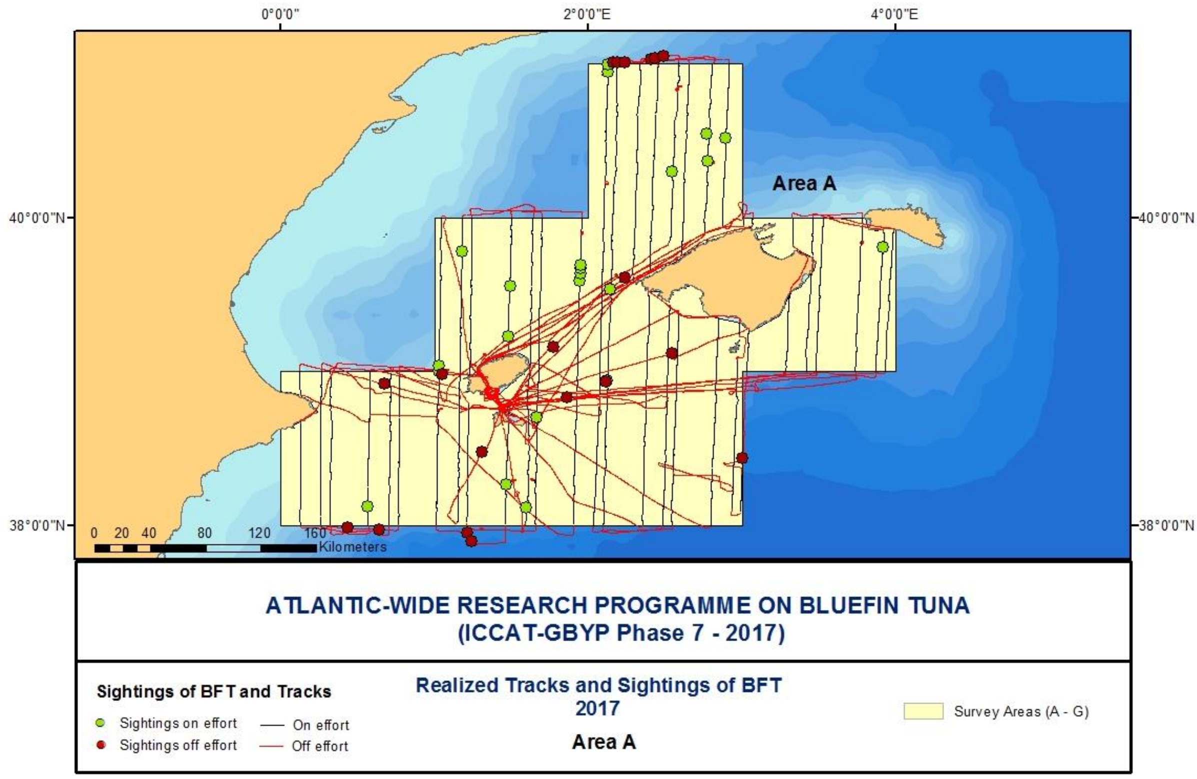


Figure 7. Transects realized in Area A (Balearic Sea), and sightings of Bluefin tuna on and off effort.

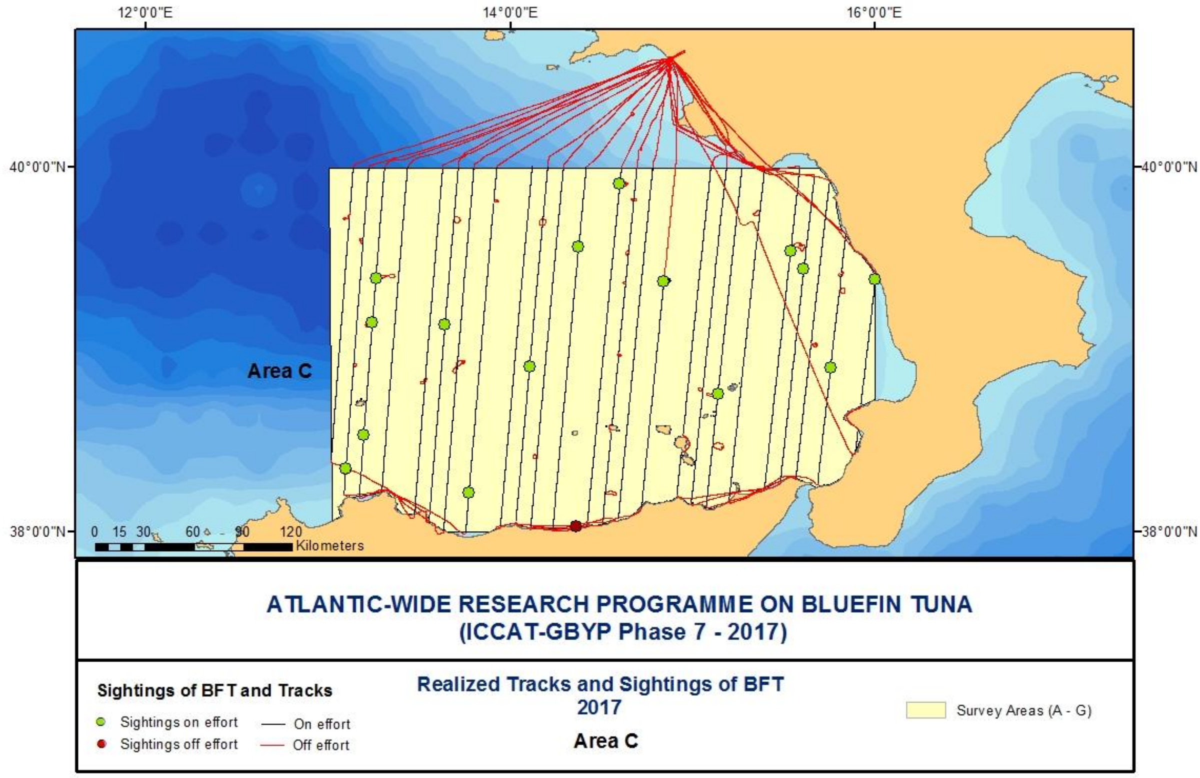


Figure 8. Transects realized in Area C (southern Tyrrhenian Sea), and sightings of Bluefin tuna on and off effort.

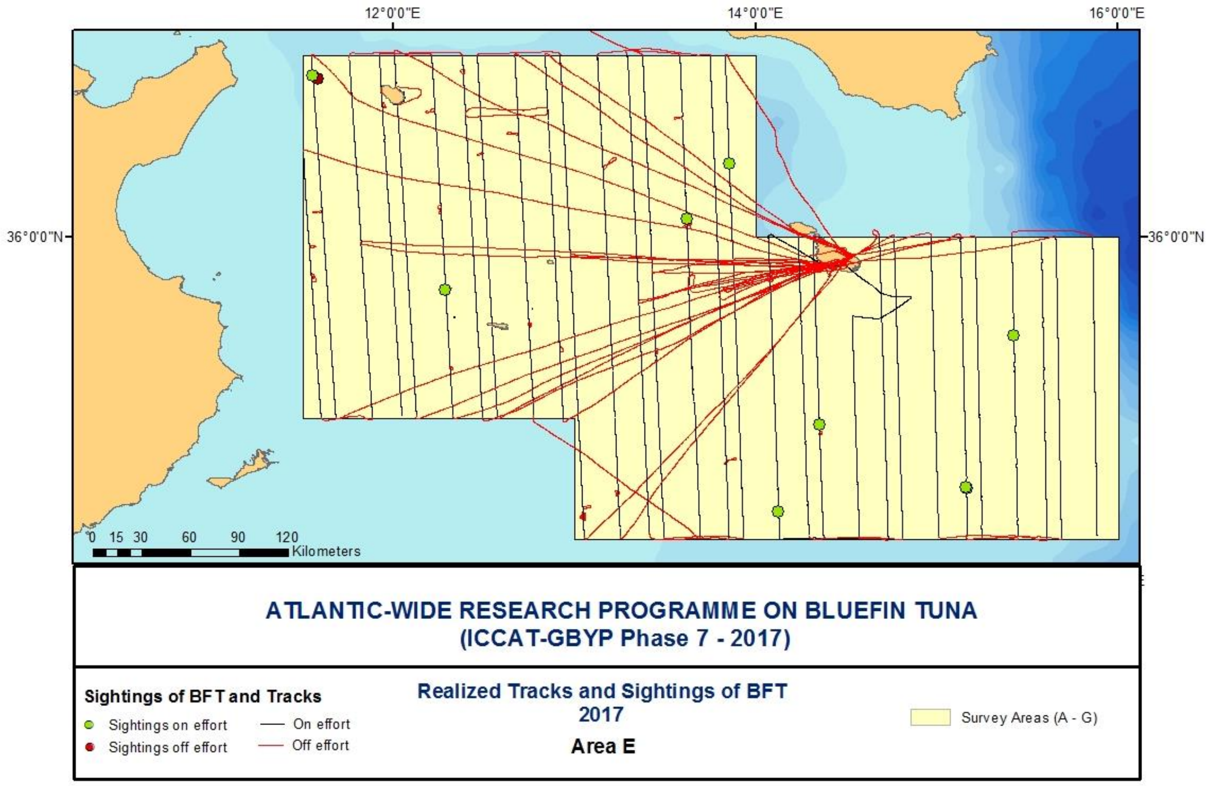


Figure 9. Transects realized in Area E (central-southern Mediterranean Sea), and sightings of Bluefin tuna on and off effort.

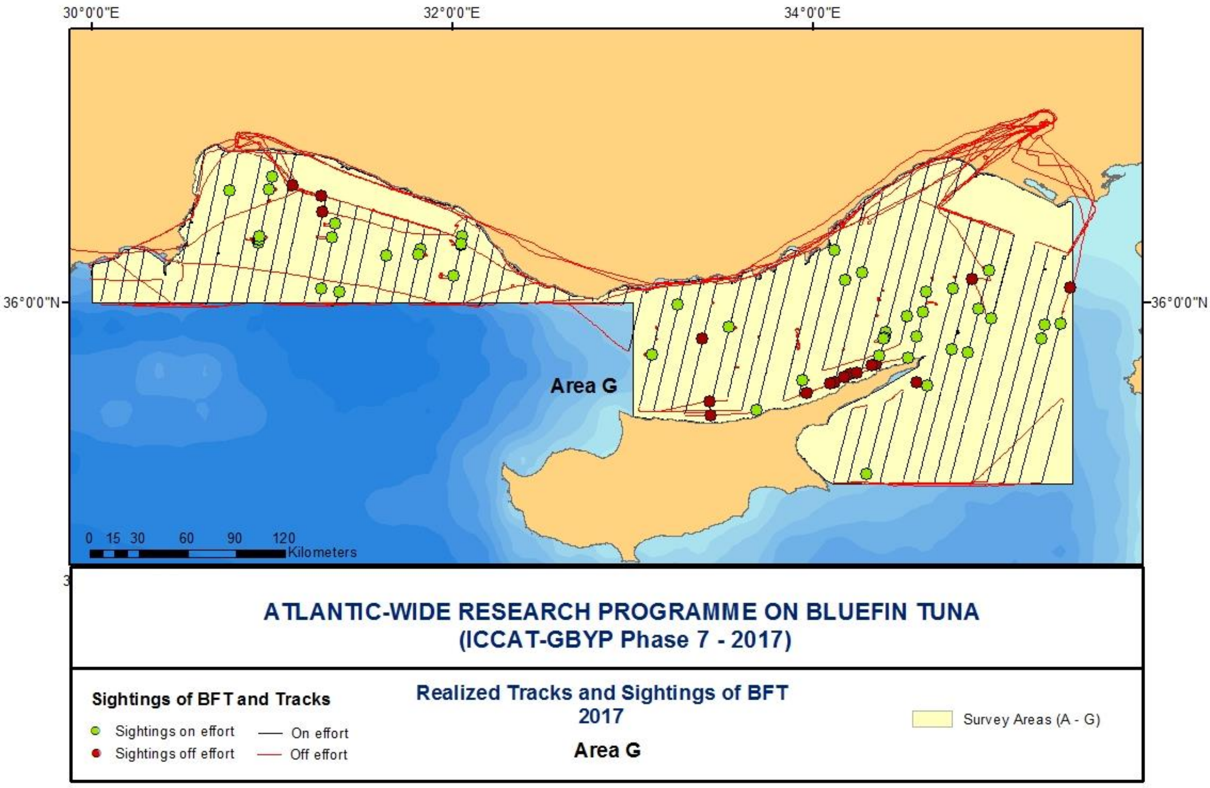


Figure 10. Transects realized in Area G (Levantine Sea), and sightings of Bluefin tuna on and off effort.

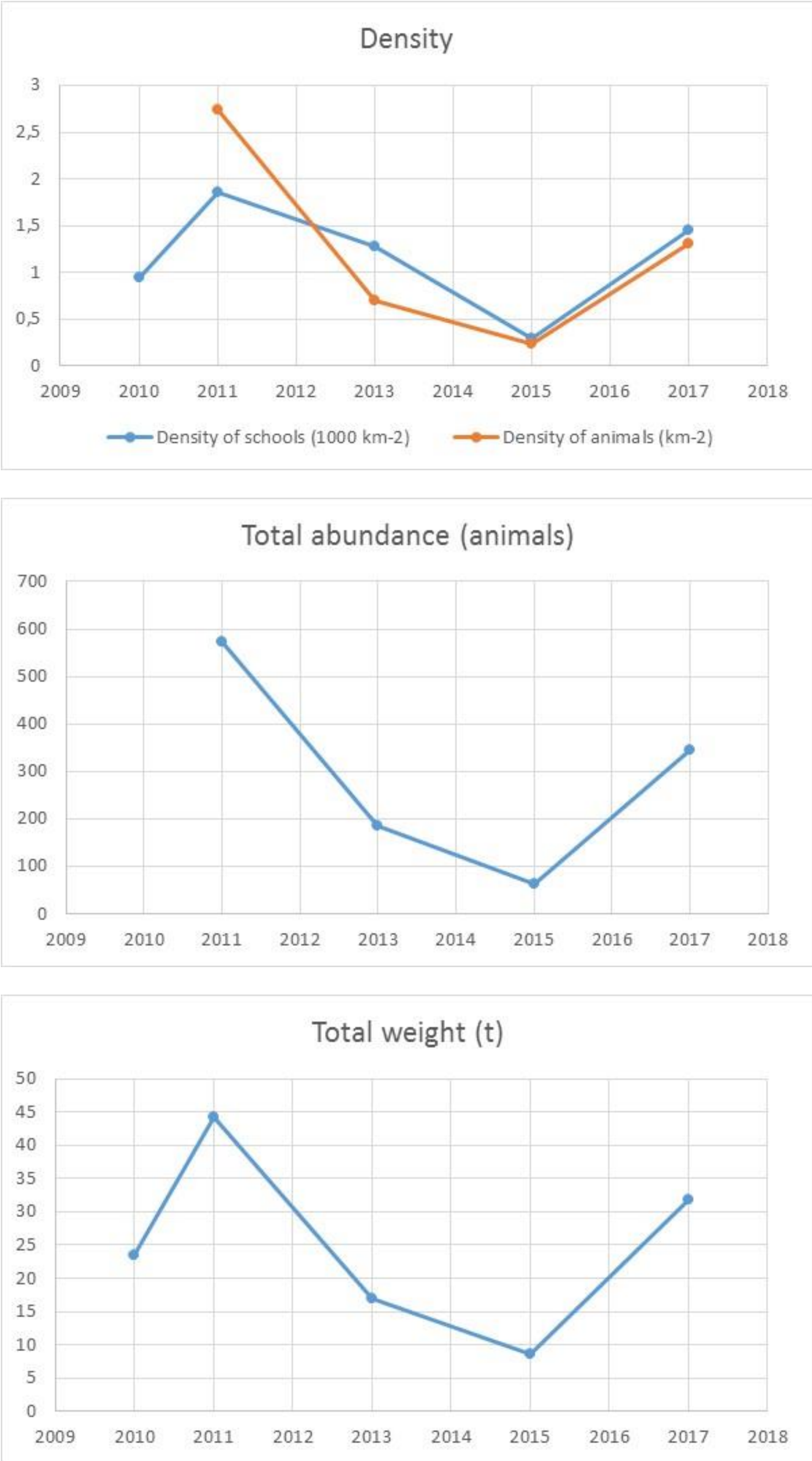


Figure 11. Graphic plots of the main results of the five ICCAT GBYP Aerial surveys on Bluefin tuna spawning aggregations for the density of schools and animals (top), the total abundance of fish (middle) and the total weight in tons (bottom).

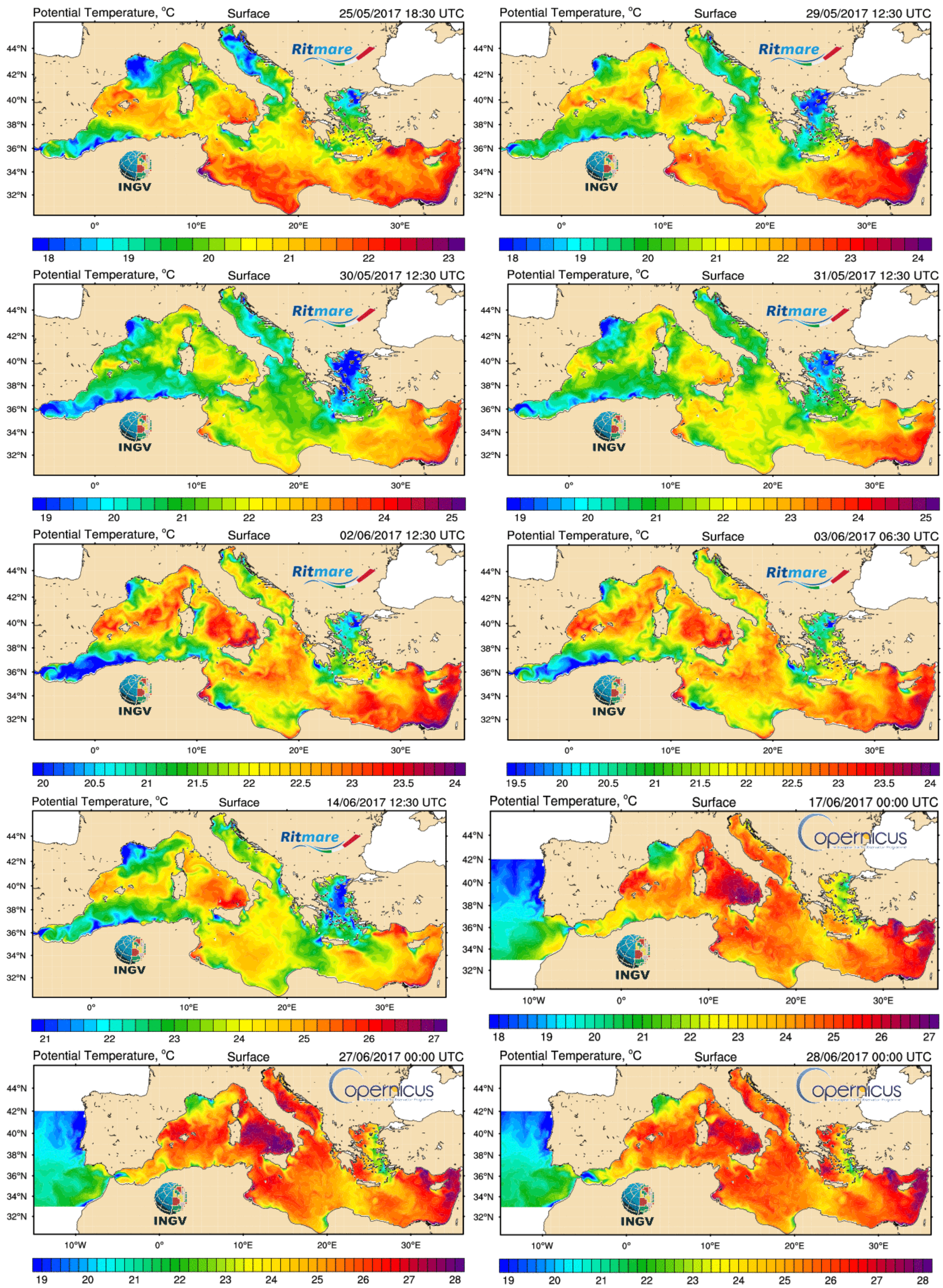


Figure 12. Few examples about the evolution of the SST in the Mediterranean Sea between the last part of May to the last days of June 2017. It is very clear that the SST reached high levels in the western Mediterranean, in the Ligurian and Tyrrhenian Sea, in the Adriac Sea and in the western Strait of Sicily, much higher than usual compare. At the same time, the southern Mediterranean Sea and the Levantine Sea were not hot as usual in this season.

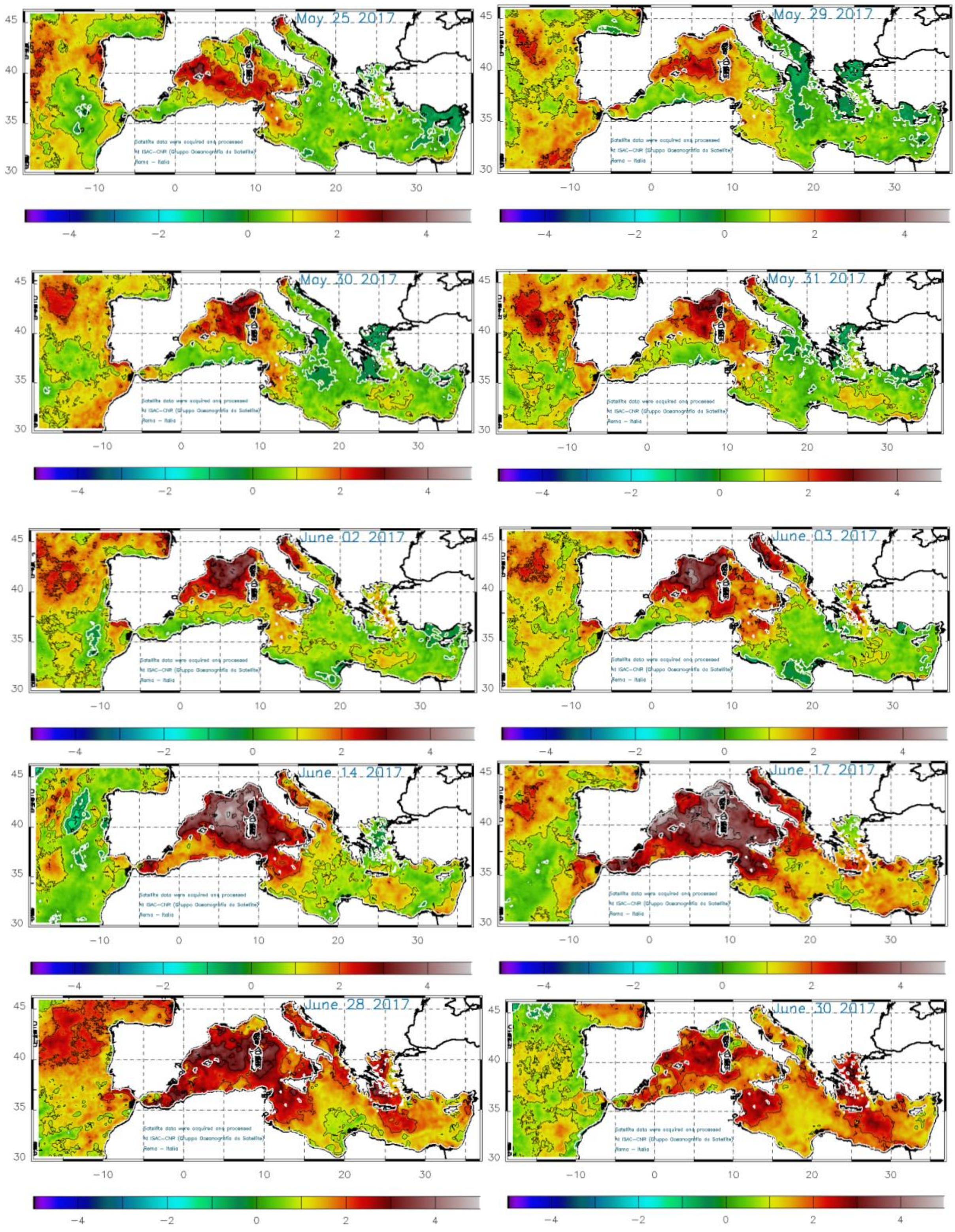


Figure 13. Few examples about the evolution of the SST anomalies in the Mediterranean Sea between the last part of May to the last days of June 2017. It is very clear that the SST was much higher tha usual in the western Mediterranean, in the Ligurian and Tyrrhenian Sea, in the Adriac Sea and in the western Strait of Sicily compared to the average. At the same time, the southern Mediterranean Sea and the Levantine Sea were not so hot.

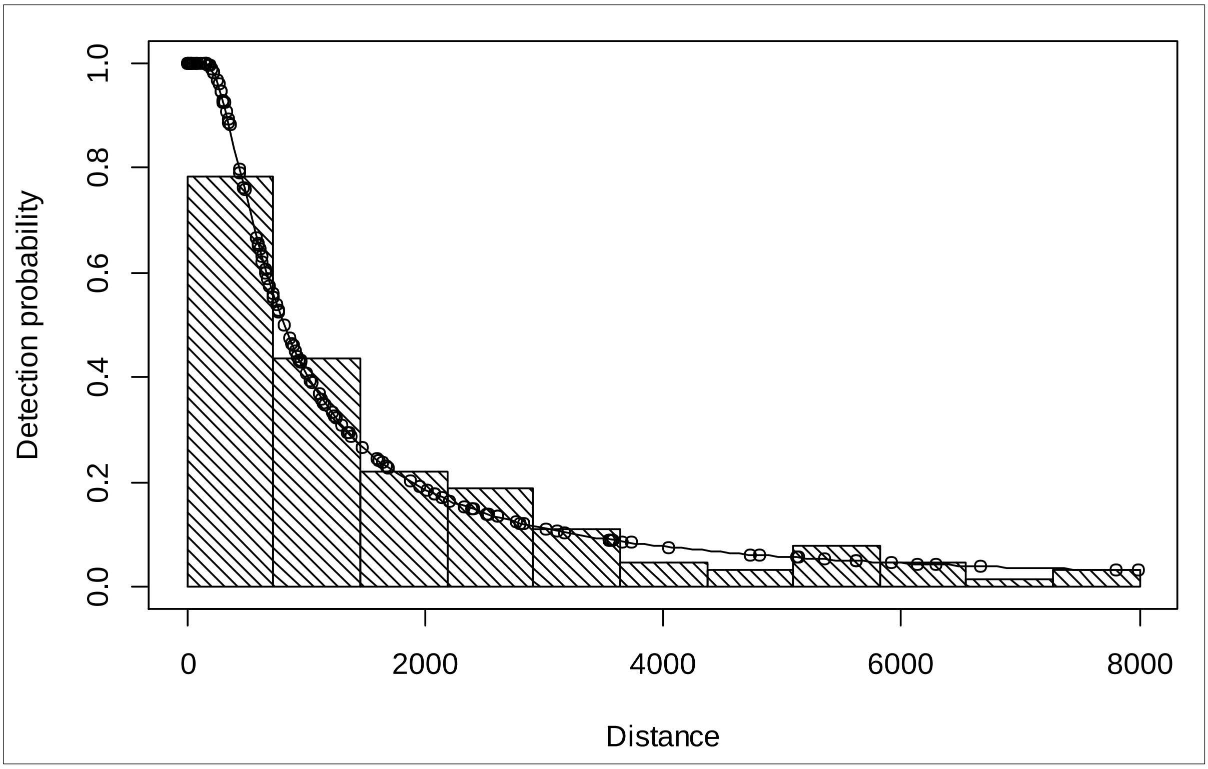


Figure 14. Detection function, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings during the ICCAT GBYP Aerial Survey in 2017.

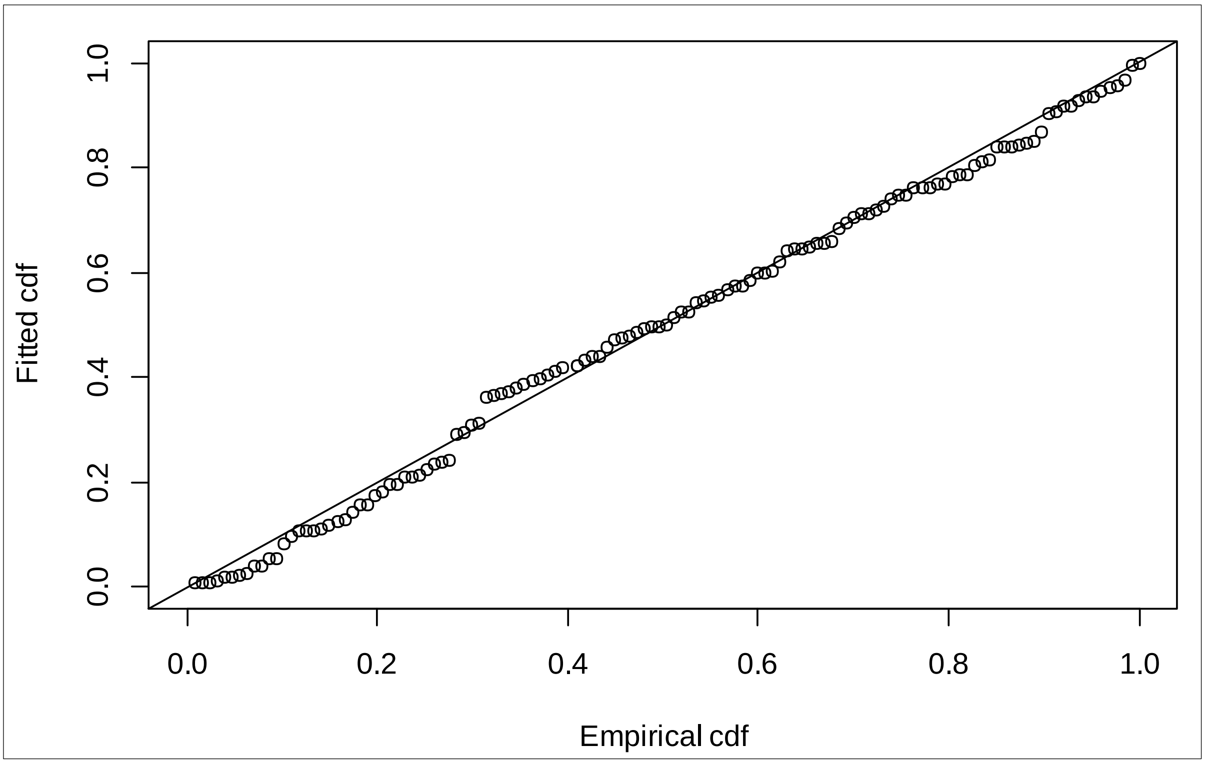


Figure 15. Q-Q plot for the ICCAT GBYP Aerial Survey in 2017.

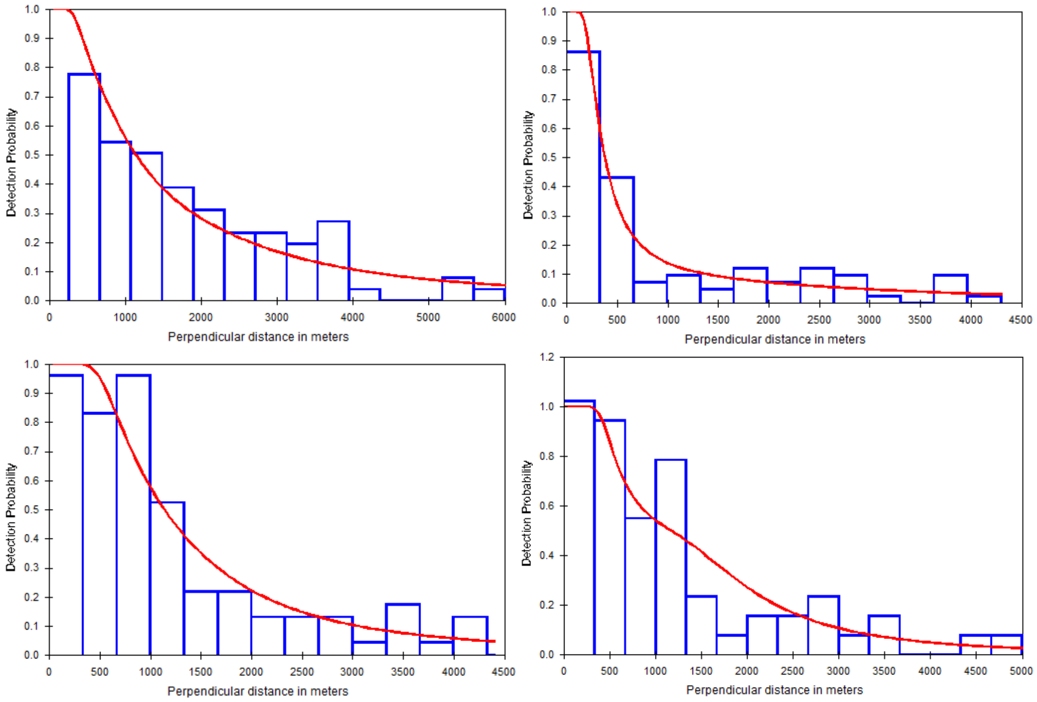


Figure 16. Detection function for 2010, 2011, 2013 and 2015, scaled to 1.0 at zero perpendicular distance, and histograms of observed sightings.

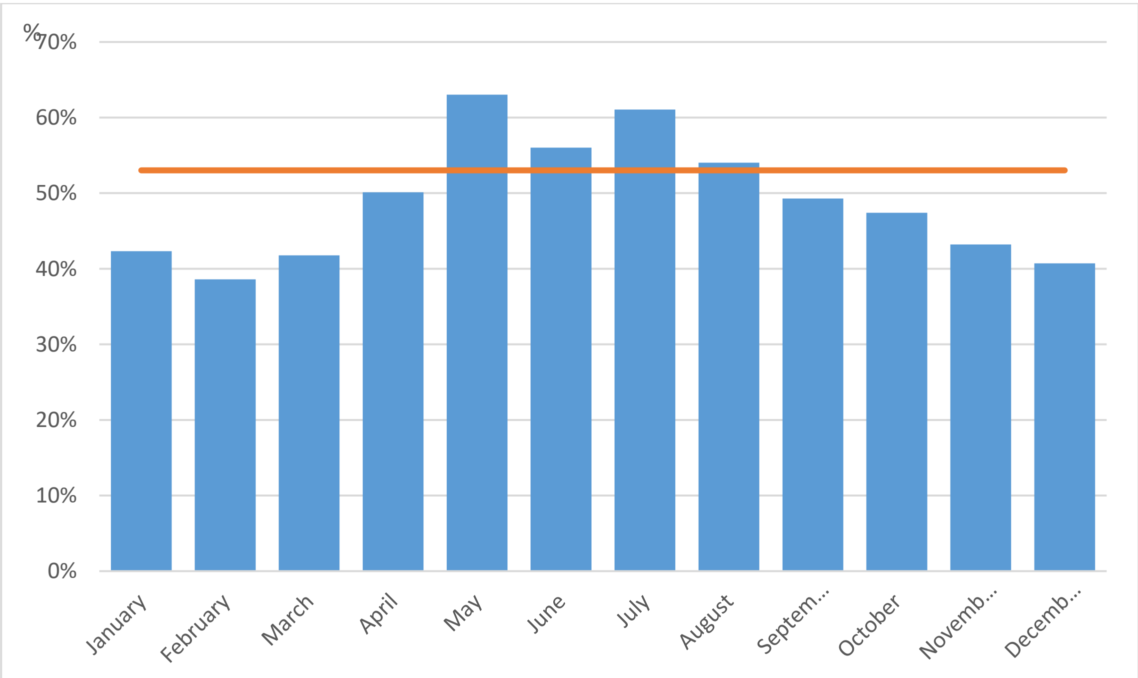


Figure 17. Mean percentage of time Bluefin tuna spent on the surface (0-10 m depth) by months, according to the data provided by electronic pop-up tags deployed by ICCAT GBYP. The data are related only to the Mediterranean Sea, for the tags deployed between 2011 and 2016, with data up to 2017. The orange line represents the mean percentage of time spent on the surface (0-10 m depth) throughout the year (from: Tensek *et al*., 2017, updated).