SCRS/2016/138 Collect. Vol. Sci. Pap. ICCAT, 73(6): 2058-2073 (2017)

ICCAT GBYP PSAT TAGGING: THE FIRST FIVE YEARS

Stasa Tensek[1], Antonio Di Natale[1], Alfonso Pagá García[1]

SUMMARY

The ICCAT GBYP deployed more than 193 PSAT tags over the course of five years (2011-2015) in different areas of Mediterranean Sea and Eastern Atlantic, out of which a total of 173 datasets were recovered. The longest received dataset was recovered from the tag which stayed 337 days attached to the fish. A brief discussion was provided on how the real tag dataset duration is in most cases shorter than the period between the deployment and pop up, because the tag detachment may happens few days before the pop-up. A brief analysis of the potential cause of the tag detachment reveals a huge number of detachments due to the fishing activities (75%). The analysis of tag reporting performance indicates slight technological improvements over the time. Tag trajectories revealed many interesting moving patterns for bluefin tunas, some of which were previously unknown. The analysis of the time bluefin tuna spends close to the surface demonstrates the significant difference in its behaviour during the spawning and non-spawning season.

RÉSUMÉ

L'ICCAT-GBYP a déployé plus de 193 marques PSAT en cinq ans (2011-2015) dans différentes zones de la mer Méditerranée et de l'Atlantique Est, dont un total de 173 jeux de données ont été récupérés. Le jeu de données le plus long qui ait été reçu a été récupéré d'une marque qui est resté 337 jours apposée au poisson. Une brève discussion a été fournie sur la façon dont la durée réelle du jeu de données de la marque est, dans la plupart des cas, plus courte que la période s'écoulant entre le déploiement et la remontée à la surface de la marque pop-up, car le détachement de la marque peut se produire quelques jours avant l'émission des signaux via satellite. Une brève analyse de la cause potentielle du détachement de la marque révèle qu'un grand nombre de détachements est dû aux activités de pêche (75%). L'analyse des performances au niveau de la déclaration des marques indique de légères améliorations technologiques au fil du temps. Les trajectoires des marques ont révélé de nombreux schémas intéressants de déplacement du thon rouge, certains d'entre eux étant auparavant inconnus. L'analyse du temps que le thon rouge passe près de la surface fait apparaître une différence significative dans son comportement pendant la saison de frai et pendant la saison de non-reproduction.

RESUMEN

El ICCAT / GBYP colocó más de 193 marcas PSAT durante cinco años (2011-2015) en diferentes zonas del Mediterráneo y en el Atlántico oriental, de las cuales se ha recuperado un total de 173 conjuntos de datos. El conjunto de datos más largo recibido se recuperó de una marca que permaneció 337 días colocada en el pez. Se planteó una breve discusión sobre si la duración real del conjunto de datos de la marca es, en la mayoría de los casos, más corta que el periodo entre la colocación y el momento en que emerge la marca, porque el desprendimiento de la marca puede tener lugar algunos días antes de que emerja. Un breve análisis de la posible causa de desprendimiento de la marca revela un elevado número de desprendimientos debidos a las actividades pesqueras (75%). El análisis del rendimiento de la comunicación de las marcas indica ligeras mejoras tecnológicas a lo largo del tiempo. Las trayectorias de las marcas revelaron muchos patrones de movimiento interesantes del atún rojo, algunos de los cuales se desconocían anteriormente. El análisis del tiempo que el atún rojo pasa cerca de la superficie demuestra la gran diferencia en su comportamiento durante la temporada de reproducción y la temporada de no reproducción.

KEYWORDS

Bluefin tuna, data collections, popup satellite archival tags, tagging, tuna behaviour

[1] ICCAT GBYP – Calle Corazón de Maria 8, 6th floor – 28002 Madrid (Spain).

1. Introduction

The ICCAT Atlantic Wide Research Programme for Bluefin Tuna (ICCAT GBYP) started with electronic tag activities on Atlantic bluefin tuna (*Thunnus thynnus*) in 2011 when the first few pop-up satellite tags were deployed. Over the course of 5 years, up to 2015, within the framework of this Program, or in joint actions with other institutions, more than 193 electronic pop-up tags were deployed (Di Natale *et al*. 2015, Di Natale *et al*. 2016). It is important to mention that the exact number of the tags deployed is somewhat higher, but still remains partly unknown, because some of the cooperating institutions, up to now, haven't provide any data to the ICCAT GBYP, despite repeated requests. Therefore, for the purpose of this study, only the tags with corresponding data on deployment were considered.

In the 2011, 8 tags were deployed, out of which 6 in Moroccan traps. A year after, significantly more tags were deployed, mainly off Morocco, in the Strait of Gibraltar and in the Bay of Biscay, reaching a total of 67 tags. In the 2013, 34 tags were released, mainly off Morocco, while in 2014 only one tag was deployed. A number of tags, precisely 83 were deployed in 2015, mainly in the purse seines in Levantine Sea, but also in the traps in the western Sardinia and Morocco.

In total, 64 electronic tags were deployed in the sea off Morocco, 30 in Levantine Sea, 28 off Sardinia, 27 in the Strait of Gibraltar, 21 in the Bay of Biscay and less in the other areas (Adriatic Sea, Gulf of Lion, Tyrrhenian Sea and Balearic Sea) (**Table 1**). Around two thirds of these fish (132) were medium-large adults, considering adult fish those of size of at least 120 cm and/or weight of at least 30 kg, and 61 specimens were juveniles. Most of adults were tagged in Moroccan traps, while juveniles were mostly tagged in the Bay of Biscay (**Table 2**).

From the tags deployed so far, ICCAT GBYP was able to recover 173 datasets. Up to date, a comprehensive data analysis has not been undertaken yet, and this study is the first attempt of a brief integrated analysis of electronic tag datasets. Nevertheless, all data have already been provided to the ICCAT SCRS scientific teams in charge of bluefin tuna modelling and MSE activities for their incorporation into the models.

2. Methodology

All pop-up satellite tags deployed within ICCAT GBYP were supplied by Wildlife Computers. We have always procured the newest and most advanced pop-up tag model developed by that manufacturer. At the beginning of the activities, Mk10-PAT model has been deployed on bluefin, but later on it was replaced by a more advanced and smaller MiniPAT. During a course of 5 years, we have experimented using different types of anchors for the attachment to the fish, in order to find the optimal for minimizing premature detachments as much as possible, taking into account also the tagging strategy requested by the ICCAT GBYP Steering Committee. Based on the trials and practical experience, we found that the Domeier darts type worked the best for our deployments, especially considering that a large number of them were underwater, an unusual technique indeed. Nevertheless, we have suggested to the manufacturer to start creating a new anchor specially designed for underwater tagging and provided him some practical ideas for that purpose.

ICCAT GBYP experimented both tagging fish on board (or at the surface) and underwater. While on board tagging incorporates the risk of higher fish post-tagging mortality and altered behaviour due to enhanced stress, along with the njot perfect tagging facilities that have been made available, it is easier from the point of view of the tag deployment, given that the anchor can be placed exactly where it would be most effective and have most holding strength. Deploying of tags underwater requires great skills and experience, considering that the tag should be attached as close as possible to the dorsal fin and the fish are usually nervous and fast swimming around. The fish were tagged underwater by well-trained and experienced divers, using a hand pole or specifically modified speargun (usually "arbalete" type, but also pneumatic types). Tagging was done in agreement with the guidelines set in the ICCAT GBYP Tagging Manual (Cort, 2010). The methodology was the one reported by Mariani *et al.* (2014) with the further improvements (Mariani *et al*., 2015), including the size estimates.

For the purpose of estimating bluefin geolocations and movements from tag data, all available datasets were processed using the best/latest available CLS algorithms. As well as the tag hardware have been improved over time, the software/algorithm for data processing has been more and more refined as well. Datasets up to 2014 were processed using the Ensemble Kalman Filter (ENSKF) model, while from 2014 onwards improved Hidden Markov Model (Grid Filter) has been used.

All datasets processed by the CLS were re-analysed afterwards by the GBYP Coordination, in order to remove non relevant data sequences, i.e. those that not correspond to the period the tag was attached to the freely moving fish. A tag pops-up and starts data transmission in the following cases: on scheduled date, when its pin breaks, if it's below 1700 meters or if the conditions are met for a conditional release. Conditional release happens in the cases when the fish dies and sinks or in case of premature detachment/fishing when the tag floats at the sea surface. It is important that the tag automatically initiate release and start the transmission immediately after it detaches from the fish or when the fish dies. The most of our tags (but not all) were configured in a way that they release after staying a certain number of days (currently 3 days) at the same depth. It is important to have in mind that the tag archives the data until it pops-up and that, in case of the conditional release, several latest days in a dataset correspond to the period when the tag was already detached from the fish or the fish was dead. In that case, attachment duration (retention period) doesn't correspond to the time between the deployment and pop-up, but to the time between the deployment and the effective tag detachment (few days prior to pop-up).

Therefore, a detailed analysis of all datasets was performed and all data between the detachment and pop-up were removed, because otherwise they would produce a considerable bias in an integrated analysis. Additionally, dataset sequences corresponding to the period when the fish that was not freely moving because of being fished (to our best knowledge) were also removed. Consequently, the effective duration of many datasets decreased, because the effective duration doesn't refer to the duration of tag archived data, but only to the number of days the tag was attached to the fish and the fish was freely moving. For instance, although one recovered dataset corresponds to 360 days deployment, the analysis revealed that the last 3 months the fish was lying dead on the bottom and therefore only 274 first days of the dataset were considered relevant, while the rest was deleted. In this case, the release mechanism seems not duly working. For the purpose of this paper and the tag data analyses, the duration of the datasets refers to the duration of the relevant sequence of the dataset only, i.e. while the fish was freely moving.

A brief analysis of the potential cause of the tag detachment was also performed. In the case the tag was released because of the reached interval for the release, the cause is obvious, as well as when a tuna exceeds the maximum depth (1700 m) or the pin breaks, because the tag reports it and transmits that information as well. It is also rather easy to detect fish mortality. It can be done by examining the diving patterns from the datasets time series of depth, when detecting that the fish was on the constant depth without further vertical movements. Nevertheless, it is rather difficult to distinguish if a tag release was due to the premature detachment or caused by a fishing activity, so the results of analyses are only approximated. By examining the time series of depth immediately prior to the tag detachment, it is sometimes possible to detect some unusual behaviour, for example that the fish stayed on the same depth for unusually long periods of time or that it had limited vertical movements. This can be attributed to fishing activities, although it should be taken with precaution. Also, sometimes it might be deducted from the characteristic tag trajectory after the pop-up (Argos data) that indicate that it was taken on board of the (fishing) vessel, rather than drifted by a current.

Finally, the GBYP Coordination performed a brief analysis of the bluefin vertical movements and diving patterns. For this purpose, tags time series of depth were analysed and put into correlation with geolocation estimates. In order to capture potential spawning, special attention was paid to the movements at the surface or immediately below it. Also, an analysis was made of the time bluefin tuna spend on the sea surface throughout the year. For this purpose, tags time at depth histograms were used.

3. Tag reporting performance and attachment duration

Out of 193 deployed tags, we have been able to recover 173 datasets. It seems that 4 tags have never transmitted, due to their malfunction or some other unknown reason. Other 16 tags did transmit, but the information they provided was corrupted and illegible or, due to the early post-tagging mortality or tag detachment, received datasets were not useful. Out of 173 datasets, 140 correspond to more than 7 days long deployments.

The longest received dataset was recovered from the tag which stayed attached 337 days on the fish (deployed 2014 in the Strait of Gibraltar). The mean dataset duration is much less, reaching 61 days only, but this is mainly due to number of short deployments because of fishing activities, as was recognised by Righton *at al*. (2015). For example, although the maximum dataset duration for the tags deployed in 2015 is 200 days, the mean retention of the same tags is 30 days only. In comparison, for the tags deployed in 2012, mean dataset duration is 93 days, while the maximum reach 274 days (**Table 3**). Out of 173 tags whose datasets have been recovered, 53 stayed more than 2 months attached on the fish, 34 tags stayed more than 4 months and 19 stayed more than 6 months on a bluefin (**Table 4**).

The recovered datasets are of different quality, depending on the quantity of information tags were able to transmit through satellite and finally the information that was received and decoded. We were able to extract the complete archived data only from the few tags that were physically recovered, while the other dataset received via satellite are always partial. One smaller or bigger part of the data is always lost in the transmission. Maximum amount of the data one tag was able to transmit was 92%. In average, leaving aside the complete datasets physically extracted from the tags, recovered datasets contain around 78% of the originally archived data. It seems there is a growing trend in the quantity of data successfully transmitted over the past few years, probably due to the improvements in the technology (**Table 5**).

4. Reading the datasets: bluefin horizontal movements

In order to examine bluefin movements between the Atlantic Ocean and the Mediterranean Sea, a brief analysis of tag trajectories was made (**Table 6**). For this purpose, only the tags with the effective retention period of more than 7 days were considered (n=140). Of the tunas that were tagged on eastern Atlantic coast (n=65), 55% entered in the Mediterranean, while of the tunas tagged in the Mediterranean (n=55), only 4% exited Mediterranean and entered the Atlantic. Of the bluefin tagged in the Strait of Gibraltar (n=20), 60% entered the Mediterranean. These results are informative only and should be taken with very much precaution. Not only that the tag retention time varied a lot, but also the tags were deployed in different time periods. Some deployments coincided with the bluefin seasonal migration between the Atlantic and the Mediterranean and the others didn't.

For the purpose of examining bluefin distribution depending on the season, daily geolocation estimates were pulled together, of 173 tunas tagged in the period between 2011 and 2015 (**Figure 1**) and plotted by month (**Figure 2**).

Tag trajectories revealed some very interesting bluefin tuna movements and migration paths. A tuna that was tagged in May 2012 in Morocco entered the Mediterranean and went to Tyrrhenian Sea in June where it probably spawned, exited the Mediterranean afterwards and headed north towards Norway, where its tag finally popped up after 93 days (**Figure 3**). The other bluefin that was tagged in Morocco in May 2013 also entered to Mediterranean and Tyrrhenian in June, but after exiting the Med headed east, towards Newfoundland (**Figure 4**). In the 2015, we were able to recover data from 2 tags deployed on the very end of May on adults in Eastern Mediterranean (Levantine Sea), that stayed attached long enough to witness these tuna entering the Atlantic in the beginning of July and going towards north. One tuna got it tag detached after 50 days off Galicia (**Figure 5**) and the other reached Faroe Islands and then after 82 days its tag pin broke (**Figure 6**).

Righton *at al*. (2015) recognise the recovery of ~180 datasets from electronic tags as one of the GBYP tagging programme key achievements, because that provide evidence of the complexity and diversity of bluefin movements and behaviour within the Mediterranean and eastern Atlantic.

5. Reading the datasets: bluefin tuna free vertical movements

For the purpose of identifying potential spawning grounds, geolocation estimates of all the moments bluefin tunas reached the sea surface (0-2 m) were pulled together and plotted, but only for the months when spawning theoretically may usually occur **(Figure 7)**.

The analysis of the time bluefin tuna spent on the sea surface in dependence to the time of the year, namely the spawning season (**Table 7**), reveals there is no obvious correlation between the percentage of time spent in the uppermost sea layer (from 0 to 2 meters depth) and the corresponding month. Nevertheless, a clear correlation does exist taking into account a deeper surface layer (from 0 to 10 meters depth). While the mean percentage of time bluefin spend at the surface throughout the year is 47.79%, during the spawning season it is higher than the average **(Figure 8),** presumably due to the fact that spawning activities occur mostly at the surface or in the upper layer of the sea, because usually bluefin tuna spawning would need also a well-defined thermocline for activating the last part of the physiological process. The results of the two sample student's t-test show there is a significant difference (t=3.87, 10 d.f., P=0.003) between an expanded spawning season (May-August) and the non-spawning season (September-April). Additional analysis of the July data shows that bluefin tuna spent more time on the surface (0-10 m) in the first part of the month (60.51%), than in the second part (58.57%), what is, again, in direct correlation with spawning activities and the known features of the spawning season in the Mediterranean Sea.

6. Reading the datasets: Analysis of tag detachment cause

Out of 173 tags whose datasets GBYP was able to recover, only 5 detached and popped up on the exact date they were programmed to (**Table 8**). 8 of them popped up when their pin broke and 5 when they exceeded the maximum depth set by the tag producer (1700 m). Mortality was also rather high among tagged tuna; 17 tags detached when the tuna died and sunk. The majority of the tags detached prematurely, either because the tag anchor detached from the fish or because the fish was captured and the tag removed. In these cases, it is impossible to determine the cause with absolute certainty and in lots of cases it is difficult to distinguish the possible fishing activity. For the purpose of this study, the cause of the detachment was attributed to fishing activities only where the probability for such an event was huge. In other cases, when the cause of detachment was less clear or certain, the tags were left in the category "unknown". If a small tagged bluefin tuna is swallowed by a predator (shark or cetacean, then it is quite difficult to detect the event, but the lack of light data sometimes might help. There was also a number of tags missing parts of the dataset that can provide better insight in the tag trajectory and vertical movements prior to its pop-up, in which cases it was not possible to determine the cause of detachment.

For the first time, GBYP Coordination tried to set-up a procedure for analysing these events. It is necessary to carry out a complex analysis of the detailed data for each tag, cross-checking them and trying to get a reasonable amount of circumstantial cumulated and correlated evidences for better defining the event.

- Vertical movements: the analysis is carried out on the detailed depth series provided by each tag, with 10' interval. It is essential to analyse the last days (usually between 1 and 3 days, depending on the pattern provided by the last data on depth and time); a preliminary control is carried out also using the correlated temperature at depth, for checking the functionality of the sensors. Missing data can create additional problems in the analyses.
- Argos data: the data obtained after the tag release are very useful for checking if the release area coincides with a known fishing area for a given gear or for various fishing gears, at that time of the year. When tracks are on land (i.e.: a fishing harbor or industrial plants), the evidence that this tag was retained by a fisherman increases substantially, providing fundamental support for a fishery event.
- Fish track: the track before the tag release sometimes provides additional elements for identifying a normal behavior or unusual movements.
- Min-max depth: the daily data on minimum and maximum depth, in correlation with the bathymetry, may help for defining the fish behavior and for providing possible correlations with sea-mounts.

A deep knowledge about the various types of fishing gears and the tuna behavior in correlation with each of them is essential.

After the analyses, these are the features of the tag data that have been possibly correlated with a given fishing gear type:

a) LONG LINE (common "surface" drifting one, depth not more than 60 m, targeting SWO or BFT)

- ✓ Hooking usually at night-time, or in marginal hours of the day.
- ✓ Limitation of vertical movements in depth (might be slightly deeper than the depth of the hook)
- ✓ Many vertical movements, sometimes up to the surface.
- ✓ Several dives at the same max depth
- ✓ If the fish is fished still alive, surfacing is fast in the last part, with several variations.
- ✓ If the fish died, there is a time at the same depth (usually the depth of the hook), followed by a constant surfacing speed.
- ✓ Most of the catches are over sea mounts.

b) LONG LINE (deep drifting type, usually targeting big SWO)

- ✓ Limitation of vertical movements in high depth
- ✓ Many vertical movements, sometimes up to the surface.
- ✓ If the fish is fished still alive, surfacing is fast in the last part, with several variations.
- ✓ If the fish died, there is a time at the same depth (usually the depth of the hook), followed by a constant surfacing speed.
- ✓ Most of the catches are over deep sea mounts.

c) LONG LINES (all), fish entangled in the line

- ✓ Before the entanglement, the fish has the usual behavior described above.
- ✓ After the entanglement, vertical movements are much more limited.
- ✓ Surfacing is very fast and constant, depending only on the retrieval speed of the LL.

d) TROLL line (including sport fishing)
- ✓ Fish hooked not far from the surface, behavior showing tentative of deeper dives, all very fast.
- ✓ Many short and quick vertical movements, last movements all close to the surface.
- ✓ Catches are usually at day-time.

e) HAND LINES
- ✓ Fish showing fast movements, including vertical ones, for not more than a couple of hours, usually much less.
- ✓ Surfacing is a slow process, always with small variation in depth. Last part is very slow.
- ✓ Catches are usually at day time, but not always.
- ✓ This is a gear which is very difficult to detect.

f) BAITBOAT
- ✓ Usually the catch is very close to the surface and the fish stay for just a few minutes at the hook.
- ✓ The behavior shows the fish going quickly close to the surface for eating the bait/hook and then suddenly surfacing.
- ✓ Catches are usually at day-time.

g) PURSE-SEINE (for fish to be moved into cages)
- ✓ Catches may happen up to about 300 m depth.
- ✓ The fish usually have vertical movements for a couple of hours, always at less max depth depending on the retrieval speed of the seine.
- ✓ If the fish will stay alive, then the transfer into the transport cage will show the fish always within the maximum depth of the cage.
- ✓ If the fish die before the transfer, then it will stay for a short time at the same depth (just the time necessary for transfer all fish into the cage) and then it is recovered by a diver; it comes to the surface very quickly.
- ✓ Catches are usually at day time.
- ✓ This is a gear which is quite difficult to detect.

h) PURSE-SEINE CATCHES MOVED TO TRANSPORT CAGES
- ✓ The first part of the behavior is as above described
- ✓ When the cage starts moving, quite often the tunas will stay for the first days about at the same depth;
- ✓ If a tagged fish is inside the cage and it stays for three days about at the same depth (or within the depth range of the sensitivity at that moment, but always at not deeper than 35 m), then the tag pops-off.
- ✓ This type of data set is always difficult to be interpreted and only the examination of the position compared to the bathymetry and all other data can sometimes provide the explanation.

7. Cost-benefit analysis

In 2015 ICCAT (both the SCRS and the Commission) had requested a cost-benefit analysis of the entire tagging activity carried out by ICCAT GBYP since the beginning. The results were provide within Phase 5 (Righton *et al*., 2016).

As concerns the costs for carrying out the PSAT tagging under GBYP, Righton et al. (2016) stated the followings: “Taking into account the costs of all the components of the GBYP tagging programme, the unit cost of each recovered tag is €9,481, and for each recovered fish €13,186. This compares favourably with the estimated cost of tag recovery in previous tagging programmes (STECF, 2008) of around €15,000 per fish (note that this has not been inflated to current prices). If physical recoveries of electronic tags are excluded from the calculation (i.e. the cost of deploying electronic tags is excluded), the unit cost per fish falls to €11,713. Electronic tags have cost €30,021 on average, taking into account deployment and procurement costs, for each physical recovery, but this cost falls dramatically when the number of recovered tag datasets is included because PSAT tags do not have to be physically recovered in for their data to be received; each dataset costs €4,868. This compares favourably with previous indicators (€20,000; STECF, 2008), largely because the reliability of tag data transmission has increased dramatically in the last decade, but also because the electronic tagging activity of the GBYP was often undertaken in collaboration with other organisations (e.g. WWF MEDPO, 2012; Di Natale & Idrissi, 2012), and was therefore delivered at lower cost than through sole deployment.”

The above mentioned costs, which have been obtained with a careful management of all contracts, but also with the dedication of all ICCAT GBYP contractors and collaborators, are lower even if compared to other electronic tagging activities carried out outside Europe.

8. Conclusions

The first five years of PSAT tagging activities carried out by ICCAT GBYP provided a first broad overview about the behavior of bluefin tunas of different ages that were tagged in the eastern Atlantic and the Mediterranean Sea. Even if the data are far too be perfect and the quality of all parts of this activity can be further improved, the amount of data recovered so far is quite important and will possibly allow for many further analyses for detecting more specific bluefin tuna behaviours.

This first tagging activity allowed to discover new movement patterns that were fully unknown before GBYP (i.e.: from Turkey to the North Sea, or for the movements from tunas tagged in Moroccan traps and going close to the Straits of Gibraltar), while others were confirmed or refined.

The opportunity to join the results of electronic tagging with those provided by other ICCAT GBYP activities, such us the genetic and micro-chemical analyses, allowed us to find the possible explanation of some unexpected behaviours, and this was specifically the case of the tagging results in Moroccan traps (Di Natale and Tensek, 2016, Di Natale *et al*., 2016).

At the same time, due to the constant monitoring of the main environmental and oceanographic parameters and the occasional coincidence of an aerial survey sighting in 2015, a serendipity result confirmed an opportunistic spawning in a marginal area off Algeria (Di Natale and Tensek, 2016, Di Natale *et al*., 2016), an important information that would never be available otherwise.

More efforts are needed for better understanding the behavior of those bluefin tuna which remain in the Mediterranean Sea after the spawning season, while mixing between the two stocks can be further refined by tagging bluefin tunas after the spawning season in the Atlantic Ocean. Both these issues have been faced in Phase 6 and tagging activities have been planned accordingly. The possible movements in the southern part of the Atlantic Ocean still remain unknown.

References

Cort J. L., Abascal F., Belda E., Bello G., Deflorio M., De la Serna J.M., Estruch V., Godoy D., Velasco M., 2010, Tagging Manual for the Atlantic-Wide Research Programme on Bluefin Tuna (GBYP). http://www.iccat.int/GBYP/Documents/TAGGING/PHASE%201/ICCAT%20GBYP%20TAGGING%20MANUAL_fin_rev.pdf

Di Natale A., and Idrissi M., 2012, 2011 ICCAT Atlantic-wide research programme for Bluefin Tuna (GBYP) - Coordination detailed activity report for Phase 2. Section 5.6. Collect. Vol. Sci. Pap. ICCAT, 68(1): 176-207 (2012).

Di Natale, A., Idrissi, M., 2015, Review of the ICCAT GBYP tagging activities 2010-2014. Collect. Vol. Sci. Pap. ICCAT, 71(3): 1125-1143.

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., Tensek, S., Pagá García, A., 2016, Preliminary Information about the ICCAT GBYP Tagging Activities in Phase 5. Collect. Vol. Sci. Pap. ICCAT, 72(6): 1589-1613.

Mariani, A., Dell'Aquila, M., Valastro, M., Buzzi, A., Scardi, M., 2015, Conventional Tagging of Adult Atlantic Bluefin Tunas (Thunnus thynnus) by Purse-Seiners in the Mediterranean – Methodological Notes. ICCAT, Collect. Vol. Sci. Pap. ICCAT, 71(4): 1832-1842.

Mariani, A., Dell'Aquila, M., Scardi, M., Valastro M., 2016, Electronic Tagging of Adult Bluefin Tunas (Thunnus thynnus) in the Eastern Mediterranean and Sardinian Sea; Improving the Precision of Tuna Size Estimates. Collect. Vol. Sci. Pap. ICCAT, 72(7): 1808-1814.

Righton, D., De Oliveira, J., Metcalfe, J., Payne, A., Riley, A., Scutt- Phillips, J., Wright S., 2016, Cost-benefit analysis of the ICCAT GBYP tagging programme http://www.iccat.int/GBYP/Documents/TAGGING/PHASE%205/TAGGING_PHASE5_REVIEW.pdf

WWF MEDPO, 2012, "On the Med Tuna Trail". 2011 Bluefin tuna tagging expedition. Report for ICCAT. http://www.iccat.int/GBYP/Documents/TAGGING/PHASE%202/WWF_MEDPO_GBYP_%202011%20tagging%20expeditions.pdf

Table 1. Electronic pop-up tags deployed by ICCAT GBYP on Atlantic bluefin tunas in the period 2011-2015 by area and year.

Deployment area/year	*2011*	*2012*	*2013*	*2014*	*2015*	***Total***
Adriatic Sea	1	1	7			**9**
Balearic Sea		1		1		**2**
Bay of Biscay		14	7			**21**
Gibraltar		21	6			**27**
Gulf of Lion	1	6				**7**
Levantine Sea					30	**30**
Morocco	6	24	14		20	**64**
Tyrrhenian Sea					5	**5**
West of Sardinia					28	**28**
Total	**8**	**67**	**34**	**1**	**83**	**193**

Table 2. Electronic pop-up tags deployed by ICCAT GBYP by deployment area and tuna age.

Deployment Area/Maturity	*Adult*	*Juvenile*	***Total***
Adriatic Sea	2	7	9
Balearic Sea	2		2
Bay of Biscay		21	21
Gibraltar	12	15	27
Gulf of Lion	2	5	7
Levantine Sea	30		30
Morocco	64		64
Tyrrhenian Sea	2	3	5
West of Sardinia	18	10	28
Total	**132**	**61**	**193**

Table 3. Number of datasets recovered from the electronic pop up tags deployed by ICCAT GBYP and their minimal duration, maximal duration and mean duration (+/-SD), by year. The duration of datasets doesn't always correspond to the time between the tag deployment and its pop-up, but only to the time the tag stayed attached to a freely moving fish (equal or less time).

Deployment year	*Number of datasets*	*Dataset duration (days) - MIN*	*Dataset duration (days) - MAX*	*Dataset duration (days) - MEAN*	*Dataset duration (days) - SD*
2011	5	3	298	82	110
2012	55	2	274	93	88
2013	31	5	337	83	70
2014	1	14	14	14	0
2015	81	1	200	30	42
Total	**173**	**1**	**337**	**61**	**73**

Table 4. Number of datasets recovered from the electronic pop up tags deployed by ICCAT GBYP according to the different categories of their duration (number of days).

Dataset duration category (No. of days)	*No. of datasets*
1-7	33
8-20	37
21-60	50
61-120	23
121-180	11
>180	19
Total	**173**

Table 5. Different quality of the datasets recovered from the electronic pop up tags deployed by ICCAT GBYP, according to the absolute number of dataset recovered and minimum, maximum and mean (+/-SD) percentage of dataset decoded, by year.

Deployment year	*Number of datasets*	*Total data percentage decoded - MIN*	*Total data percentage decoded -MAX*	*Total data percentage decoded -MEAN*	*Total data percentage decoded - SD*
2011	5	59	87	67	11
2012	55	48	92	76	13
2013	31	44	90	77	12
2014	1	72	72	72	0
2015	81	36	91	80	9
Total	**173**	**36**	**92**	**78**	**11**

Table 6. Bluefin tuna movements between the Atlantic Ocean and the Mediterranean Sea, according to the estimate trajectories recovered from the tags deployed by ICCAT GBYP, according to the deployment area and number (percentage) of the fish that was following the similar pattern. Only datasets of more than 7 days were used.

Deployment area	*First destination*	*Percentage*	*Total number of datasets >7 days*
Atlantic	Atlantic	45%	29
	Mediterranean	55%	36
Gibraltar	Atlantic	40%	8
	Mediterranean	60%	12
Mediterranean	Atlantic	4%	2
	Mediterranean	96%	53
Total			**140**

Table 7. Mean percentage of time spent on the sea surface up to 2 meters depth and up to 10 meters depth, of all bluefin tuna that were tagged by GBYP, by month.

Month	*Mean time spent at 0-2 m depth (%)*	*Mean time spent at 0-10 m depth (%)*
January	31,02	43,88
February	27,82	39,05
March	26,73	41,12
April	37,31	48,45
May	26,13	48,73
June	25,26	56,19
July	23,70	59,70
August	25,79	50,87
September	27,86	47,42
October	29,06	46,65
November	31,63	45,10
December	35,65	46,33
Total	**29,00**	**47,79**

Table 8. The exact (interval, mortality, pin broke, max depth exceeded) or probable (premature detachment or fishing) cause of detachment of the tags deployed by ICCAT GBYP the datasets of which have been recovered, by year. Since in later cases it is impossible to determine the cause of detachment with absolute security, it was attributed to fishing activities only where the probabilities were many according to the criteria, while where was less certain it was left in the category of premature detachment, although possibly a majority of these fish was captured as well.

Deployment year/ Detachment Cause	*unknown*	*probable fishing*	*interval*	*mortality*	*pin broke*	*max depth exceeded*	***Total***
2011	1	1	1	2			**5**
2012	2	44	2	5	2		**55**
2013	3	15		6	3	4	**31**
2014				1			**1**
2015	3	69	2	3	3	1	**81**
Total	**9**	**129**	**5**	**17**	**8**	**5**	**173**
Total (%)	**5%**	**75%**	**3%**	**10%**	**5%**	**3%**	**100%**

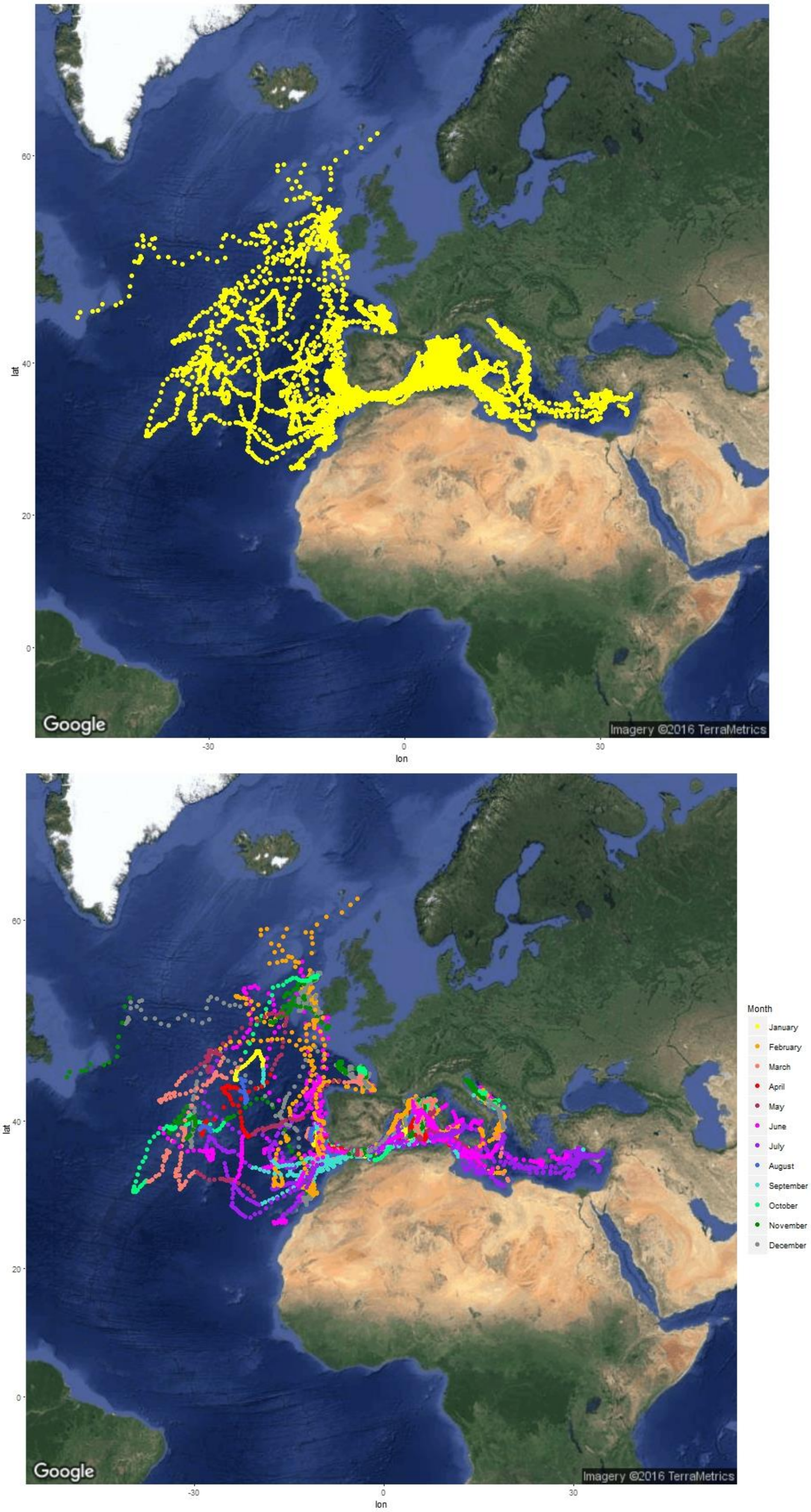

Figure 1. Upper image: Daily geolocation estimates of 173 bluefin tunas tagged by ICCAT GBYP in the period between 2011 and 2015 pooled together; lower image: Each month is represented by a different colour.

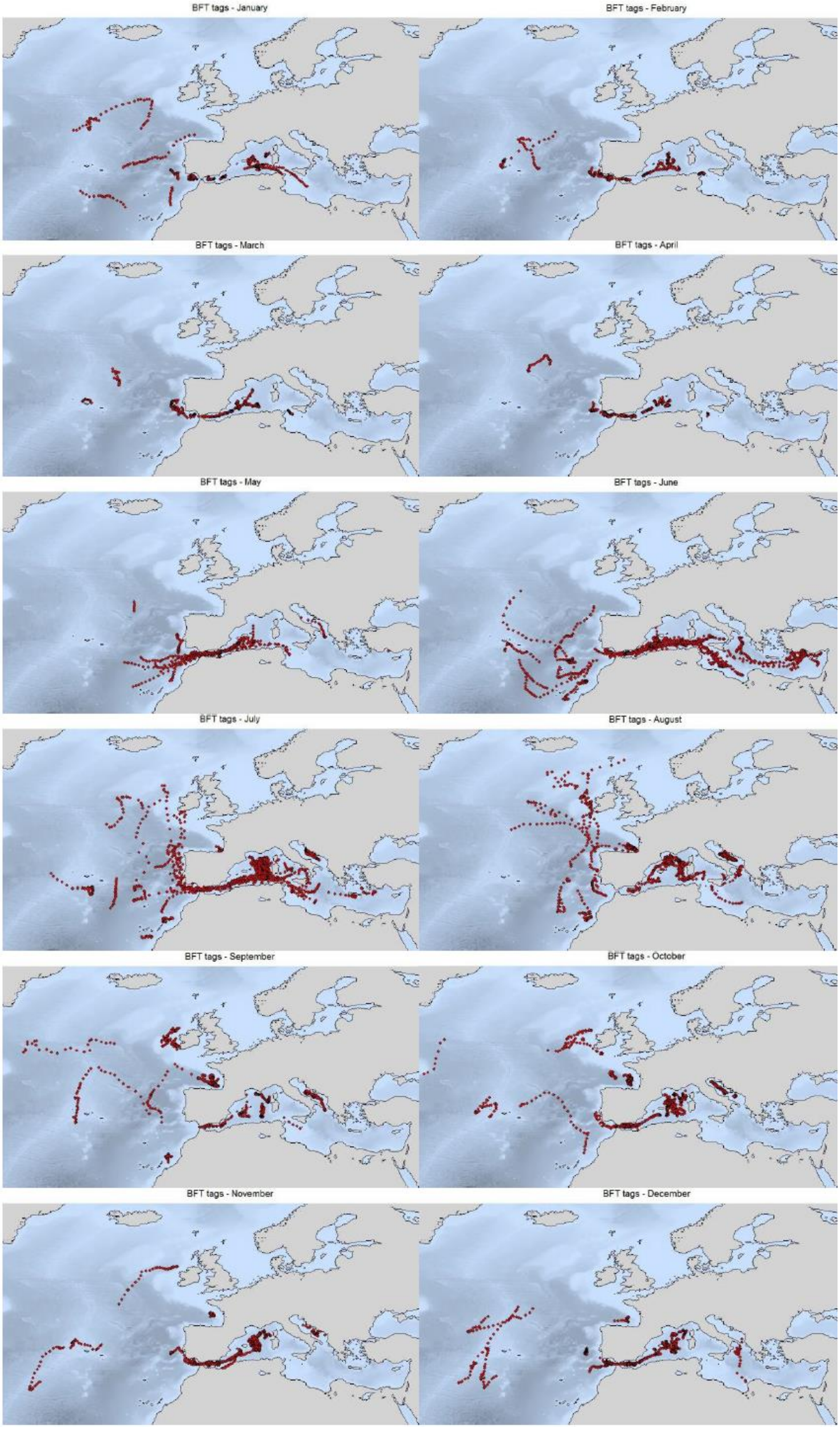

Figure 2. Daily geolocation estimates of 173 bluefin tunas tagged by ICCAT GBYP in the period between 2011 and 2015, by month.

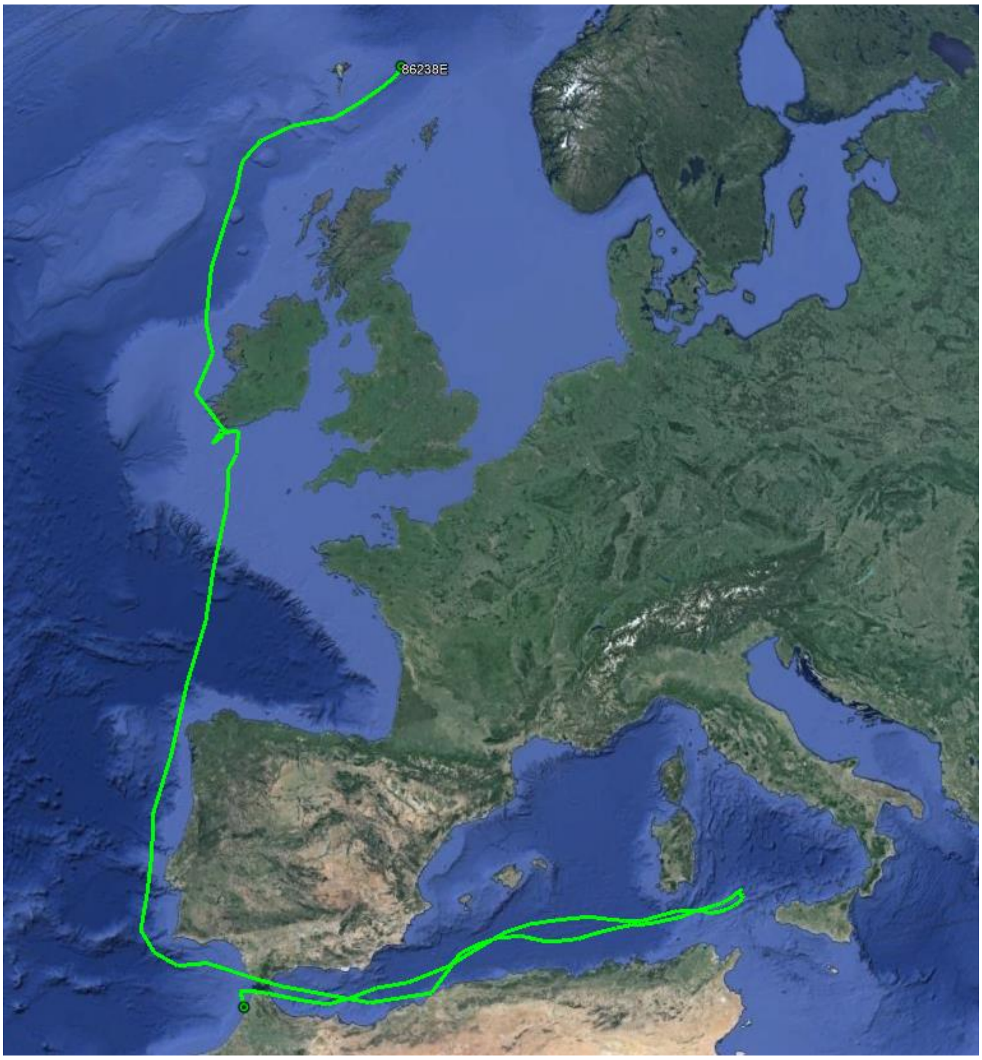

Figure 3. Estimated track of a tag 86238E deployed in Morocco on 14 May 2012 that popped up after 93 days.

Figure 4. Estimated track of a tag 118760 deployed in Morocco on 25 May 2013 that popped up after 142 days.

Figure 5. Estimated track of a tag 145461 deployed in Turkey on 31 May 2015 that popped up after 50 days.

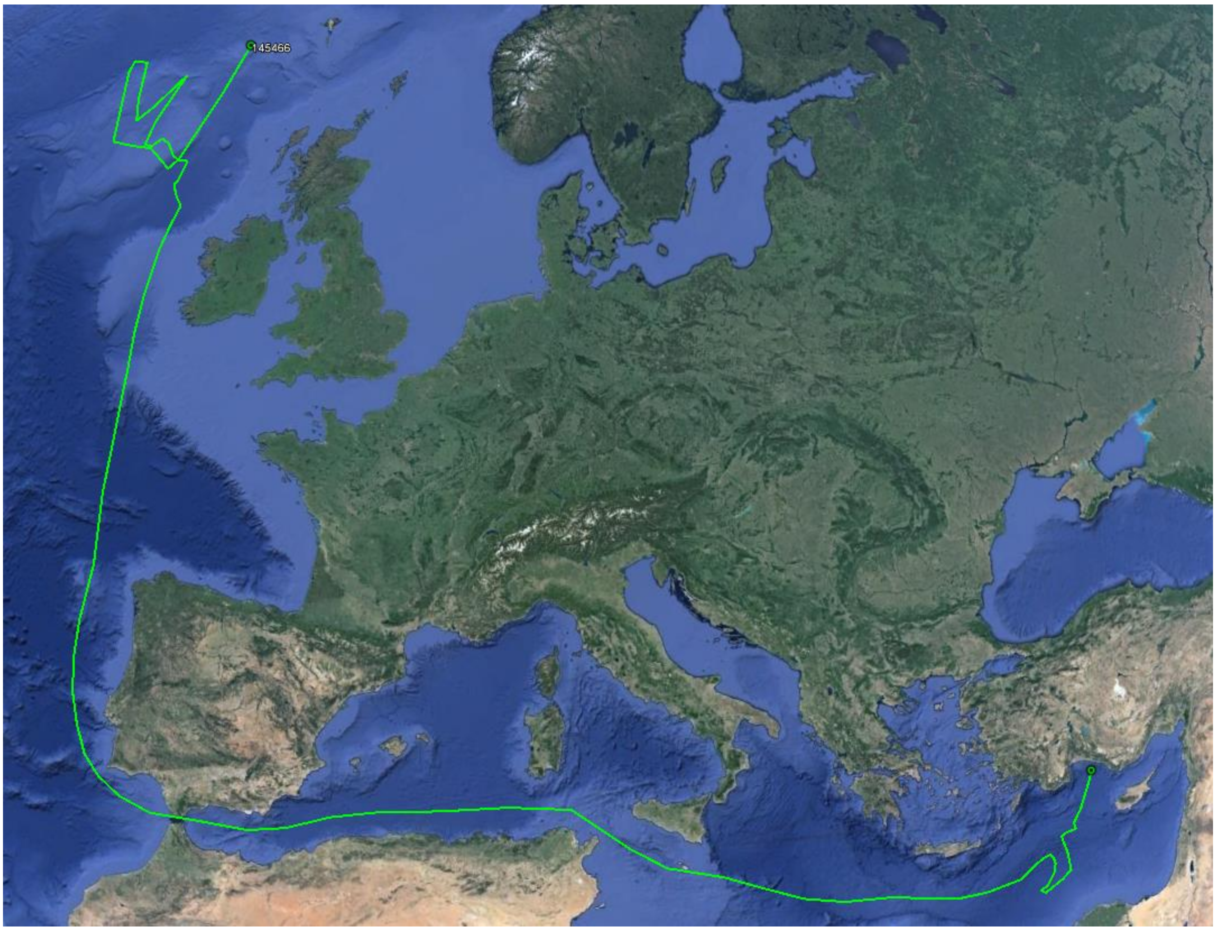

Figure 6. Estimated track of a tag 145466 deployed in Turkey on 31 May 2015 that popped up after 82 days.

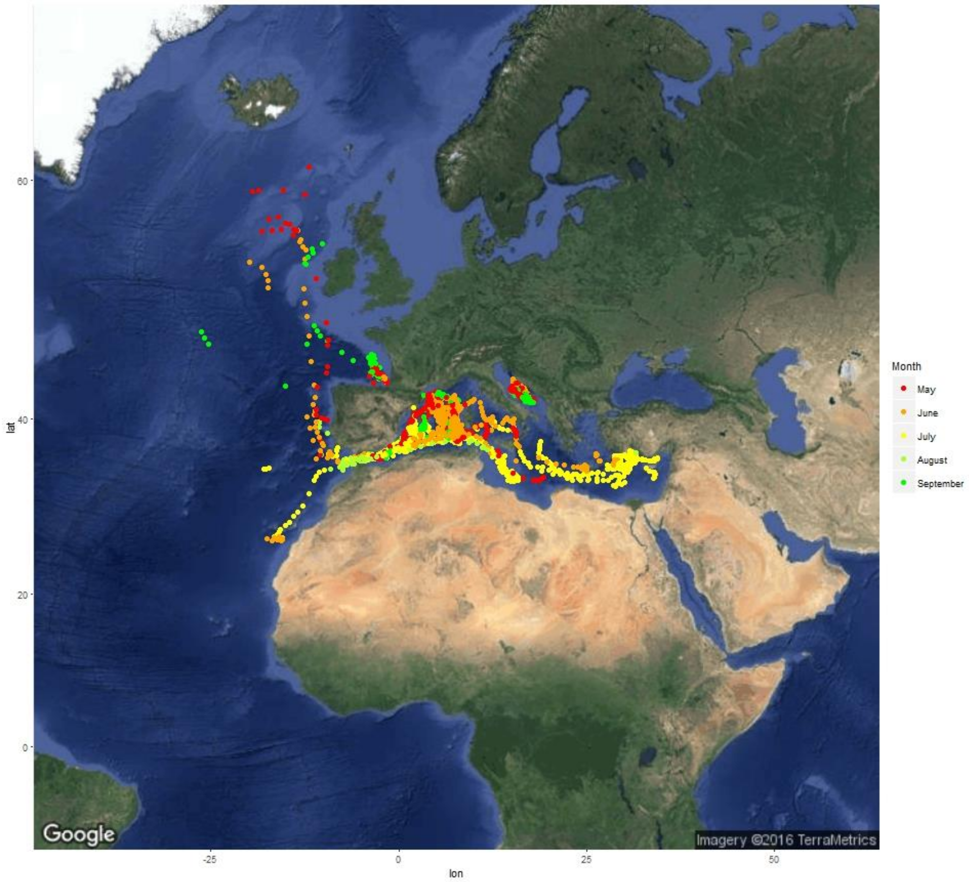

Figure 7. Estimated geolocations of bluefin tunas at surface (0-2 m), for all bluefin tunas tagged by ICCAT GBYP. Each month is represented by different colour. Only the period of the year that corresponds to potential spawning activities was taken into account.

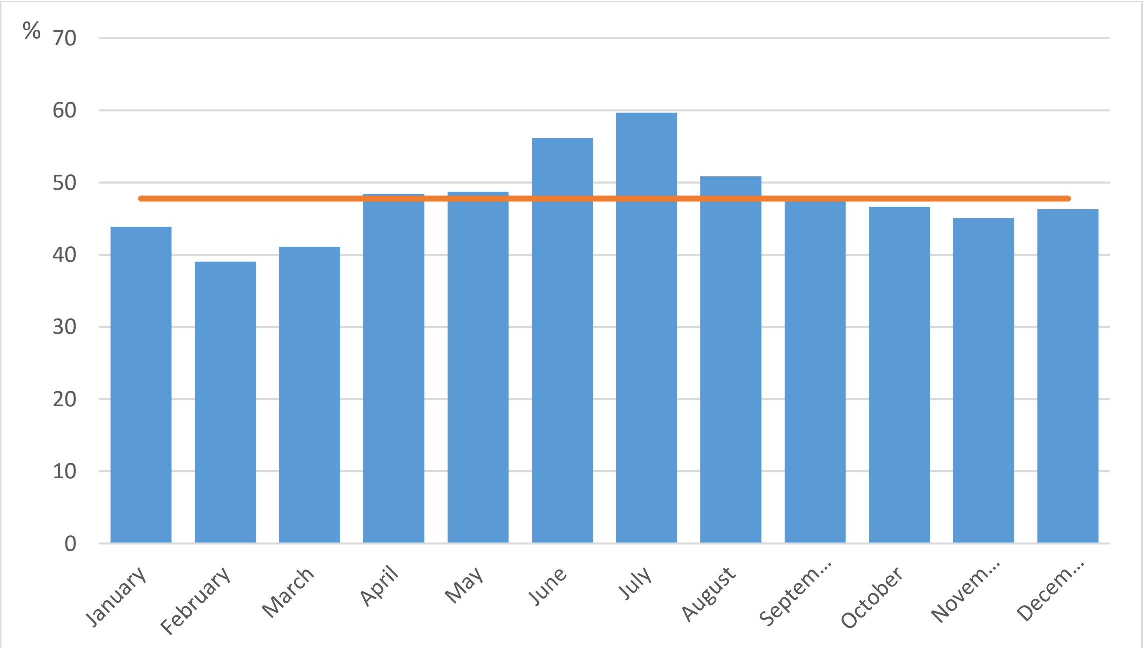

Figure 8. Mean percentage of time bluefin tuna spent on the surface (0-10 m) by months, according to the data provided by electronic pop up tags deployed by ICCAT GBYP. Orange line represents the mean percentage of time spent on the surface (1-10 m) throughout the year.