SUMMARY OF BLUEFIN TUNA TAGGING ACTIVITIES CARRIED OUT BETWEEN 2009 AND 2010 IN THE EAST ATLANTIC AND MEDITERRANEAN

Antonio Medina[1], José Luis Cort[2], Guillermo Aranda[1],
José Luis Varela[1], Lourdes Aragón[1], Francisco J. Abascal[3]

SUMMARY

A total of 140 archival (MK9, Wildife Computers®; LTD2310, Lotek Wireless®) and 31 pop-up tags (MK10 and MiniPAT, Wildlife Computers®) implanted on Atlantic bluefin tuna (ABFT) where deployed in the eastern Atlantic and Mediterranean between 2008 and 2010. Only two archival tags have been recovered so far, whereas 9 pop-up tags have been returned. Although the pop-up tags were programmed to detach 12 months after their deployment, the maximum retention time recorded is 101 days. Of the 29 pop-up tags attached to Atlantic bluefin tuna breeders in the Balearic spawning ground, 10 (34.5%) popped off earlier than 15 days after deployment, another 10 surfaced between 15 and 44 days, and 9 (31%) were retained for over 44 days. Most of the tags that remained attached for 45 days or longer (7 of 8) surfaced in the Atlantic, but one popped off only 100 miles east of the deployment site. This suggests that the majority of spawners tagged at the beginning of the reproductive season in the western Mediterranean spawning ground tend to initiate the backward migration to Atlantic waters once the reproductive function has been accomplished, though a small proportion of breeders may stay for longer in the Mediterranean Sea.

RÉSUMÉ

Au total, 140 marques-archives (MK9, Wildife Computers®; LTD2310, Lotek Wireless®) et 31 marques pop-up (MK10 and MiniPAT, Wildlife Computers®) ont été apposées sur des thons rouges de l'Atlantique (ABFT) qui ont été déployées dans l'Atlantique Est et la Méditerranée entre 2008 et 2010. Seules deux marques-archives ont été récupérées jusqu'à présent, tandis que neuf marques pop-up ont été retournées. Même si les marques pop-up étaient programmées pour se détacher 12 mois après leur déploiement, le temps de rétention maximum enregistré a été de 101 jours. Parmi les 29 marques pop-up apposées sur des reproducteurs de thon rouge de l'Atlantique dans la zone de frai des Baléares, 10 (soit 34,5 %) se sont détachées avant les 15 premiers jours de déploiement, 10 autres ont atteint la surface entre le 15e et le 44e jour et 9 (soit 31 %) sont restées apposées pendant plus de 44 jours. La plupart des marques qui sont demeurées apposées pendant 45 jours ou plus (sept sur huit) ont atteint la surface dans l'Atlantique, mais l'une d'entre elles est apparue à seulement 100 milles à l'Est du lieu de déploiement. Cela suggère que la majorité des reproducteurs marqués au début de la saison de reproduction dans la zone de frai située à l'Ouest de la Méditerranée ont tendance à entamer leur migration de retour dans les eaux atlantiques une fois que la fonction reproductive a été accomplie, même si une faible proportion de reproducteurs peut demeurer plus longtemps dans la Méditerranée.

RESUMEN

Un total de 140 marcas archivo (MK9, Wildife Computers®; LTD2310, Lotek Wireless®) y 31 marcas pop-up (MK10 and MiniPAT, Wildlife Computers®) implantadas en atunes rojos del Atlántico (ABFT) fueron liberadas en el Atlántico este y Mediterráneo entre 2008 y 2010. Hasta ahora sólo se han recuperado dos marcas archivo, y nueve marcas pop-up. Aunque las marcas pop-up estaban programadas para soltarse 12 meses después de su colocación, el tiempo de retención máximo registrado hasta la fecha es de 101 días. De las 29 marcas pop-up colocadas en reproductores de atún rojo Atlántico en las zonas de reproducción de Baleares, 10 (34,5%) se liberaron trascurridos menos de 15 días tras su colocación, otras emergieron en

[1] Departamento de Biología, Universidad de Cádiz. antonio.medina@uca.es
[2] Instituto Español de Oceanografía (Centro de Santander).
[3] Instituto Español de Oceanografía (Centro de Tenerife).

el transcurso de entre 15 y 44 días y 9 (31%) se mantuvieron durante más de 44 días. La mayoría de las marcas que permanecieron colocadas durante 45 días o más (7 de 8) emergieron en el Atlántico, pero una emergió a solo 100 millas al Este del sitio de colocación. Esto sugiere que la mayoría de los reproductores marcados al inicio de la temporada de reproducción en la zona de desove del Mediterráneo occidental tienden a iniciar la migración de regreso a aguas del Atlántico una vez que han cumplido su función reproductiva, aunque una pequeña proporción de reproductores podría permanecer más tiempo en el Mediterráneo.

KEY WORDS

Electronic tagging, bluefin tuna, Thunnus thynnus*, pop-up satellite tags*

1. Introduction

In the last decades the Atlantic bluefin tuna (ABFT), *Thunnus thynnus* (L.), has been subject to intense over-fishing, which has caused a decline in both the eastern and western populations (ICCAT, 2008). In spite of the economic importance of the species, the population structure of the ABFT remains unclear and controversial. The development of electronic tags in recent years has provided a wealth of information on the behavior, habitat preferences and horizontal movements of ABFT (e.g. Lutcavage *et al*., 1999, 2000; Block *et al.*, 2001, 2005; Brill *et al*., 2002; Stokesbury *et al*., 2004; Wilson *et al*., 2005; Sibert *et al*., 2006; Teo *et al*., 2007; Wilson and Block, 2009; Galuardi *et al*., 2010). However, most of the tagging surveys have been carried out in the northwestern Atlantic Ocean, off the northeastern coast of the United States and Canada. In the eastern Atlantic and Mediterranean, there are fewer electronic tagging studies (e.g. Yamashita and Miyabe, 2001; De Metrio et al., 2001, 2002, 2005a,b; Semba and Takeuchi, 2009; Fromentin, 2010; et al., 2011), mainly based on pop-up tags. Although these studies have improved our knowledge on the species' behavior and distribution, the short retention time of pop-up tags, the low return rate of archival tags, and the difficulty to cover different areas and time strata result in a highly incomplete understanding of the stock structure in the eastern Atlantic and Mediterranean.

A research project funded by the Spanish Ministry of Science and Innovation and the Government of Andalusia is being carried out with the aim of improving our knowledge on the migratory patterns of the ABFT in the eastern Atlantic and Mediterranean Sea, as well as their relationship with the trophic and reproductive ecology of the species. The project is being developed jointly by the University of Cadiz and the Spanish Institute of Oceanography. Archival tags obtained from a research agreement between IEO and ICCAT, partially funded in the framework of the EU Data Collection Regulation, have also been deployed and are included in the present progress report. With regard to the reproductive study, the main goals of the project are the spatial and temporal characterization of the reproductive condition in the western Mediterranean Sea, and the determination of key reproductive parameters, such as spawning frequency and fecundity. The central objective of the trophic study is the identification of principal prey species and preferential foraging grounds. Horizontal and vertical movements are being estimated using electronic archival and satellite tags. In the present document we report preliminary results of the ongoing tagging activities.

2. Materials and methods

A total of 140 archival (MK9, Wildife Computers®; LTD2310, Lotek Wireless®) and 31 pop-up tags (MK10 and MiniPAT, Wildlife Computers®) implanted on ABFT where deployed in the eastern Atlantic and Mediterranean between 2009 and 2010. Data on tag deployments and pop-up positions are summarized and illustrated in **Table 1** and **Figures 1** and **2**.

Archival tags were implanted into the abdominal cavity of the fish, with the external stalk protruding outside. Pop-up tags were attached by a monofilament leader to the dart, which was inserted into the dorsal musculature close to the second dorsal fin with the aid of a tagging pole once the fish was brought alongside the vessel. When the tuna were captured by purse-seine, they were tagged underwater with the aid of a conventional spear gun.

Information downloaded from recaptured tags or transmitted through the Argos satellites was processed using the manufacturer software. For track estimation, carried out by Collecte Localisation Satellites (CLS), an ensemble Kalman filter constrained by light level positions, sea surface temperature (daily fields obtained at a 9 km resolution by blending microwave and infrared SST from REMSS) and bottom topography (ETOPO2) was applied (Royer et al., 2005).

3. Results and discussion

Figure 1 shows the deployment positions of all tags. The Bay of Biscay (archival tags) and different areas of the western Mediterranean (archival and pop-up satellite tags) were covered in the tagging surveys. The recovery of nine pop-up tags allowed for downloading of high-resolution data. One of these devices was found by a purse-seine fisherman on a tuna that was caught four days after the tag deployment. All other satellite tags were returned by people who found them on the seashore or floating very close to the coastline. Up to date only two archival tags have been recovered. One of them had been deployed in the Bay of Biscay (eastern Atlantic) and was found in a waste recycling plant of A Coruña (NW of Spain). Unfortunately, the information contained in this tag was corrupt. The other was retrieved by a longline fisherman from Blanes (NE Spanish coast) and has just been returned, whereby the recorded data has not yet been downloaded. Low return rates render archival tag programs very ineffective in the Mediterranean and East Atlantic in comparison to the Northwest Atlantic (see Fromentin, 2010). This is a serious handicap for the use of this type of tags in spite of their better performance and greater capacity of data storage compared to pop-up satellite tags.

Although the pop-up tags were programmed to detach 12 months after their deployment, the maximum retention time recorded so far is 101days (tag 86432). Premature release is a major drawback of pop-up tagging surveys, since it greatly limits the performance of these tags and can lead to biased conclusions. Of the 29 pop-up tags deployed on fish caught by purse seiners operating around the Balearic archipelago, 10 (34.5%) detached earlier than 15 days after deployment, another 10 popped-off between 15 and 44 days, and 9 (31%) stood on the fish for more than 44 days. Previous pop-up tagging surveys (Fromentin, 2010) have also shown that premature release is an important technical problem that should be worked out to enhance the great potential of these tools.

Two of the 10 tuna that were pop-up tagged in the western Mediterranean (Balearic archipelago) on June 14, 2009 (**Figure 3**) crossed the Strait of Gibraltar by the same date (July, 21-23). Afterwards, they swam fast northwards; one tag detached off the north-west coast of the Iberian Peninsula. The other fish swam further north, but it turned around abruptly at about 58ºN, taking a southward direction, and eventually releasing the tag on September 23 in the central North Atlantic. The other eight tags deployed on the same date surfaced earlier in the Mediterranean.

The analysis of results from the pop-up tagging expedition carried out on June 8, 2010 in the Balearic Sea is still under way, but we can advance that two of the 19 deployed tags popped off in the Strait of Gibraltar area on July 17 and 24. Tag 61125 started to transmit on August 7 in the Atlantic Ocean, NW of Iberia. Another tag surfaced on July 7 in the Tyrrhenian Sea, east of Sardinia (**Figure 2**), suggesting that the tagged fish could have visited two distinct putative spawning grounds throughout the reproductive season. Most of the tags popped off within the Mediterranean, but those that persisted beyond July 16 (retention time of 45 days or longer) were released in the Atlantic, with the exception of tag 86444, which surfaced on July 23 about 100 miles east of the deployment site (**Figure 4**). This data suggests that the majority of the presumptive spawners tagged at the beginning of the reproductive season in the western Mediterranean spawning ground tended to initiate the backward migration to Atlantic waters once the reproductive function had been accomplished. Our observations are in agreement with those of De Metrio *et al.* (2005a), who reported that after spawning adult ABFT migrate to the Atlantic, either south towards the Cape Verde Islands or north to Iceland and the Norwegian Sea. Nevertheless, as inferred from tag 86444 data, some of the breeders may stay for longer in the Mediterranean Sea. The preliminary analysis of the Kalman-filtered tracks indicates that most of the fish exit the Mediterranean Sea within a short temporal window (**Figure 5**). The first estimated position west of the Strait of Gibraltar was recorded on July 13, while the last estimated position within the Mediterranean was observed on July 24. By that time, only 6 tags were still attached.

Prior tagging surveys carried out in the western Mediterranean Sea showed that most tagged ABFT did not migrate to the Atlantic (De Metrio *et al.*, 2001, 2002, 2005b; Fromentin, 2010; Tudela *et al.*, 2011). From such observations it has been concluded that ABFT may stay in the Mediterranean for a longer time than previously believed or even remain there all year round (Fromentin, 2010; Tudela *et al.*, 2011). The differences between the present and earlier results are most probably due to the different dates when the fish were tagged. It is well

known that following spawning, ABFT undertake a trophic migration to the Atlantic, passing through the Strait of Gibraltar primarily in July-August, though some adults extend their residency time in the Mediterranean (De la Serna *et al.*, 2004). Obviously, the likelihood of tracking movements of adults from the Mediterranean into the Atlantic decreases as the tag deployments shift away from those dates. This is especially true because of the low retention rates of pop-up tags.

Figure 6 shows the 5th percentile of the Fisrt Passage Time (FPT: natural logarithm of the time required to cross a circle of a given radius, 500 km in this case; see Fauchald and Tveraa (2003) for further details) distribution of the tuna bearing tags 86432 and 86434 after 2000 bootstraps. Residency times seem to be significantly high around the Balearic Islands, as well as in other areas in the Atlantic, although the geometry of the coastline may affect the use of FPT as an indicator of residency in certain areas. These zones of prolonged residency are envisaged as having been used as reproductive and foraging areas, respectively.

Preliminary analysis of both Argos-transmitted and archival-quality information downloaded from recovered pop-up tags seem to show a shallower distribution of fish in the spawning ground during daylight hours (**Figure 7**). This may in turn be related to the availability or vertical distribution of prey resources in each area.

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Table 1. Summary of tag deployments.

Year	*Fishery*	*Location*	*Type of tag*	*Number*
	Baitboat	Strait of Gibraltar	pop-up	1
2008	Sport	off NE Spain	archival	15
	Sport	off SE Spain	archival	3
	Baitboat	Bay of Biscay	archival	101
	Sport	off NE Spain	archival	21
2009	Purse seine	Balearic Islands	pop-up	10
	Sport	off NE Spain	pop-up	1
2010	Purse seine	Balearic Islands	pop-up	19

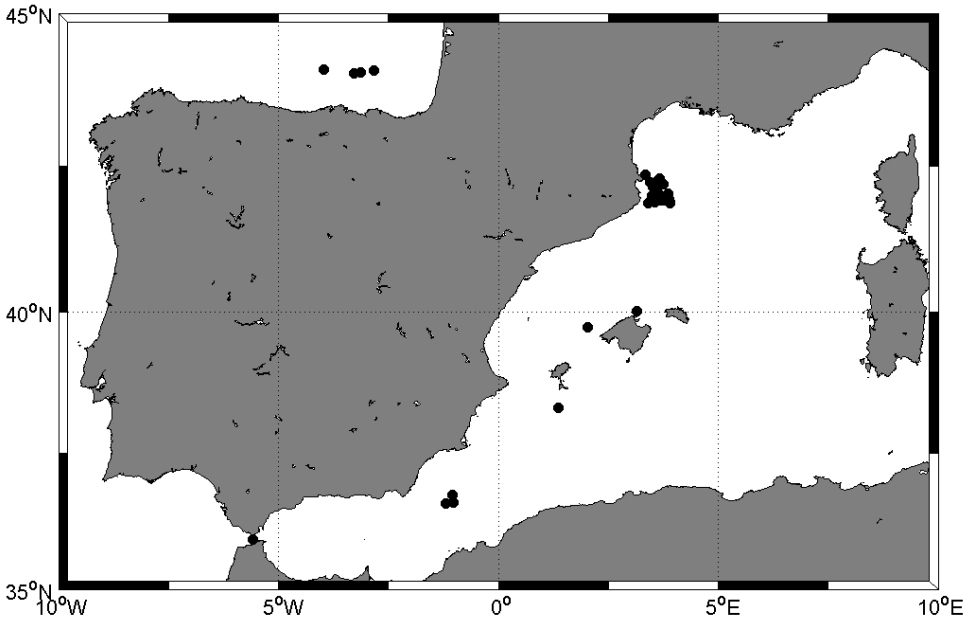

Figure 1. Map showing deployment positions. In the case of pop-up tagging of purse-seine caught fish, a single point may represent several deployments.

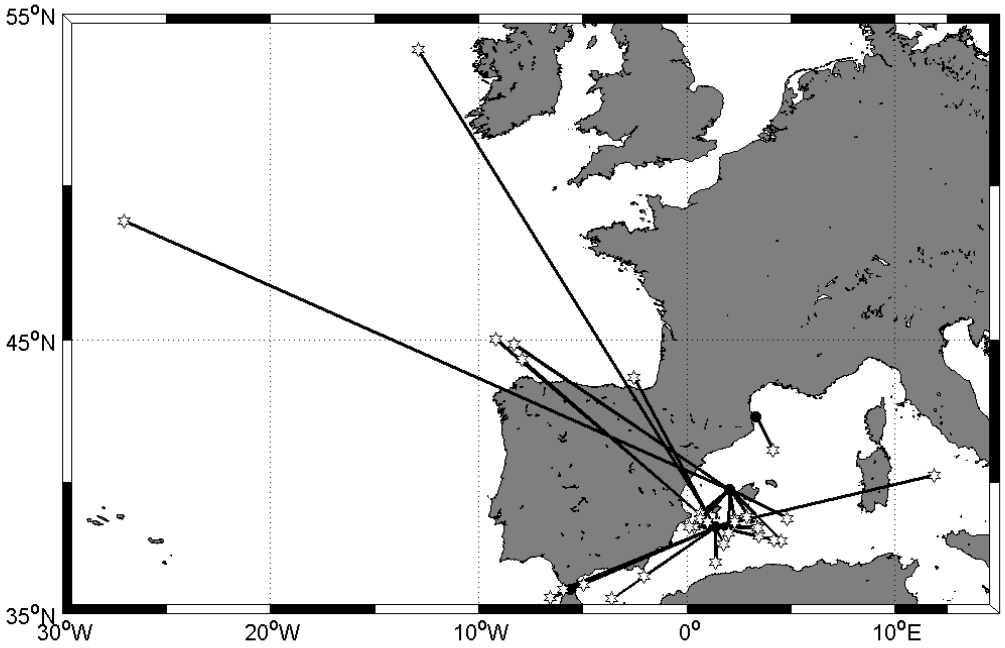

Figure 2. Deployment (●) and pop-off positions (✡) of the pop-up tags.

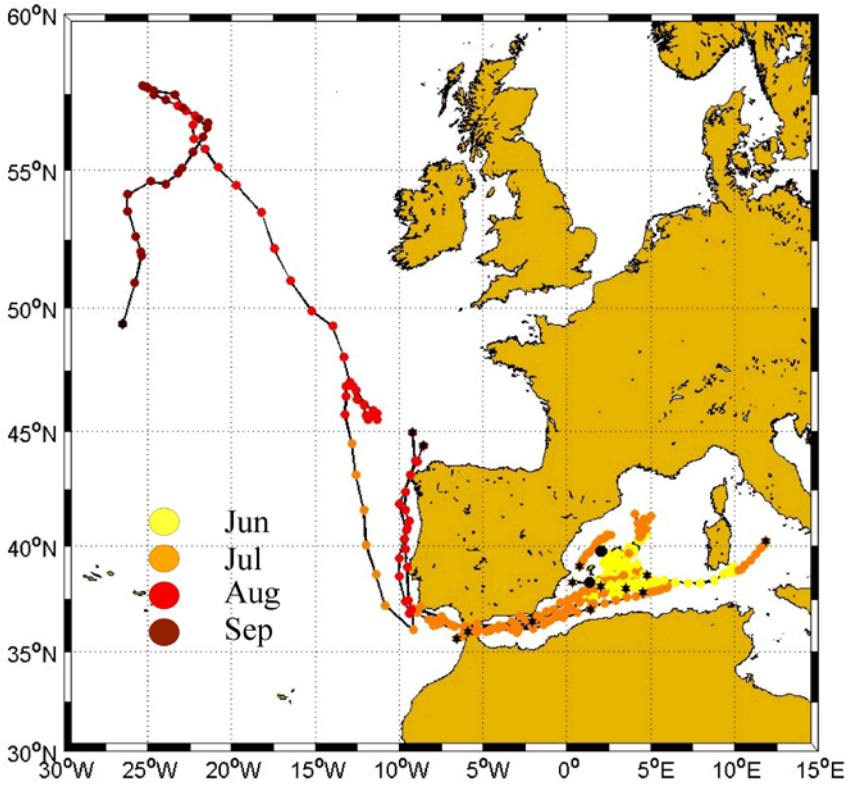

Figure 3. Synthetic map of pop-up tagged BFT by month.

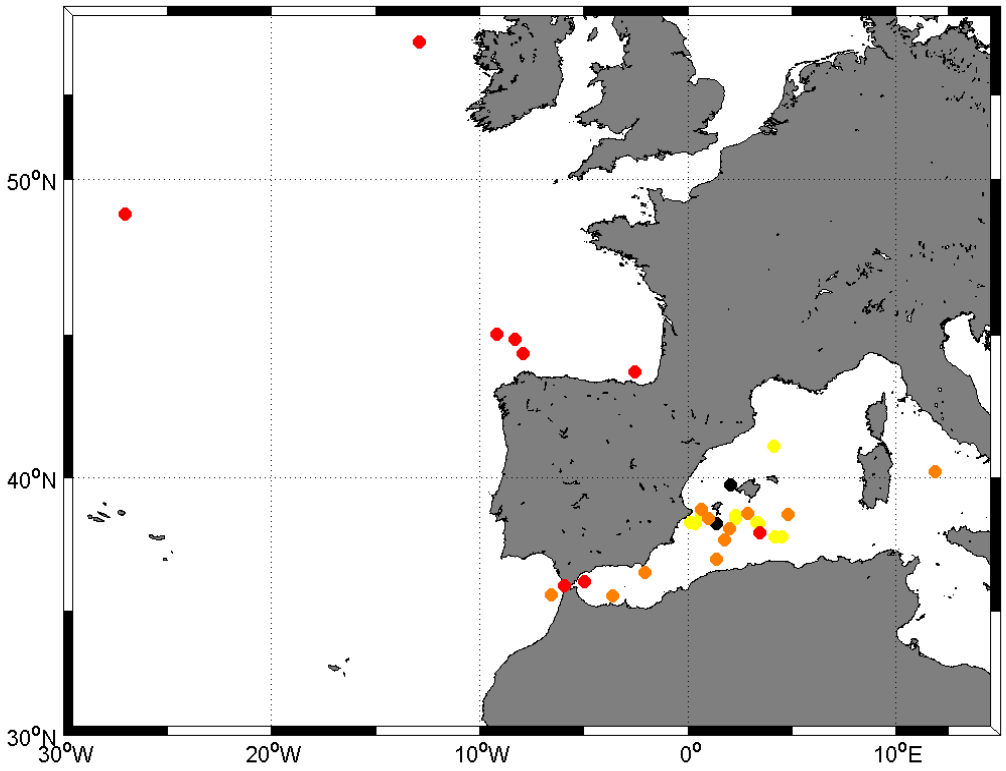

Figure 4. Pop-off positions of satellite tags deployed on June 14, 2009 and June 8, 2010 (black circles). Different colors indicate retention times lower than 15 days (yellow circles), between 15 and 44 days (orange circles) and higher than 44 days (red circles).

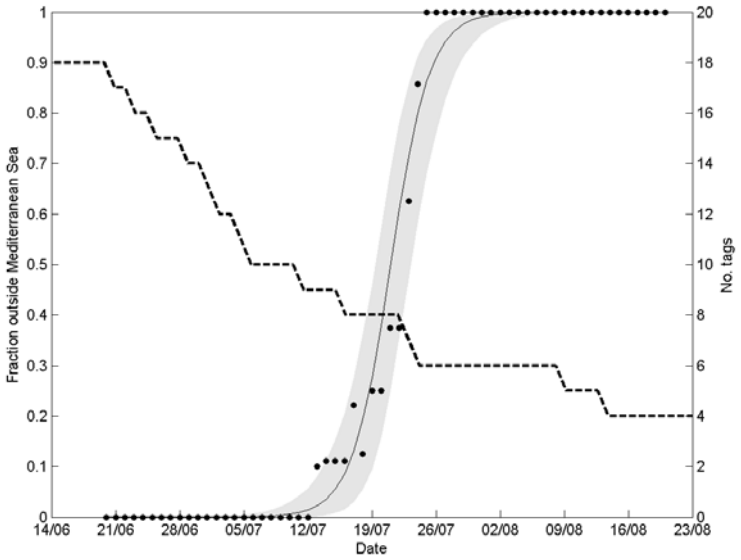

Figure 5. Fraction of fish outside the Mediterranean Sea vs. date (circles: observed, solid line: logistic model fitted, dashed line: number of tags attached). Fish were caught by purse-seine and pop-up tagged in the spawning grounds around the Balearic Islands during 2009 and 2010.

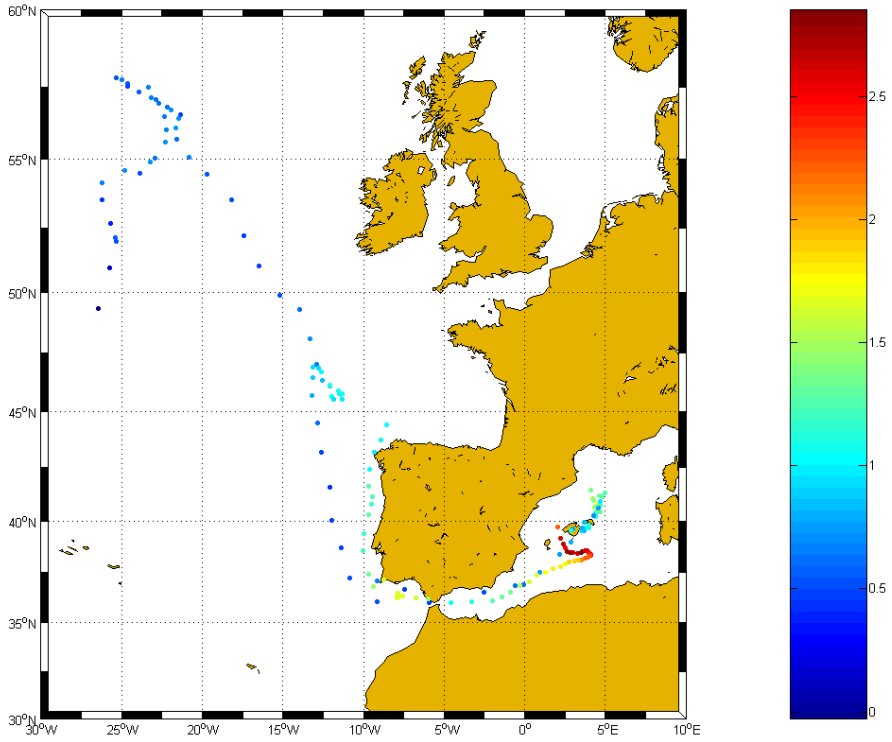

Figure 6. Map showing the 5th percentile of the first-passage time (ln(days)) distribution for each kalman-filtered position for two pop-up tagged ABFT.

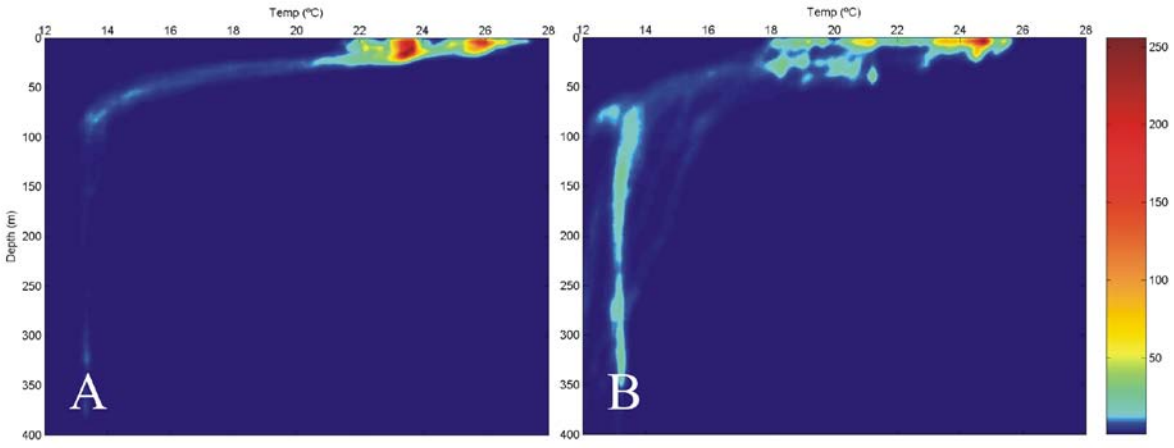

Figure 7. Density plots showing the relative times spent at depths and temperatures by fish 86434 during daytime, before (A) and after (B) July 17.