ICCAT GBYP AERIAL SURVEY FOR BLUEFIN TUNA SPAWNING AGGREGATIONS IN 2018

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SUMMARY

In June of 2018 the sixth ICCAT GBYP aerial survey was carried out in the 4 overlapped areas selected in 2015 using the same survey design as in 2017. Data were analysed using DISTANCE software. This is the first time that all replicates for all areas were totally completed, covering 23,308 km on effort. The total number of BFT sightings detected was 79; 26 in area A, 8 in area C, 11 in area E and 34 in area G. The detection functions fitted for each area pointed out the differences in searching behaviour between PS and SS, and between PS of each area suggesting the need to consider an inter-calibration test in the future. The total weight in 2018 is 47% larger than the mean 2010-2017, and the total abundance is 31% larger than the mean for 5 previous years. However, the total abundance estimate for 2018 (361,995) is very similar to 2017 (346,272). A better understanding of the factors affecting this strong inter-annual and spatial variability could be explored by using spatial modelling analysis.

RÉSUMÉ

En juin 2018, la sixième prospection aérienne du GBYP de l'ICCAT a été réalisée dans les 4 zones chevauchantes sélectionnées en 2015 en appliquant le même protocole de prospection qu'en 2017. Les données ont été analysées au moyen du logiciel DISTANCE. C'est la première fois que toutes les répliques de toutes les zones sont totalement achevées et couvrent 23.308 km d'effort. Le nombre total d'observations de thon rouge détectées était de 79 : 26 dans la zone A, 8 dans la zone C, 11 dans la zone E et 34 dans la zone G. Les fonctions de détection ajustées à chaque zone ont mis en évidence les différences de comportement de recherche entre PS et SS, et entre les PS de chaque zone, ce qui amène à penser qu'il serait nécessaire d'envisager de réaliser un test d'inter-calibration à l'avenir. Le poids total en 2018 est 47% plus élevé que la moyenne de 2010-2017 et l'abondance totale est 31% plus grande que la moyenne des 5 années précédentes. Cependant, l'abondance totale estimée pour 2018 (361.995) est très similaire à celle de 2017 (346.272). Une meilleure compréhension des facteurs affectant cette forte variabilité interannuelle et spatiale pourrait être explorée en utilisant l'analyse par modélisation spatiale.

RESUMEN

En Junio de 2018 se llevó a cabo el sexto muestreo aéreo ICCAT GBYP en las 4 áreas comunes seleccionadas en el año 2015, utilizando el mismo diseño de muestreo de 2017. Los datos fueron analizados usando el programa DISTANCE. Esta es la primera vez que se han completado todas las réplicas en las 4 áreas, cubriendo un total de 23,308 km en esfuerzo. El número total de avistamientos de BFT detectados fue de 79; 26 en el área A, 8 en el área C, 11 en el área E y 34 en el área G. Las funciones de detección ajustadas para cada área ponen de manifiesto diferencias en los patrones de búsqueda entre los PS y SS, y entre los PS de cada área, sugiriendo la necesidad de considerar un ejercicio de inter-calibración en un futuro. El peso total en 2018 es un 47% mayor que la media de 2010-2017, y la estima de abundancia total es un 31% mayor que la media de los cinco años previos. Sin embargo, la estima de abundancia total para 2018 (361,995) es muy similar a la de 2017 (346,272). La modelización espacial podría ser una herramienta a explorar de cara al mejor conocimiento de los factores que afectan a esta fuerte variabilidad interanual y espacial.

KEYWORDS

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

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1. Introduction

Aerial surveys 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.*, 2017; Kessel *et al.*, 2013; Basson and Farley, 2014; Bower *et al.*, 2014; Bauer *et al.*, 2015b; Rouyer *et al.*, 2017).

The ICCAT GBYP aerial survey for bluefin tuna spawning aggregations is a method for having 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 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 several natural factors. From a management point of view, this 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 and confirmed again after 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), 2015 (Di Natale and Tensek, 2016; Di Natale *et al.*, 2016) and 2017 (Di Natale *et al.*, 2017), 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.asp.

The first 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), in which it was stated that a minimum of 6 years was necessary to this end. Due to the changes in methodologies and definition of areas where these surveys were carried out, the datasets produced by the first four surveys were reanalysed in order to standardise the results. During this exercise, four overlapping areas were defined, which were common to all surveys and the results were obtained for these areas only. In order to keep the same methodology and get the comparable series of results, the fifth and sixth aerial survey were carried out on four, previously defined overlapping areas.

The first survey (2010) was carried on 3 full areas and 3 partial areas by aircrafts not equipped with bubble windows and declinometers. The second survey (2011) was carried out on three areas by aircrafts equipped with bubble windows and declinometers and these tools were used in all following surveys. The third survey (2013) was an extended survey, following the GBYP Steering Committee request, 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. For the fourth survey (2015) the GBYP Steering Committee requested again an extended survey, covering all possible areas in the Mediterranean Sea, which 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. As already mentioned, the fifth survey (2017) was carried out on four overlapping areas only, keeping the same methodology.

The GBYP Steering Committee has been requesting a calibration exercise for the spotters since 2013, 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 has been not possible to carry out it due to serious budget or operational constraints. In 2015 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.

In 2016 new power analysis was carried out (Cañadas and Ben Mhamed, 2016), which confirmed the results obtained in the previous two studies, and gave detailed results on variables included in the previous surveys, including the so-called additional variance.

In 2016 the full GBYP activity was 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."

2. Methods

2.1 Aerial survey design and development

The same survey design as in 2017, done using program DISTANCE http://www.ruwpa.st-and.ac.uk/distance/ and the "industry standard" software for line and point transect distance sampling, was used for the survey in 2018 (see Cañadas and Vazquez 2017 for the report on the survey design). Thus, the survey covered the four identified main spawning areas: A) Balearic Sea; C) Southern Tyrrhenian Sea, E) Central-southern Mediterranean Sea and G) Levantine Sea (**Figure 1**).

For the calculations of the percentage of coverage for each block, an effective half strip width of 4 km was considered. This value was chosen as it was the mean effective half strip width for all years and all areas analysed in the previous surveys (2010, 2011, 2013 and 2015). The proportion of the total trackline effort (32,000 km) was calculated for each block according to the proportion of the surface area of each block (see **Table 1**). Four replicas were assigned to each area given the high coverage given by the allocated effort in them, while keeping similar track line spacing as previous years. The Projected Coordinate System used to calculate distances and areas in DISTANCE software was TRANSVERSE MERCATOR.

Figures 2 to **5** show the realized effort and sightings in each sub-area. In general, coverage of all sub-areas was comprehensive and the four envisaged replicas could be completed in all the areas The data on school size were recorded in two ways: estimated number of animals in the school, and estimated total weight in tons of the school. Both were used as a measure of school size in analysis, performing two analyses for each sub-area to consider both measures of school size. Sightings made while the aircraft was transiting to and from the survey area or between transects were labelled as "off effort". They were used to estimate the detection function, but not to estimate abundance.

Perpendicular distance was estimated in two ways: a) with the declination angles; and b) considering data from Geographic Information System (GIS), taking as a reference the aeroplane circling over the schools. The procedure followed to estimate perpendicular distances with GIS using GPS tracks was the same as explained in Cañadas & Vazquez (2016). ArcGIS software was used to estimate perpendicular distances based on spatial measurements. Each GPS data set was plotted on a map covering the study area together with the BFT sightings recorded in that area. Perpendicular distances were estimated measuring the length between the centre of the contiguous circles made by the airplane while flying over the BFT to obtain school size and weight estimates, and the direction of flight in a straight line.

Out of 87 sightings of BFT in 2018, 82 had distances estimated with the inclinometer and 46 had perpendicular distances estimated with GIS from the circling (including 4 of the 5 sightings with missing distance from the inclinometer). In 41 of the 87 BFT sightings it was not possible to estimate perpendicular distances with GIS, mainly because the circles were not concentric so it was not possible to identify a clear point to measure and in those cases where the group size was not big enough so there was risk of losing it once leaving the transect if a circle was attempted. A combined dataset was created that was consistent across all data fields, with the selected perpendicular distance for each sighting. This dataset was entered into software DISTANCE for analysis.

2.2 Data analysis

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

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

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

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

Abundance was estimated as:

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

where A is the size of the survey area.

Because school size was measured in tonnes in one of the analysis, the final estimate of abundance in that case is the total estimated weight of tunas in the surveyed areas. Given the large amount of sightings "off effort", a two steps process was followed: (a) a detection function was fitted to all sightings, on and off effort; and (b) an estimate of abundance was obtained using the fitted detection function but applied only to data on effort. To do this, the MRDS (Mark-recapture distance sampling) engine in DISTANCE was used with the configuration of "single observer".

Detection functions were fitted to the perpendicular distance data to estimate the effective strip half-width, esw. Multi-Covariate Distance Sampling (MCDS) methods, within the MRDS engine, were used to allow detection probability to be modelled as a function of covariates additional to perpendicular distance from the transect line. These covariates were defined in the survey design phase and included sea state, air haziness, water turbidity, glare, subjective (a factor indicating whether the sighting conditions were good, moderate or poor), observers searching and cue. **Table 2** shows the covariates tested in the models.

A detection function could not be fitted for each area independently because of insufficient sample size in most of the areas to perform a robust independent analysis. Instead, a single detection function was estimated, post-stratified by areas in the analysis. It is common practice to right truncate perpendicular distance data to eliminate sightings at large distances that have no influence on the fit of the detection function close to the transect line (the quantity of interest) but may adversely affect the fit. After initial exploration of the data, 3500m right truncation distance was chosen, removing the furthest four sightings, and therefore leaving 78 on/off sightings for the detection function, out of a total of 82 useful sightings (with both perpendicular distance and group size).

The best functional form (Half Normal or Hazard Rate model) of the detection function and the covariates retained by the best fitting models were selected based on model fitting diagnostics: AIC, goodness of fit tests, Q-Q plots, and inspection of plots of fitted functions. Q-Q plots (quantile-quantile plots) compare the distribution of two variables; if they follow the same distribution, a plot of the quantiles of the first variable against the quantiles of the second should follow a straight line. To compare the fit of a detection function model to the data, we used a Q-Q plot of the fitted cumulative distribution function (cdf) against the empirical distribution function (edf). For goodness of fit tests, we used the Kolmogorov-Smirnov statistic (a goodness of fit test that focuses on the largest difference between the cdf and the edf), Cramer-von Mises statistics (that focus on the sum of squared differences between cdf and edf) and the Chi-square goodness of fit statistic (that compares observed with expected frequencies of observations in each selected range of perpendicular distances).

3. Results

3.1 Searching patterns

Figure 6 shows the detection functions for each area (same truncation distance of 3500m for each one). **Table 3** shows the number of observations of BFT available for the detection function (with data on perpendicular distances and size), and their mean perpendicular distances for each area and observer type (in brackets the maximum distance registered within the truncation distance).

3.2 Abundance and weight estimates

Table 4 shows the surface area of each survey sub-area, the number and length of searched transects and the number of sightings of Bluefin tuna schools used for analysis. The detection functions either using weight or number of animals as school size are identical, and the only thing changing is the final estimate provided. Therefore, we refer to it here as "the detection function", even if it was performed twice.

The final model of detection function selected had two covariates (Team and Observer Type) with a Hazard-rate key function. There was a model with the lowest AIC which had also two covariates (cue2 and Block) with a Hazard-rate key function. However, all diagnostics were better for selected model and the CV of the estimate was lower. Therefore, the model with Team and Observer Type was chosen. The Cramer-von Mises test performed very well and overall there were no significant differences between the cdf and the edf. The Kolmogorov-Smirnov test, however, did not perform very well in any of the models, probably due to small sample size. The q-q plot showed a moderately good agreement between the cdf and the edf. **Table 5** shows the main parameters for the detection function and **Table 6** the results of the diagnostics tests. **Figure 7** shows the fitted detection function and **Figure 8** shows the Q-Q plot. Overall, a total of 47,946 (CV = 33.4%) tonnes and 365,091 (CV = 28.4%) individuals of Bluefin tuna were estimated in all the spawning sub-areas together.

4. Comparison with previous surveys

Table 6 shows a comparison of track effort, sightings on effort (after truncation), encounter rate of schools, total estimated weight and total estimated number of animals, between 2018 and the mean of 2010 to 2017, as well as percentage differences with each of the previous five surveys.

Area A

In Area A there was a bit more effort than in 2015 and 2017 but less than in 2010, 2011 and 2013, although the inter-annual differences are small. Overall, there was 7% less effort in 2018 than the mean effort of 2010 to 2017. However, there was 55% more sightings on effort this year than the mean of the previous 5 years and this was the year with most sightings in Area A so far, even if the effort was lower. All encounter rate, total weight and total number of animals were much higher in 2018 than in the mean and each of the previous years (except encounter rate in 2017), up to 85% increase. The fact that the encounter rates and final estimates are much higher than the previous years when at the same time there was similar effort in 2018 than the rest of the years, indicates that there was a real increase of BFT in area A in 2018 in respect to the previous 5 years. There was already an important increase in 2017 in comparison to the previous years, but the increment is much larger in 2018 even with respect to 2017.

Area C

In area C, there was approximately half the amount of effort than in 2010 and 2011, but double than in 2013 and 2015 and similar than in 2017. However, the amount of sightings of BFT was similar to the mean of the previous years but much less than in 2017 (for similar amount of effort). The encounter rate of groups, total abundance and total weight are similar to the mean of 2010-2017, but much lower than in 2017 and 2013 taken individually.

Area E

This area had a much smaller number of sightings of BFT in 2015, 2017 and 2018 with respect to 2010, 2011 and 2013, not corresponding exactly to the variations of effort. For example, in 2011 there was only 125 km more of effort than in 2018 but there were 75% more sightings; or in 2018 there was 51% more effort than in 2013 but there were 45% more sightings in 2013. Overall, 2015 was the year with the lowest encounter rate, total weight and total abundance, and 2011 the year with much larger abundance and total weight. 2018 is similar to 2013 in terms of final total abundance but also similar to 2017 in terms of total weight.

Area G

Area G was not surveyed in 2011, and mean school size was not recorded in 2010, so comparisons are more limited than for the other areas. There was 13% less effort and 51% less sightings than in 2017. Overall, there was 29% more effort in 2018 than the mean for 2010-2017, but the same amount of sightings, and much smaller mean weight and school size, resulting in 80% smaller total weight and 68.5% lower abundance than the mean for 2010-2017.

All areas together

Overall, there has been similar amount of effort in 2018 as in the five previous surveys (only 9% more than the mean), and 10% more sightings. The mean weight is 25% smaller than the mean for 2010-2017 (113) and the mean school size is 73% smaller than the mean (1018). The total weight in 2018 is 47% larger than the mean 2010-2017, and the total abundance is 31% larger than the mean for the 5 previous years. However, the total abundance estimate for 2018 (361,995) is very similar to 2017 (346,272), so total abundance has not really changed overall from last year to this one, although distribution has. This year abundance in area A is much higher and in E is much lower than in 2017. Therefore, the distribution pattern may have changed due to environmental conditions that may have affected the timing of the migration. Moreover, there have been observed important differences in the structure of sizes among different areas, as well interannual changes in the size structure in all areas. Thus, there is a general decreasing trend in the sizes from west to East, predominating in area A (Balearic Islands) large/giant specimens, large /medium in area C (Tyrrhenian Sea), medium/small in area E (Ionian Sea) and small /medium in area G (Levantine Sea). In all areas it has been observed an increasing trend of the mean size in the last 2-3 years, or even along the whole time series in some areas as A and C. The exception would be area G, which showed a high predominance of medium size individuals in the first year of the series (2010), but, contrastingly, in 2013 and 2015 only small individuals were observed. From 2017 an increase in the proportion of medium sized fishes have been detected in this area, but the absence of large/giant individuals remains along the series (except one single sighting of large individuals in 2017). Given the strong inter-annual and spatial variability in the different components (encounter rate of groups, mean weight and mean school size), there is no clear pattern discerned in weight and/or abundance among years and areas.

5. Discussion

5.1 Searching patterns

A homogeneous coverage was achieved in all areas despite some temporally disruptions or delays due to exclusion of areas due to military/political reasons. Data collection worked much better than in previous surveys and it seems to be improving from year to year. The weekly review of the data collected helped in great deal to detect small issues at an early stage and correct them for the rest of the survey.

However, the problem of observers searching too far away and not that much close to the transect, especially PS (in all areas) and sometimes SS (especially in areas C and G and to lesser extent E), persist after making strong recommendations each year to do it properly, i.e. most of the searching effort closer to the transect and much less further away. This is a problem that prevents the fit of a good detection function and forces in some cases to truncate the furthest sightings, decreasing the sample size to estimate abundance and therefore increasing the CV.

5.2 Precision of estimates

The CV of abundance is determined by the CVs of estimated density of schools and mean school sizes in each sub-area. The CV of estimated density of schools is determined by the CVs of encounter rate (number of schools seen per survey km) and effective strip half width (*esw*). All of these quantities are functions of the number of schools seen, as well as the distribution of the data. CVs for density of schools in all areas varied between 31 % and 46%. The precision of mean school size varied between 24 and 40%. CVs for estimates of mean weight were more variable: 29-59%. Summing over all areas surveyed, the CV of total abundance was 28.6%.

In **Table 5** it is obvious that the largest CVs correspond to the area C. This is probably due to the very small number of observations of BFT this year, which has increased the variance for the encounter rate (the largest of all areas: 36% compared to 21-31% in the other areas).

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

The main way to reduce the estimated CVs in future surveys is to increase the number of sightings. This can be achieved partly by more efficient searching and partly by increasing the amount of searching effort (transect length). But it is also a consequence of the study year real density of animals. The number of sightings was smaller this year in areas C and G with respect to 2017, which increased considerably the CV of the encounter rate and density of schools in those areas.

However, another component of the overall CV, the mean school size, varies considerably and is relatively independent of sample size. The CV of school size in 2018 was much larger, again, in areas C and G compared with 2017, and the same pattern occurred with the CV of the mean weight. Due to the lower number of sightings, the total CV for abundance of animals and for total weight increased considerably in areas C and G.

5.3 Relative estimates of abundance

Line transect sampling assumes that detection on the transect line itself is certain. In aerial surveys, in general, it is not possible to assume this because the speed of flight means that potentially some schools available to be sampled will inevitably not be detected (so-called perception bias), although we believe this bias to be very small for spawning BFT given their usual large group sizes and conspicuous behaviour when spawning. But this cannot be quantified without a double-platform configuration, which is usually difficult and expensive for aerial surveys if done with two airplanes or with airplanes that allow two sets of observers simultaneously. However, it could be potentially possible to quantify with a continuous recording video system installed on the airplane to cover the area closer to the transect line. In addition, tuna spend some of the time beneath the surface and unavailable to be detected (so-called availability bias) when at depth of more than just a few meters, and depending on the distance from the track line (due to the angle of observation and therefore ability to see underwater). The analysis done in 2016 in this regard (Cañadas and Vazquez 2016) showed that the time spent during day time between 10m depth and surface and therefore available for detection can be around 50% average (between 40% and 62%) depending on year and area. Estimates of abundance from these surveys are thus underestimates (minimum estimates). If mini-PATs for Bluefin tuna passing through the areas sampled by the aerial survey in the same period of time were available for 2018, a correction for availability bias could be attempted as in 2016.

The appropriateness of these estimates as indices of abundance for the future depends on a number of factors including: timing of surveys; areas surveyed; stability of availability and perception biases. Perception bias can reasonably be assumed to be stable over time but availability bias may be affected by the sea surface temperature at the time of the survey, and fluctuation of the distribution in time and space of Bluefin tuna throughout the Mediterranean Sea is influenced by environmental factors and the knowledge on the subject is incomplete. Therefore, an understanding of the variability of the environmental conditions that affect the distribution and abundance of BFT, across years and areas, might help interpret much better the variability in distribution and abundance observed. In consequence, the development of spawners habitat models, which would permit to standardize the results from aerial surveys accounting for the variations in environmental scenarios, should be recommendable. In addition, further efforts should be devoted to the right application of the observation protocols, to prevent or minimize any bias, and to the development of working protocols that minimize the logistical limitations to effective sampling effort.

References

- Arena P., 1980, Observations aeriennes sur la distribution et le comportement du Thon rouge, *Thunnus thynnus* (L.), de la Mer Tyrrhenienne. XXVII Congr. Assem. Plen. CIESM, Cagliari.
- Arena P., 1981, Osservazioni sulle concentrazioni e sulla pesca del Tonno e dell'Alalunga nelle zone di mare meridionali. Quad.Lab.Tecn.Pesca., 3(1), suppl.: 77-79.
- Arena P., 1982a, Biologia, ecologia e pesca del tonno (*Thunnus thynnus* L) osservati in un quinquennio nel Tirreno meridionale. Atti Conv. UU.OO: sottop. Ris.Biol.Inq.Marino, Roma: 381-405.
- Arena P., 1982b, Composizione demografica dei branchi di tonno (*Thunnus thynnus*, L.) durante il periodo genetico, con indicazioni utili alla individuazione dello stock di riproduttori che affluiscono nel Mar Tirreno. Atti Conv. UU.OO. sottop. Ris. Biol. Inq. Marino, Roma.
- Arena P., 1982c, La pêche a la senne tournante du thon rouge, *Thunnus thynnus* (L.), dans les bassins maritimes occidentaux italiens. Collect. Vol. Sci. Pap. ICCAT, 17(2): 281-292.
- Arena P., 1985, La pesca del tonno in Sicilia. Atti Conv.Pesca e Trasf. Prod. Itt. Siciliani, Trapani: 23-28.
- Arena P., 1986a, Sullo stato e le caratteristiche della pesca in Italia dei grandi Teleostei pelagici (Tonno, Alalunga e Pescespada). Rapp. Min.Mar.Merc., miméo: 1-17.
- Arena P., 1986b. Pesca dei grandi Scombroidei e degli Xifioidei nei mari Italiani. Nova Thalassia, 8 (3): 657-658.
- Arena P., 1988a, Risultati delle rilevazioni sulle affluenze del tonno nel Tirreno e sull'andamento della pesca da parte delle "tonnare volanti" nel triennio 1984-1986. MMM-CNR, Atti Seminari UU.OO. Resp.Prog. Ric., Roma: 273-297.
- Arena P., 1988b, Rilevazioni e studi sulle affluenze del tonno nel Tirreno e sull'andamento della pesca da parte delle "tonnare volanti" nel quadriennio 1984-1988. Report to: ESPI, Ente Siciliano per la Promozione Industriale, Palermo, 1-55, I-XI.
- Arena P., 1990, Rilevazioni e studi sulle caratteristiche e lo stato delle risorse di Tonno e sugli andamenti della pesca (Relazione sulla prosecuzione 1987-89). Report to: ESPI, Ente Siciliano per la Promozione Industriale, Palermo, 1-58.
- Arena P., Cefali A., Potoschi A., 1979, Risultati di studi sulla biologia, la distribuzione e la pesca dei grandi scombro idei nel Tirreno meridionale e nello Ionio. X(4): 329-345.
- Arena P., Cefali A., 2002, Composizione demografica dei branchi di tonno, *Thunnus thynnus* (L.) durante il periodo genetico, con indicazioni utili alla individuazione dello stock di riproduttori che affluiscono nel Mar Tirreno. Atti Conv. UU: OO. Ris. Biol. Inq. Marino, Roma: 425-442.
- Basson M., Farley J.H., 2014, A standardised abundance index from commercial spotting data of Southern Bluefin Tuna (*Thunnus maccoyii*): random effects to the rescue. PLOS One, https://doi.org/10.1371/journal.pone.0116245
- Bauer R., Bonhommeau S., Brisset B., Fromentin J.-M., 2015a, Aerial surveys to monitor bluefin tuna abundance and track efficiency of management measures. Marine Ecology Progress Series, 534: 221-234. Publisher's official version: http://doi.org/10.3354/meps11392, Open Access version: http://archimer.ifremer.fr/doc/00281/39192/
- Bauer R.B., Fromentin J.-M., Demarcq H., Brisset B., Bonhommeau S., 2015b, Co-occurrence and habitat use of Fin Whales, Striped Dolphins and Atlantic Bluefin tuna in the Northwestern Mediterranean Sea. PLOS ONE, DOI: 10-1371/journal.pone.0139218.
- Bonhommeau S., Farrugio H., Poisson F., Fromentin J.M., 2010, Aerial surveys of bluefin tuna in the Western Mediterranean sea: retrospective, prospective, perspective. ICCAT Coll. Vol. Sci. Pap., 65 (3): 801-811.
- Bower R., Fromentin J.M., Bonhommeau S., Demarcq H., 2014, Estimating Juvenile Bluefin Tuna Abundance through Aerial Surveys in the Northwestern Mediterranean. Quebec 2014, 144 Annual Meeting American Fisheries Society. https://afs.confex.com/afs/2014/webprogram/Paper14274.html
- Buckland S.T., Anderson D.R., Burnham K.P., Laake J.L., Borchers D.L., Thomas L., 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, Oxford.
- Cañadas, A. and Ben Mhamed, A., 2016, Power Analysis and Cost-Benefit Analysis for the ICCAT GBYP Aerial Survey on Bluefin Tuna Spawning Aggregations, Final report, 12 February 2016
 - http://www.iccat.int/GBYP/Docs/Aerial_Survey_Phase_5_Power_Analysis_and_Cost_Benefit_Analysis.p df

- Cañadas A., Vázquez J.A., 2013, Short-term contract for assessing the feasibility of a large-scale aerial survey on Bluefin tuna spawning aggregations in all the Mediterranean Sea for obtaining useful data for operating modelling purposes. Final Report, 13 January 2013. ICCAT GBYP, Phase 3. https://www.iccat.int/GBYP/Docs/Aerial_Survey_Phase_3_Feasibility_Study.pdf
- Cañadas, A. and Vázquez, J.A. 2016. Atlantic-wide research programme on bluefin tuna (ICCAT GBYP PHASE 5 2015). Elaboration of data from the aerial surveys on spawning aggregations. Report available from ICCAT.
- Cañadas A., Vázquez J.A., 2017, Atlantic-wide Research Programme on Bluefin Tuna (ICCAT GBYP- Phase 7 2017). Elaboration of data from the aerial survey on spawning aggregations. Report, 18/07/2017: 1-25. https://www.iccat.int/GBYP/Docs/Aerial Survey Phase 7 Data Analysis.pdf
- Cowling, A. O'Reilly, J., 1999, Background to review of aerial survey: 3rd draft. 1999 Aerial Survey Workshop, Caloundra: 1-61.
- Cowling A., Millar C., Polacheck T., 1996, Data analysis of the aerial surveys (1991–1997) for juvenile southern bluefin tuna in the Great Australian Bight. Rep. RMWS/96/4, 87 p. Recruitment Monitoring Program, CSIRO Division of Marine Research, GPO Box 1538, Hobart 7001, Australia
- Cram D.L., Hampton I., 1976, A proposed aerial/acoustic strategy for pelagic fish stock assessment. J. Cons. int. expl. Mer., 37: 91–97.
- Di Natale A., 2011, ICCAT GBYP. Atlantic-wide Bluefin Tuna Research Programme 2010. GBYP Coordinator Detailed Activity Report for 2009-2010. Coll. Vol. Sci. Pap., ICCAT, 66(2): 995-1009.
- Di Natale A., 2016, Tentative SWOT analysis for the calibration of ICCAT GBYP aerial survey for Bluefin tuna spawning aggregations. Collect. Vol. Sci. Pap., ICCAT, 72 (6): 1463-1476.
- Di Natale A., Idrissi M., 2012, ICCAT-GBYP Atlantic-wide Research Programme for Bluefin Tuna (GBYP) Coordination. Detailed Activity Report for Phase 2. Coll. Vol. Sci. Pap., ICCAT, 68 (1): 176-207.
- Di Natale A., Idrissi M., 2013a, ICCAT-GBYP Atlantic-wide Research Programme for Bluefin Tuna 2012. GBYP Coordination detailed activity report on Phase 2 (last part) and Phase 3 (first part). Coll. Vol. Sci. Pap., ICCAT, 69 (2): 760-802.
- Di Natale A., Idrissi M., 2013b, ICCAT GBYP aerial survey: juveniles versus spawners, a SWOT analysis of both perspectives. Coll. Vol. Sci. Pap., ICCAT, 69 (2): 803-815.
- Di Natale A., Tensek S., 2016, ICCAT Atlantic-wide Research Programme for Bluefin Tuna (GBYP): activity report for the last part of Phase 4 and the first part of Phase 5 (2014-2015). Collect. Vol. Sci. Pap., ICCAT, 72 (6): 1477-1530.
- Di Natale A., Idrissi M., Justel Rubío A., 2014a, ICCAT-GBYP activities for improving knowledge of bluefin tuna biological and behavioral aspects (ICCAT-GBYP phases 1 to 3). Coll. Vol. Sci. Pap., ICCAT, 70 (1): 249-270.
- Di Natale A., Idrissi M., Justel Rubío A., 2014b, ICCAT Atlantic-wide Research Programme for Bluefin Tuna (GBYP) activity report for 2013 (extension of Phase 3 and first part of Phase 4). Coll. Vol. Sci. Pap., ICCAT, 70 (2): 459-498.
- Di Natale A., Cañadas A., Vázquez Bonales J.A., Tensek S. and Pagá García A., 2016, ICCAT GBYP aerial survey for bluefin tuna spawning aggregations in 2015. Preliminary report. Collect. Vol. Sci. Pap., ICCAT, 72 (6): 1553-1577.
- Di Natale A., Cañadas A., Vázquez-Bonales J.A., Tensek S., and Pagá-García A., 2017, Report of ICCAT GBYP aerial survey for bluefin tuna spawning aggregations in 2017, Collect. Vol. Sci. Pap., ICCAT, 74 (6): 3172-3204.
- Everson E.J., Bravington M.V., Farley J.H., 2011, A mixed effects model for estimating juvenile southern bluefin tuna abundance from aerial survey data. ICCAT GBYP Worshop on Aerial Survey, Madrid, 1-27.
- Farley J., Bennet B., 2008, A bird's eye view of Southern Bluefin Tuna. CSIRO, Wealth from Oceans: 4 p.
- Fortuna C., Holcer D., Filidei E. Jr, Donovan G., Tunesi L., 2011, First cetacean aerial survey in the Adriatic Sea: summer 2010. In: Seventh Meet ACCOBAMS Sci Committee. ACCOBAMS-SC7/2011/Doc06, 29–31 March 2011, Monaco.
- Fortuna M.C., Kell T.L., Holcer D., Canese S., Filidei E.Jr., Mackelworth P., Donovan G., 2014, Summer distribution and abundance of the giant devil ray (*Mobula mobular*) in the Adriatic Sea: baseline data for an integrated management framework. Scientia Marina, 78 (2): doi: http://dx.doi.org/10.3989/scimar.03920.30D
- Fromentin J.-M. 2001, Interim Report of STROMBOLI EU-DG XIV project 99/022. 60 pp.
- Fromentin J.-M., Farrugio H., Deflorio M., De Metrio G. 2003, Preliminary results of aerials surveys of bluefin tuna in the Western Mediterranean Sea. Collect. Vol. Sci. Pap. ICCAT, 55(3): 1019-1027.

- Fromentin J.M., Bonhommeau S., Brisset B., 2013, Update of the index of abundance of juvenile bluefin tuna in the western Mediterranean Sea until 2011. Collect. Vol. Sci. Pap., ICCAT, 69 (1): 454-641.
- Gerrodette, T (1987). A power analysis for detecting trends. Ecology 68: 1364-72. Software TRENDS available from http://swfsc.noaa.gov/textblock.aspx?Division=PRD&ParentMenuId=228&id=4740.
- Grierson J., 1949, Air whaler.Sampson Low, Morston & Co. Ed., London: 1-243.
- Hammond P.S., Berggren P., Benke H., Borchers D.L., Collet A., Heide-Jørgensen M.P., Heimlich S., Hiby A.R., Leopold M.F., Øien N., 2002, Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology 39, 361–376
- Hiby L., Lovell P., 1998, Using aircraft in tandem formation to estimate abundance of harbor porpoise. Biometrics, 54, 1280–1289.
- Kessel S.T., Gruber S.H., K. S. Gledhill K.S., Bond M.E., Perkins R. G., 2013, Aerial Survey as a tool to estimate abundance and describe distribution of a Carcharhinid species, the Lemon Shark, *Negaprion brevirostris*. Journal of marine Biology,
- Lauriano G., Panigada S., Casale P., Pierantonio N., Donovan G.P., 2011, Aerial survey abundance estimates of the loggerhead sea turtle *Caretta caretta* in the Pelagos Sanctuary, northwestern Mediterranean Sea. Mar. Ecol. Prog. Ser., 437: 291–302.
- Lauriano G., Pierantonio N., Kell L., Cañadas A., Donovan G., Panigada S., 2017, Fishery-independent surface abundance and density estimates of swordfish (*Xiphias gladius*) from aerial surveys in the Central Mediterranean Sea. Deep-Sea Research, Part II: Topical studies in Oceanography, 141: 102-114.
- Lutcavage M., Krauss S., Hoggar W., 1997, Aerial survey of giant bluefin tuna, Thunnus thynnus, in the Great Bahama bank, Straits of Florida, 1995. Fishery Bulletin, 95: 300-310.
- Lutcavage M., Newlands N., 1999, A strategic framework for fishery-independent aerial assessment of bluefin tuna. Collect. Vol. Sci. Pap. ICCAT, 49: 400-402.
- Marsh H., Sinclair D.F., 1989, Correcting for visibility bias in strip transect aerial surveys of aquatic fauna, Journal of Wildlife Management, vol. 53 (4): 1017–1024.
- Newlands N.T., Lutcavage M.E., Pitcher T.J., 2007, Atlantic bluefin tuna in the Gulf of Maine, II: precision of sampling designs in estimating seasonal abundance accounting for tuna behaviour. Envir. Biol. Fish.,
- Palka D., 2011, U.S. Survey aerial survey experience. ICCAT GBYP Workshop on Aerial Survey, Madrid, 10-11 February 2011: 1-32.
- Panigada S., Lauriano G., Burt L., Pierantonio N., Donovan G., 2011, Monitoring Winter and Summer Abundance of Cetaceans in the Pelagos Sanctuary (Northwestern Mediterranean Sea) Through Aerial Surveys. PLOS ONE, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0022878
- Panigada S., Lauriano S., Donovan G., Pierantonio N., Cañadas A., Vazquez J.A., Burt L., 2017, Estimating cetacean density and abundance in the Central and Western Mediterranean Sea through aerial surveys: Implications for management. Deep-Sea Research, Part II: Topical studies in Oceanography, 141: 102-114.
- Polacheck T., Pikitch E., Lo. N. 1996, Evaluation and recommendations for the use of aerial surveys in the assessment of Atlantic bluefin tuna. Coll. Vol. Sci. Pap. ICCAT, 68(1):61–68.
- Rivas L.R., 1978. Aerial surveys leading to 1974-1976 estimates of the numbers of spawning giant bluefin tuna (*Thunnus thynnus*) migrating past the western Bahamas. Coll. Vol. Sci., ICCAT (7): 301-312.
- Rouyer T., Brisset B., Bonhommeau S., Fromentin J.-M., 2017, Update of the abundance index for juvenile fish derived from aerial survey of bluefin tuna in the western Mediterranean Sea. Collect. Vol. Sci. Pap., ICCAT, 74 (6): 2887-2902.
- Sissenwine M., Pearce J., 2017, Second review of the ICCAT Atlantic-wide Research Programme for Bluefin tuna (ICCAT GBYP Phase 6-2016). Collect. Vol. Sci. Pap., ICCAT, 73 (7): 2340-2423.

Sub-area	Area (km²)	Proport. of total area	Expected proport. Length of Trackline on effort	% coverage	On effort track Replica 1	On effort track Replica 2	On effort track Replica 3	On effort track Replica 4	Total on effort track
А	61,933	23.3	7,461	20.1	1,659	1,589	1,629	1,523	6,400
С	53,868	20.3	6,489	18.7	1,270	1,273	1,228	1,332	5,103
Е	93,614	35.2	11,278	19.3	2,199	2,216	2,326	2,321	9,062
G	56,211	21.2	6,772	19.6	1,431	1,410	1,404	1,455	5,700
Total	265,626		32,000		6,559	6,488	6,587	6,631	26,265

Table 1. Proportion of the total trackline effort, percentage of coverage and on effort kilometers for each area and replica.

Table 2. Covariates tested in the models and their ranges or factor levels.

Covariate	Туре	Levels
Sighting related		
Cue2	factor	Jump, ripples, splash, underwater
		other
School size class	factor	1-20
		21-100
		101-500
		501-2000
o) T		2001-5000
Observer Type	factor	SS – Scientific spotter
		PS – Professional spotter
Effort related		
Beaufort sea state	factor	0 (calm)
		1 (very light)
		2 (light breeze)
		2.5 (isolated whitecaps)
		3 (gentle breeze)
		4 (moderate breeze)
Air haziness	factor	0 (clear)
		1 (slight)
		2 (moderate)
		3 (diffused)
***	6	4 (heavy)
Water turbidity	factor	0 (clear)
		1 (moderately clear)
		2 (moderately turbid)
01	Constant and	
Observer level	factor	
Team	factor	AirMed, ActionAir, Unimar
Block	factor	A, C, E, G
Airplane	factor	Cessna, Partenavia
Glare intensity	factor	0 (null)
		l (slight)
		2 (moderate)
$C_{1} = 20$	Co t	3 (strong)
Glare 30	Tactor	Same as Glare intensity but only
		considering 30° each side of abeam (60° 120° / 240° 200°)
		$abealii (00 - 120 / 240 - 500^{\circ})$

	Nu	mber of sighti	ings	Mean perpendicular distance (m)			
Area	PS	SS	Total	PS	SS	Total	
Α	5	21	26	1535 (2545)	159 (447)	424	
С	4	4	8	753 (1102)	527 (789)	640	
E	6	5	11	1156 (3016)	852 (1574)	1018	
G	20	14	34	954 (3254)	930 (2728)	944	
Total	35	44	79	1049	517	752	

Table 3. Number of sightings used for fitting the detection function.

Table 4. Areas, total length of transects and number of sightings of Bluefin tuna for each surveyed sub-area.

Sub-area	Area (km²)	Length of transects on effort (km)	Number of observations (after truncation) Detection Function	Number of observations (after truncation) Abundance estimate
А	61,849	5560	26	25
С	51,777	4832	8	8
Е	90,097	8933	11	11
G	38,801	3983	33	22
Total	242,523	23,308	78	66

Table 5. Parameters and diagnostics of the detection function.

Average probability of detection (p)	CV probability of detection	Effective strip width (esw) (m)	Chi- square test (p)	Cramer-von Mises test (unweighted) (p)
0.2045	17.32%	715	0.0033	0.167

Table 6. Mean school size, density and total weight and abundance of Bluefin tuna for each subarea in 2018. All data are for on effort-observations.

Year	А	С	Ε	G	Total (sum)	Total (mean)
Survey area (km ²)	61,933	53,868	93,614	47,719	257,135	
Transect length (km)	5,560	4,832	8,933	3,984	23,308	
Effective strip width x2 (km)	1.43	1.43	1.43	1.43		1.43
Area searched (km ²)	7,959	6,917	12,788	5,702	33,365	
% coverage	12.9	12.8	13.7	11.9		13.0
Number of schools ON effort	25	8	11	23	67	
Abundance of schools	384	36	45	103	568	
%CV abundance of schools	30.6	45.6	41.2	30.7	22.5	
Encounter rate of schools	0.0045	0.0017	0.0012	0.0058		0.0029
%CV encounter rate	20.8	36.3	30.9	23.0		13.6
Density of schools (1000 km ⁻²)	6.198	0.660	0.481	2.163		2.208
%CV density of schools	30.6	45.6	41.2	30.7		22.5
Mean weight (t)	98.6	140.8	97.0	6.9		84.5
%CV weight	28.4	58.8	26.1	46.6		24.4
Mean cluster size (animals)	663	1,222	1,013	208		643
%CV abundance	23.9	39.9	24.8	39.3		18.5
Density of animals (km ⁻²)	4.110	0.807	0.487	0.450		1.420
%CV density of animals	37.2	62.8	46.1	48.5		28.4
Total weight (t)	37,861	5,007	4,369	709	47,946	
%CV total weight	40.3	74.9	47.3	53.1	33.4	
L 95% CI total weight	17,658	1,317	1,798	365	25,283	
U 95% CI total weight	81,183	19,040	10,613	1,897	90,921	
Total abundance (animals)	254,552	43,466	45,600	21,474	365,091	
%CV total abundance	37.2	62.8	46.1	48.5	28.4	
L 95% CI total abundance	125,322	13,998	19,214	8,092	211,128	
U 95% CI total abundance	517,039	140,079	107,869	51,779	631,334	

	Values		Percentage difference					
Area A	2018	Mean 2010-2017	2010	2011	2013	2015	2017	Mean 2010- 2017
Effort 5,560		5,970	9.1	29.1	18.3	26.1	10.4	6.9
Sightings	25	11	68.0	60.0	60.0	76.0	12.0	55.2
ER schools	0.0045	0.0020	70.9	71.6	67.3	67.9	1.8	55.9
Total weight	37,861	5,780	90.5	88.5	90.7	87.6	66.5	84.7
Total animals	254,552	37,116	0.0	84.5	92.7	92.5	71.9	85.4
Area C								
Effort	4,832	5,551	43.1	45.3	42.2	43.3	1.6	12.9
Sightings	8	9	25.0	20.0	20.0	62.5	46.7	9.1
ER schools	0.0017	0.0019	57.3	31.6	53.8	44.0	45.8	12.0
Total weight	5,007	5,819	68. 7	62.4	55.2	47.7	55.8	14.0
Total animals	43,466	41,643	77.9	70.5	46.5	55.5	46.6	4.2
Area E								
Effort	8,933	7,396	32.0	12.4	51.0	71.3	24.9	17.2
Sightings	11	21	62.1	75.6	45.0	72.7	18.2	48.1
ER schools	0.0012	0.0027	44.2	72.1	73.0	32.7	8.3	53.9
Total weight	4,369	10,520	43.1	88.5	65.3	75.0	2.0	58.5
Total animals	45,600	138,140	38.2	91.3	6.9	77.8	18.9	67.0
Area G								
Effort	3,983	2,828	4.9		47.8	78.5	13.0	29.0
Sightings	23	23	33.3		45.5	90.9	51.1	0.0
ER schools	0.0058	0.0065	36.6		4.2	72.0	43.8	10.6
Total weight	709	3,581	93.8		32.7	66.4	79.3	80.2
Total animals	21,474	68,234			43.7	34.3	86.8	68.5
All areas								
Effort	23,308	21,180	26.1	13.2	31.1	55.9	9.1	9.1
Sightings	67	60	11.8	3.0	22.4	79.1	26.4	11.0
ER schools	0.0029	0.0027	16.2	15.8	11.2	52.6	33.1	4.5
Total weight	47,946	24,984	51.3	7.9	64.8	81.9	33.6	47.9
Total animals	365,091	250,415	77.1	36.3	48.9	82.9	5.2	31.4

Table 7. Comparison between 2018 and the previous surveys. In bold the values that are larger in 2018.

Table 8. Result	s for all	surveys in	all areas	combined.
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Year	2010	2011	2013	2015	2017	2018	Total (sum)	Total (mean)
Survey area (km ²)	265,627	209,416	265,627	265,627	265,627	257,135		265,627
Transect length (km)	31,532	26,856	16,060	10,272	21,178	23,308	129,206	21,534
Effective strip width x2 (km)	2.96	1.36	3.00	3.9	2.9	1.4		2.6
Area searched (km ²)	93,442	36,525	48,127	39,904	61,096	33,365	334,307	52.08
% coverage	35.2	17.4	18.1	15.0	23.0	13.0		20.3
Number of schools ON effort	76	65	52	14	91	67	365	60.8
Abundance of schools	250	388	338	78	387	568		335
%CV abundance of schools	22.8	19.9	21.5	38.9	20.2	22.5		
Encounter rate of schools	0.0024	0.0024	0.0032	0.0014	0.0043	0.0029		0.0028
%CV encounter rate				20.2	11.6	13.6		
Density of schools (1000 km ⁻²)	0.942	1.852	1.274	0.295	1.457	2.208		1.261
%CV density of schools	22.8	19.9	21.5	38.9	23.4	22.5		
Mean weight (t)	87.9	101.1	22.6	272.2	82.3	84.5		108.420
%CV weight	16.8	27.5	51.0	41.4	19.2	24.4		
Mean cluster size (animals)	791	1,275	582	1,548	895	643		956
%CV abundance	18.6	37.3	18.5	40.5	17.0	18.5		
Density of animals (km ⁻²)		2.7388	0.702	0.234	1.304	1.420		1.161
%CV density of animals		29.9	29.4	39.1	25.9	28.4		
Total weight (t)	23,371	44,139	16,866	8,690	31,855	47,946		28,811
%CV total weight	25.6	28.7	30.3	35.3	26.7	33.4		
L 95% CI total weight	14,243	25,315	9,343	4,398	19,018	25,283		
U 95% CI total weight	38,347	76,964	30,447	17,169	53,355	90,921		
Total abundance (animals)		573,543	186,505	62,284	346,272	365,091		269,528
%CV total abundance		29.9	29.4	39.1	25.9	28.4		
L 95% CI total abundance		321,620	105,320	28,766	209,816	211,128		
U 95% CI total abundance		1,022,800	330,270	134,860	571,473	631,334		



Figure 1. Sightings of Bluefin tuna on (black circles) and off effort (red circles).



Figure 2. Tracks realized, and sightings of Bluefin tuna on (black lines) and off effort (red lines) in sub-area A.



Figure 3. Tracks realized, and sightings of Bluefin tuna on (black lines) and off effort (red lines) in sub-area C.



Figure 4. Tracks realized, and sightings of Bluefin tuna on (black lines) and off effort (red lines) in sub-area E.



Figure 5. Tracks realized, and sightings of Bluefin tuna on (black lines) and off effort (red lines) in sub-area G.







Area E

Area G

Figure 6. Detection functions for each area.



Figure 7. Histograms of observed sightings.



Figure 8. Q-Q plot.