THE WWF/GBYP MULTI-ANNUAL BLUEFIN TUNA ELECTRONIC TAGGING PROGRAM (2008-2013): REPERCUSSIONS FOR MANAGEMENT

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SUMMARY

During the duration of a multi-annual (2008-2013) bluefin tuna electronic tagging program, 130 electronic tags (99 pop-up satellite and 31 internal archival) were deployed in both adult and juvenile fish in the western and central Mediterranean and in the Atlantic coast of Morocco. For the 64 analyzed tuna, weight ranged from 17 up to 250 kg and time at liberty of their tags spanned from 19 up to 391 days. In the western and central Mediterranean, two behavioral patterns (migratory and resident) were observed to co-occur, and from all the tuna that were in the Mediterranean Sea at some point, none crossed over to the eastern Mediterranean basin. Noteworthy, none of the resident individuals left the Mediterranean during the whole tracking period. Furthermore, the occurrence of potential Mediterranean spawners in North Atlantic waters beyond the 45°W was observed.

RÉSUMÉ

Dans le cadre d'un programme pluriannuel de marquage électronique des thons rouges (2008-2013), 130 marques électroniques (99 marques pop-up reliées par satellite et 31 marques archives internes) ont été apposées sur des adultes et des juvéniles dans l'Ouest et le centre de la Méditerranée et sur la côte atlantique du Maroc. En ce qui concerne les 64 thons analysés, le poids oscillait entre 17 et 250 kg et la durée d'apposition de la marque oscillait entre 19 et 391 jours. Dans l'Ouest et le centre de la Méditerranée, il a été observé que les deux modèles de comportement (migratoire et sédentaire) surviennent simultanément et aucun thonidé qui se trouvait dans la Méditerranée à un moment donné n'a franchi le bassin méditerranéen occidental. Il convient de noter qu'aucun des résidents n'a quitté la mer Méditerranée pendant toute la durée de la période de suivi. De plus, la présence de reproducteurs méditerranéens potentiels dans les eaux de l'Atlantique Nord au-delà de 45ºW a été observée.

RESUMEN

Durante el programa de marcado electrónico plurianual de atún rojo (2008-2013), se colocaron 130 marcas electrónicas (99 marcas pop-up por satélite y 31 marcas archivo internas) tanto en adultos como en juveniles en el Mediterráneo central y occidental y en la costa atlántica de Marruecos. En los 64 atunes analizados, el peso oscilaba entre 17 y 250 kg, y el tiempo en libertad de las marcas se extendía de 19 hasta 391 días. En el Mediterráneo occidental y central, se observó que se producían a la vez dos patrones de comportamiento (migratorios y residentes) y, de todos los atunes que se encontraban en el Mediterráneo en algún momento, ninguno cruzó hacia la cuenca del Mediterráneo oriental. Cabe señalar que ninguno de los ejemplares residentes abandonó el Mediterráneo en todo el periodo de seguimiento. Además, se observó la presencia de posibles reproductores mediterráneos en aguas del Atlántico norte más allá de los 45ºW.

KEYWORDS

Thunnus thynnus, *Electronic tagging, Western Mediterranean, Adriatic, Morocco, Migration, Habitat use, Population structure*

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1. Introduction

Atlantic bluefin tuna (*Thunnus thynnus*) has been a focus of marine fisheries research and a target of fishers since ancient times (Fromentin and Powers 2005; Rooker *et al.* 2007), but its populations have suffered a sharp decline in the past four decades (Taylor *et al.* 2011) and its breeding populations, both within the Gulf of Mexico and the Mediterranean Sea, have been at risk of collapse (Anon. 2007; MacKenzie *et al.* 2009). Improving fisheries models of Atlantic bluefin tuna population structure, migration patterns and habitat use is necessary, particularly on their spawning grounds where they are heavily exploited. Understanding habitat utilization is, thus, critical for the design of more effective management measures.

Mature bluefin tuna of eastern origin are hypothesized to undertake two types of migrations: movements into the Mediterranean Sea during April and May to spawn (Medina *et al.* 2002), and a post-spawning foraging migration to the north Atlantic Ocean around the end of July and August (De la Serna *et al.* 2004; De Metrio *et al.* 2005a; De Metrio *et al.* 2005b). While a recent study using PSAT tags has confirmed the rapid migration of some post-spawning adults from the western Mediterranean to the Atlantic (Aranda *et al.* 2013), other studies have recently highlighted the importance of the Mediterranean habitat not only for spawning but also as an ecological foraging area significant during overwintering periods (Fromentin 2009; De la Serna *et al.* 2011; Tudela *et al.* 2011; Cermeño *et al.* 2012; Aranda *et al.* 2013; Fromentin and Lopuszanski 2013; Quílez-Badia *et al.* 2013).

Data on the migratory behaviors and other ecological features of the eastern Atlantic bluefin tuna tagged in the Atlantic coast of Morocco and the western and central Mediterranean were collected from 2008 to 2013 to be able to increase our knowledge on the habitat use, migration patterns and possible population structure of bluefin tuna within the Mediterranean.

2. Materials and Methods

Atlantic bluefin tuna were tagged with electronic tags in expeditions that occurred between 2008 and 2013 in the western Mediterranean, the Adriatic Sea and the Atlantic coast of Morocco **(Table 1)**. The tagging expeditions were conducted in locations along the eastern Spanish coast - Roses and Llançà (NE Spain), Moraira (E Spain) and Algeciras (SE Spain) -, in the Balearic Islands - Port of Pollença (N Majorca, Spain) -, in the Adriatic Sea - in San Benedetto del Tronto and Porto Barricata (E and NE Italy, respectively) -, and in the Atlantic coast of Morocco – in Larache (NW Morocco) - **(Figure 1)**. Tagging seasons started in May (at the earliest) and ended by November. Tagging times depended on the accessibility of fishers to bluefin tuna.

Everywhere apart from Morocco, bluefin tuna were caught using recreational rod and reel fishing: i.e., by means of chumming the water with sardines (for most bluefin tuna over 30 kg), or by trolling lures (for most tuna under 30 kg). In 2008 and 2009 bluefin tuna were tagged in the water using an aluminum tagging pole with only one insertion point and tag anchor. From 2010 to 2013, bluefin tuna were brought on-board using a lip hook placed in the most rostral position of the lower jaw and pulled from the water to a vinyl mat. For this (on-board) type of tagging, a second attachment loop was used to prevent excessive motion of the pop-up satellite tag. Pop-up satellite tags were programmed to release from the tuna between 150 and 300 days.

From 2011 to 2013, giant tunas (fork length (FL) > 2.10 m) trapped by the Moroccan tuna trap “Es Sahel” - operated by Maromadraba, s.a.r.l. - in Larache were also tagged. Approximately half of the individuals were tagged (with double attachment) on board one of the tuna trap vessels after being pulled out of the trap by means of a small crane and placed on to a mat. The other half were tagged in the water using an aluminum tagging pole. These tunas had entered the trap 24-48 h prior to the tagging operation and were all safely released at sea afterwards.

Bluefin tuna that were brought on board had a soft cloth soaked in fish slime replacement (PolyAqua, Novalek) placed over their eyes while a seawater hose oxygenated their gills. A clip of a fin was kept for future genetic analyses, and curved fork length (CFL) was measured to the nearest 0.5 cm. CFL was transformed to fork length (Parrack and Phares 1979) and then to weight using the formulas adopted by ICCAT for Mediterranean and Atlantic tuna (Arena *unpublished* and Rey and Cort *unpublished* for Mediterranean and Atlantic individuals, respectively, and cited in Arena (*unpublished*)). For those tuna tagged in the water a conservative estimation of the weight was made by the tagging team.

Electronic tagging was conducted with Pop-up Satellite Archival Transmitting tags (PAT MK10 and MiniPAT built by Wildlife Computers, Redmond Washington, using PAT Hardware version 2.0). Both types of tags were placed on juveniles and adults in the base of the second dorsal fin. In addition, archival tags (MK9, Wildlife Computers), were surgically deployed in juvenile bluefin tunas considered too small for an external satellite tag.

Pop-up satellite tags recorded pressure, light and water temperature every 60 seconds interval and were grouped in 6-, 12- or 24-hour binned histograms (for 2012 and 2013, 2008 to 2010, and 2011 tags, respectively). Pop-up satellite tag number # 10P0648 was returned by a fisherman, getting access to the 5-second interval archival record.

The MK9 archival tags were surgically implanted in the peritoneal cavity of juvenile tuna and programmed to record pressure, light, external temperature and internal temperature every 60 seconds. To implant the archival tags, a 3-4 cm incision with a sterile surgical blade was carefully placed in the ventral musculature of the tuna following the surgery methodology described in Boustany *et al.* (2010). A conventional green external tag (Floy Tags) was also inserted close to the second dorsal fin to inform about the existence of an archival tag inside the tuna.

Bluefin tuna geolocations were estimated from light level and sea surface temperature data recorded by the tags. All tracks were processed by CLS (Collecte Localisation Satellites) using a tool based in state-space models (SSM). SSM's constitute a robust statistical approach to refine satellite tracking data by accounting for observation errors and stochasticity in animal movement. The algorithm uses sea surface temperature and bottom topography data to better constrain the tracks. An ensemble Kalman filter is applied to solve for the trajectory, thus estimating the state vector and its covariance from a set of samples rather than the usual deterministic equations (Sibert *et al.* 2003; Royer *et al.* 2005; Nielsen *et al.* 2006; Nielsen and Sibert 2007).

In order to infer potential spawning behavior we took into account the timing of spawning in the Mediterranean Sea (Sarà 1964, 1973; De la Serna and Alot 1992; Susca *et al.* 2001; Medina *et al.* 2002; Sarasquete *et al.* 2002; Corriero *et al.* 2003), oceanographic features that have been associated to the spawning strategy in the Mediterranean and in the Gulf of Mexico (Platonenko and De la Serna 1997; García *et al.* 2005a; García *et al.* 2005b; Teo *et al.* 2007a; Alemany *et al.* 2010; Druon *et al.* 2011; Reglero *et al.* 2012), the residential and more sinuous behavior during the breeding phase (Teo *et al.* 2007b), the prolonged surface intervals during nighttime (Block *et al.* 2001; Teo *et al.* 2007a; Teo *et al.* 2007b), and the well-defined thermocline (Di Natale 2010; Piccinetti *et al.* 2013).

FAO's Major Fishing areas in the Mediterranean were adopted to separate the different basins (FAO 2013) **(Figure 1)**.

3. Results

A total of 130 electronic tags were deployed during the duration of this study: 99 pop-up satellite and 31 archival tags. From the 99 pop-up satellite tags deployed, 63 (i.e. 18 from 29 MK10 and 45 from 70 MiniPAT) transmitted data and were at liberty for more than 19 days, which was the minimum time that we chose to include in this study (**Table 1**). From the 31 surgically implanted archival tags, 2 were recovered (**Table 2**), although only one (ID # 890138) provided a complete archival time series record. The second one (ID # 890152) had the external temperature sensor damaged and its thermal data could not be taken into account in the analyses. Out of the 64 analyzed tunas, 54 were in the Mediterranean Sea at some point, i.e. 37 fish were tagged within the Mediterranean and 17 entered the basin after being tagged in the Atlantic coast of Morocco. These 54 tags provided a wide time-span: from 19 up to 304 days at liberty for pop-ups and up to 391 for the archival tag. The remaining 10 fish did not enter the Mediterranean Sea after having been tagged in the Atlantic coast of Morocco.

Plotting the daily positions of the 54 tuna that were in the Mediterranean Sea at some point, we observed that there is a coexistence of two behavioral/demographic contingents in the western and central Mediterranean Sea. On one hand, we found individuals (N = 37) of a wide size range (from 17 up to 250 kg) clearly **resident** - but carrying out long intra-Mediterranean migrations, e.g. from the Gulf of Lions to Libya (Quílez-Badia *et al.* 2013) - in the Mediterranean basin for a substantial period of time which even overwintered there (**Figures 2 and 3**). And on the other, we observed highly **migratory** individuals (N = 11) that performed the rapid trophic migration into the Atlantic Ocean (time-span ranged from 42 up to 300 days at liberty) (**Figure 4**). The remaining 6 individuals entered the Mediterranean from the Atlantic coast of Morocco but their tags released relatively shortly after (from 19 up to 36 days at liberty), while still in the basin. Regarding the relationship and proportion between these two contingents, these are unknown.

When analyzing the 37 resident individuals tagged within the Mediterranean, we observed that none of them ever left this sea, nor ventured into the eastern Mediterranean (**Figures 2 and 3**). In fact, the archival tag that had the external temperature sensor damaged (**Table 2**, ID # 890152), even though we could not have the complete geolocation track, we were able to use the light level longitude record to establish its position and concluded that this bluefin tuna neither left the Mediterranean, nor visited the eastern Mediterranean during the nearly 3 years of monitoring. This bluefin inhabited waters comprised between the 0 and the 18th meridian east.

Therefore, if we include this latter tuna to the other 54 aforementioned, we realized that none of the 55 ever crossed over to the eastern Mediterranean basin (**Figure 5**).

After analyzing those individuals who showed potential reproduction, we observed that spawning shows considerable geographical plasticity within the western and central Mediterranean, it being contingent upon the occurrence of the adequate oceanographic features and environmental conditions. Potential spawning was observed to occur only south of 40^{o} N, where adequate environmental and oceanographic conditions occurred (**Figure 6**). In addition, it is worth noting that breeding individuals from the two contingents (resident – orange - and migratory – yellow -, **Figure 6**) met in the same spawning areas.

An individual tagged in the Atlantic coast of Morocco (ID # 11P0474), after entering the Mediterranean during the breeding season, engaged in the trophic migration towards the Atlantic Ocean and its tag released off Newfoundland (Canada) (**Figure 7**).

Discussion and Conclusions

Three main results have been found out, which in turn have raised new questions in terms of management. These are the following:

1. Two behavioral patterns appear to occur in the western and central Mediterranean: on one hand the migratory fish and on the other the resident fish that even overwinter there. It is noteworthy that both contingents share the same spawning areas in the Mediterranean basin, which suggests that these are likely drawn from a single panmictic population. The next step, therefore, would be to ascertain the precise demographic relationship between both contingents.

2. None of the 54 tuna that were in the Mediterranean Sea at some point (including the archival - ID # 890152 - with the external temperature sensor damaged) ever crossed over to the eastern Mediterranean basin (**Figure 5**). These results raise the question of whether the eastern Mediterranean fish are in fact a distinct population.

3. None of the resident individuals (i.e. 37 or 38 if we include the archival ID # 890152) left the Mediterranean, while the migratory fish quickly returned to the Atlantic feeding areas.

4. Only three out of the 54 tuna that were in the Mediterranean Sea at some point visited the Tyrrhenian Sea, while both historical and fishery data strongly indicate that the southern Tyrrhenian Sea is a typical and intense spawning area (Arena 1963, 1981, 1982, 1988; Di Natale *et al.* 2005; Di Natale *et al.* 2006).

5. The occurrence after the spawning season of potential Mediterranean spawners in N Atlantic waters beyond the 45^{o}W has been observed. This result stresses the extent of mixing and points to a link between spawning grounds in the Mediterranean Sea and feeding grounds off Newfoundland.

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Table 1. Summary information on the deployments of electronic tags (> 19 days on fish) - from 2008-2013 on western Mediterranean, Adriatic Sea and Moroccan bluefin tuna, analyzed in this study. Note: † two darts were used to anchor the tag. Different tagging locations: 1. Roses/Llançà (NE Spain), 2. Pollença (N Mallorca, Spain), 3. Moraira (E Spain), 4. Algeciras (S Spain), 5. San Benedetto del Tronto (E Italy), 6. Porto Barricata (NE Italy) and 7. Larache (NW Morocco).

Year	Pop-up ID	Area	Deployment position	Deployment Date	CFL (cm)	Weight (kg)	Pop-off position	Pop-off Date	Days at liberty	Dart
2008	08A0398	Mallorca, Spain	40º00´N 03º09´E	16/08/2008	-	100	37º88´N 01º74´E	15/10/2008	60	Umbrella
	08A0391	Mallorca, Spain	40º00´N 03º09´E	16/08/2008	-	150	35º88´N 00º49´E	19/12/2008	125	Umbrella
	08A0393	Mallorca, Spain	40º00´N 03 09´E	17/08/2008	-	150	38º96´N 00º 21´E	26/10/2008	70	Umbrella
	08A0405	Mallorca, Spain	40º00´N 03º09´E	17/08/2008	-	50	40º26´N 04º29´E	29/10/2008	73	Umbrella
2009	08A0407	Mallorca, Spain	40º01´N 03º01´E	14/08/2009	-	110	39º46´N 02º40´E	23/10/2009	70	Umbrella
	08A0390	Mallorca, Spain	40º01´N 03º01´E	15/08/2009	-	65	39º58´N 03º37´E	14/09/2009	30	Umbrella
	08A0399	Roses, Spain	42º20´N 03º20'E	27/08/2009	160	73.2	38º09´N 14º00´E	07/12/2009	102	Umbrella
	08A0385	Adriatic	42º48´N 14º35´E	13/09/2009	-	45	43º46´N 13º42´E	25/12/2009	103	Umbrella
	08A0394	Adriatic	42º49´N 14º37´E	14/09/2009	132	41.1	30º38´N 19º02´E	05/03/2010	172	Titanium†
	08A0409	Roses, Spain	42º23´N 03º20´E	04/09/2009	-	45	38º58´N 05º19´E	17/12/2009	104	Prince
2010	08A0403	Mallorca, Spain	40º02'N 03º10´E	08/08/2010	190	122.8	38º16'N 07º01'E	25/09/2010	48	Titanium†
	10P0049	Roses, Spain	42º15´N 03º40´E	01/09/2010	95	15.3	39º52' N 6º20´E	11/11/2010	71	Titanium†
	10P0052	Roses, Spain	41º51´N 03º50´E	05/09/2010	96	15.7	37º48' N 9º27´E	02/11/2010	58	Titanium†
	08A0390	Adriatic	42º55´N 14º14´E	13/09/2010	143	52.2	41º34'N 15º57'E	18/05/2011	247	Titanium†
	08A0396	Adriatic	44º49 N 12º51'E	24/09/2010	153	64	42º34'N 15º49'E	20/03/2011	177	Titanium†
2011	10P0044	Larache, Morocco	35º18'N 06º11'W	26/05/2011	260	259	27°2'N 17°44'W	19/07/2011	54	Titanium†
	10P0035	Larache, Morocco	35º18'N 06º11'W	27/05/2011	210	139	38°18'N 27°14'W	22/03/2012	300	Titanium†
	08A0395	Larache, Morocco	35º18'N 06º11'W	27/05/2011	237	198	38°23'N 22°25'W	18/072011	52	Titanium†
	10P0406	Adriatic	43º01'N 14º09'E	26/07/2011	155	66.6	40°55'N 18°05'E	02/09/2011	38	Titanium†
	10P0400	Adriatic	43º01'N 14º09'E	26/07/2011	136	44.9	44°05'N 14°57'E	30/09/2011	66	Titanium†
	10P0038	Adriatic	42°57'N 14°16'E	06/08/2011	125	34.8	40°40'N 01°16'E	05/04/2012	243	Titanium†
	10P0401	Adriatic	42°56'N 14°17'E	06/08/2011	134	43	32°23'N 17°47'E	09/02/2012	187	Titanium†
	08A0389	Mallorca, Spain	40º03'N 3º08'E	12/08/2011	177	99.2	39°58'N 02°57'E	30/09/2011	49	Titanium†
	10P0398	Moraira, Spain	39º06'N 0º 29'E	29/05/2011	135	43.9	39°46'N 0°59'E	25/08/2011	88	Titanium†

	10P0402	Roses, Spain	42º21'N 3º19'E	31/08/2011	144	53.4	37°48’N 10°36'E	30/06/2012	304	Titanium†
	10P0546	Roses, Spain	42º20'N 3º09’E	01/09/2011	135	43.9	35°55'N 13°25'E	30/06/2012	303	Titanium†
	10P0547	Roses, Spain	42º20'N 3º20'E	01/09/2011	149	59.1	40°55'N 04°59'E	29/09/2011	28	Umbrella
	08A0388	Roses, Spain	42º20'N 3º20'E	01/09/2011	240	248.1	41°58'N 03°43'E	03/11/2011	63	Titanium†
	09P0412	Llançà, Spain	42º20'N 3º20'E	03/09/2011	199	141.2	37°09'N 04°29'E	26/09/2011	23	Titanium†
2012	11P0150	Larache, Morocco	35º18'N 06º11'W	14/05/2012	254	242	30°08'N 20°20'W	19/01/2013	250	Titanium†
	11P0134	Larache, Morocco	35º18'N 06º11'W	14/05/2012	247	223	49°18'N 26°45'W	17/09/2012	126	Titanium†
	09P0437	Larache, Morocco	35º18'N 06º11'W	14/05/2012	251	234	34°53'N 14°22'E	05/06/2012	22	Titanium†
	11P0531	Larache, Morocco	35º18'N 06º11'W	14/05/2012	243	213	46°35'N 27°30'W	19/01/2013	250	Titanium†
	11P0533	Larache, Morocco	35º18'N 06º11'W	14/05/2012	226	172	35°29'N 14°48'W	14/06/2012	31	Titanium†
	08A0390	Larache, Morocco	35º18'N 06º11'W	14/05/2012		200-300	62°25'N 3°08'W	16/08/2012	94	Titanium
	11P0138	Larache, Morocco	35º18'N 06º11'W	14/05/2012		200-300	39°32'N 35°41'W	31/07/2012	78	Titanium
	11P0133	Larache, Morocco	35º18'N 06º11'W	14/05/2012		200-300	47°12'N 12°11'W	26/09/2012	135	Titanium
	08A0386	Larache, Morocco	35º18'N 06º11'W	14/05/2012		200-300	34°04'N 12°31'E	02/06/2012	19	Titanium
	11P0530	Larache, Morocco	35º18'N 06º11'W	14/05/2012		200-300	51°05'N 20°01'W	24/10/2012	163	Titanium
	11P0378	Larache, Morocco	35º18'N 06º11'W	16/05/2012	265	273	35°36'N 24°51'W	20/06/2012	35	Titanium†
	11P0363	Larache, Morocco	35º18'N 06º11'W	16/05/2012	203	126	31°28'N 17°07'E	20/06/2012	35	Titanium†
	11P0372	Larache, Morocco	35º18'N 06º11'W	16/05/2012	238	200	35°29'N 17°30'W	24/06/2012	39	Titanium†
	11P0375	Larache, Morocco	35º18'N 06º11'W	16/05/2012	206	132	38°23'N 6°50'E	21/06/2012	36	Titanium†
	10P0648	Adriatic	43º03N 14º08'E	12/05/2012	135	43.9	43º17´N 16º4´E	07/11/2012	179	Titanium†
	10P0632	Adriatic	45º16'N 13º07'E	09/23/2012	138	46.9	43°39'N 13°40'E	11/21/2012	84	Titanium†
	11P0483	Mallorca, Spain	40º01'N 3º09'E	11/08/2012	179	103	39°46'N 3°12'E	19/04/2013	251	Titanium†
	11P0468	Mallorca, Spain	40º02'N 3º09'E	11/08/2012	161	75	36°49'N 11°55'E	18/04/2013	250	Titanium†
	11P0482	Mallorca, Spain	40º02'N 03º10'E	24/11/2012	102	18.9	38°18'N 4°01'E	16/12/2012	22	Titanium†
	11P0480	Llançà, Spain	42º01'N 3º19'E	08/09/2012	179	102.7	37°27'N 8°18'E	11/01/2013	125	Titanium†
	11P0455	Llançà, Spain	42º21'N 3º19'E	09/09/2012	174	94.3	38°31'N 8°30'E	18/05/2013	251	Titanium†
	11P0481	Llançà, Spain	42º21'N 3º19'E	09/09/2012	199	141.2	30°38'N 19°52'E	06/02/2013	150	Titanium†
	11P0465	Llançà, Spain	42º20'N 3º20'E	09/09/2012	142	51.2	38°40'N 3°44'E	31/10/2012	52	Titanium†
	11P0452	Strait of Gibraltar	35º57'N 5º29'W	16/09/2012	214	175.8	42°55'N 13°47'W	29/03/2013	194	Titanium†
2013	11P0028	Larache, Morocco	35º18'N 06º11'W	20/05/2013	245	218	35°55'N 5°44'W	18/07/2013	59	Umbrella+Titanium

12P0133	Larache, Morocco	35º18'N 06º11'W	20/05/2013	240	205	54°34'N 10°18'W	07/10/2013	140	Umbrella+Titanium
12P0134	Larache, Morocco	35º18'N 06º11'W	20/05/2013	235	193	51°56'N 17°29'W	24/07/2013	65	Umbrella+Titanium
12P0136	Larache, Morocco	35º18'N 06º11'W	20/05/2013	227	175	38°54'N 10°15'W	01/07/2013	42	Umbrella+Titanium
12P0139	Larache, Morocco	35º18'N 06º11'W	21/05/2013	240	205	35°56'N 5°50'W	19/07/2013	59	Umbrella
12P0140	Larache, Morocco	35º18'N 06º11'W	21/05/2013	212	143	38°14'N 10°28'E	06/09/2013	108	Umbrella
11P0474	Larache, Morocco	35º18'N 06º11'W	21/05/2013	230	181	44°40'N 49°54'W	14/10/2013	146	Titanium
11P0467	Larache, Morocco	35º18'N 06º11'W	21/05/2013	242	210	34°04'N 14°1'E	11/06/2013	21	Titanium
11P0445	Larache, Morocco	35º18'N 06º11'W	21/05/2013	246	220	35°40'N 14°51'W	29/06/2013	39	Titanium
11P0446	Larache, Morocco	35º18'N 06º11'W	21/05/2013	260	259	48°50'N 11°12'W	06/09/2013	108	Titanium

Table 2. Deployment and recapture information of the implanted archival tags deployed in 2008 in Roses, NE Spain.

Year	Tag ID	Area	Deployment position	Deployment date	Weight (kg)	Recapture	Recapture position	Days at liberty
2008	890138	Roses, Spain	41º 56´N 03º 36´E	31/08/2008	12.1	26/09/2009	41° 01´N 02° 45´E	391
2008	890152	Roses, Spain	41º 56´N 03º 36´E	31/08/2008	13	23/4/2011	37° 30´N 11° 30´E	965

Figure 1. Different tagging locations: 1. Roses/Llançà (NE Spain), 2. Pollença (N Mallorca, Spain), 3. Moraira (E Spain), 4. Algeciras (S Spain), 5. San Benedetto del Tronto (E Italy), 6. Porto Barricata (NE Italy), and 7. Larache (NW Morocco). Red lines indicate the separation between the different Mediterranean basins based on FAO Fishing area criteria.

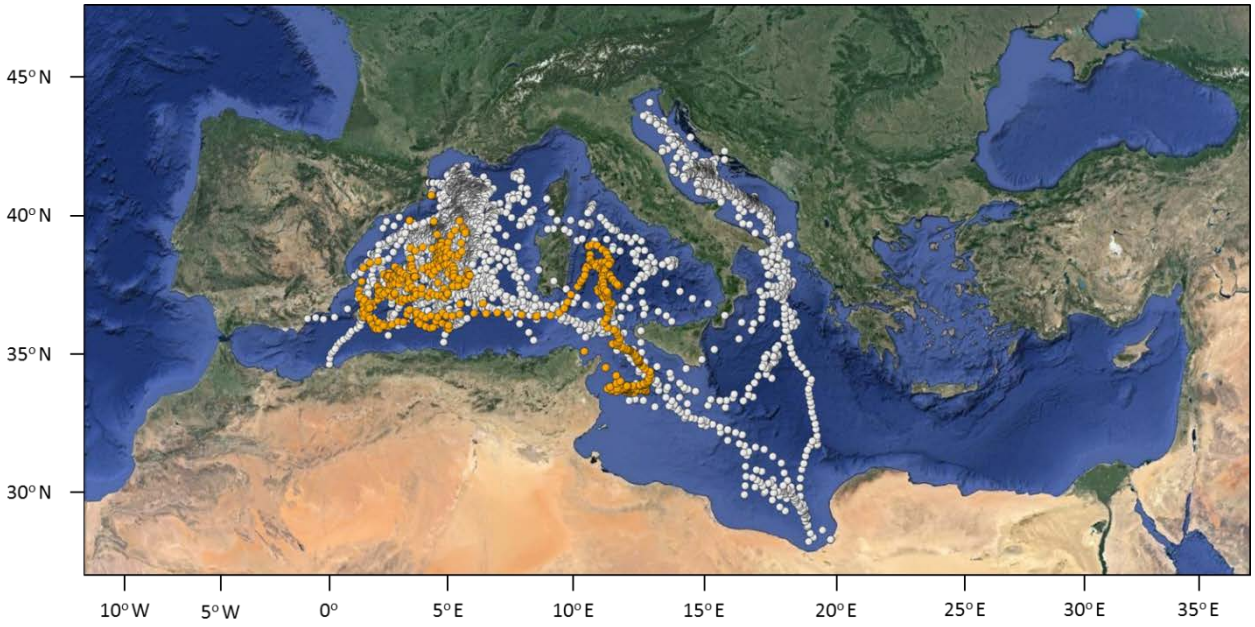

Figure 2. Daily positions of the 36 pop-up (white dots) and the archival (orange dots) tags deployed within the Mediterranean. Tuna weight ranging from 17 up to 250 kg. Time-span ranging from 19 up to 304 days at liberty (pop-ups) and up to 391 (archival).

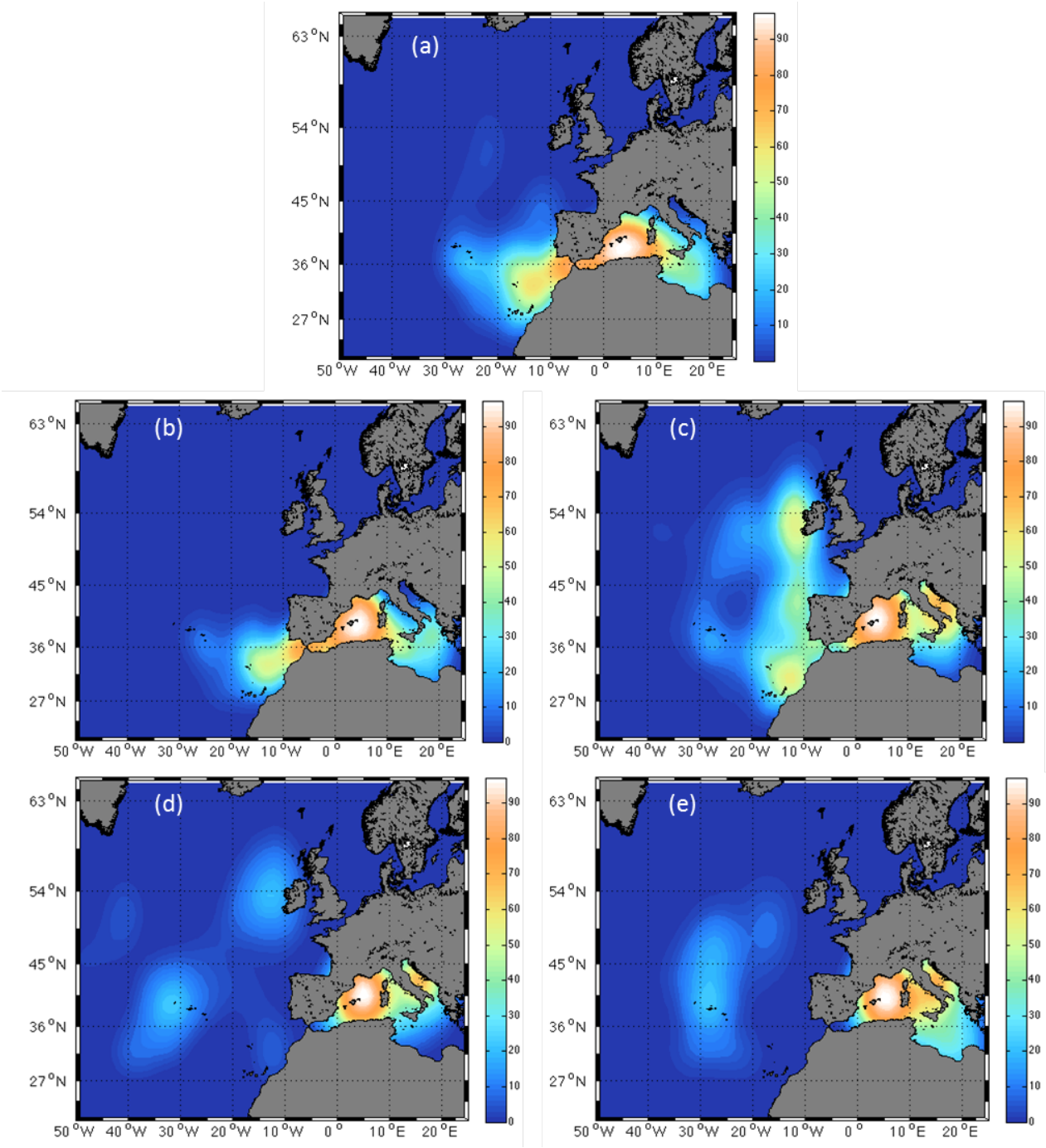

Figure 3. Seasonal Utilization Distributions (UDs) of all bluefin tuna analyzed in this study (N = 64). The locations of the tunas were examined for the (a) spawning period (i.e. May 15 to July 15) and the seasonal periods of (b) spring, (c) summer, (d) autumn and (e) winter. UDs were computed using the Kernel method through the ad hoc method (h = Sigma*n^(-1/6), Sigma = 0.5*(sd(x)+sd(y))). The graphs show the UDs cumulative frequencies up to 95% (the color attributed to a given percentage p applies to areas comprised between p and p–1% isopleths).

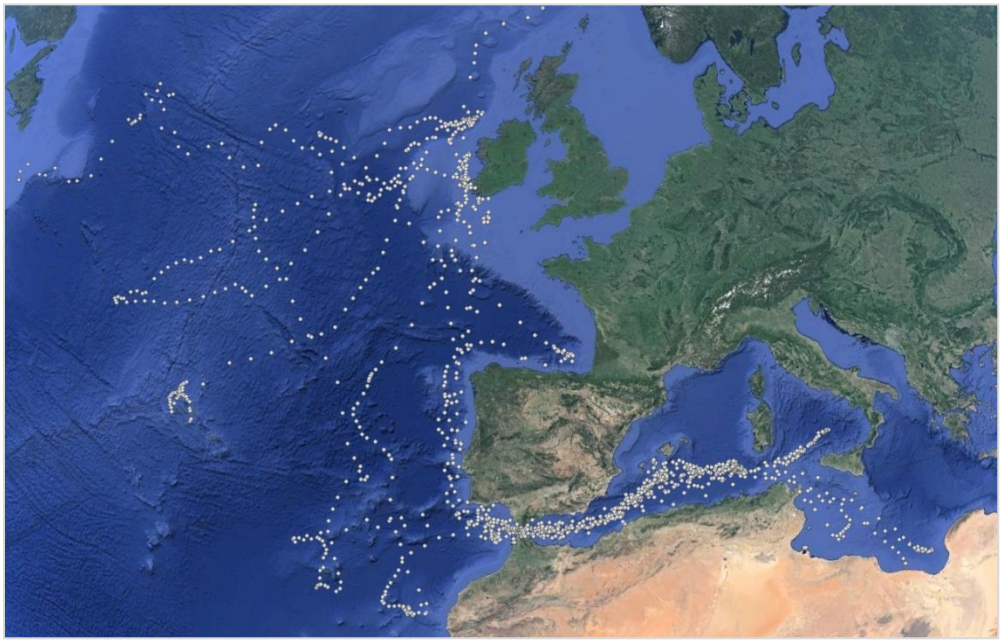

Figure 4. Daily positions of the 11 pop-up tags deployed on giant tuna (all but one over 2 m CFL) in the Atlantic coast of Morocco which performed the trophic migration into the Atlantic Ocean after entering the Mediterranean during the spawning season. Time-span ranged from 42 up to 300 days at liberty.

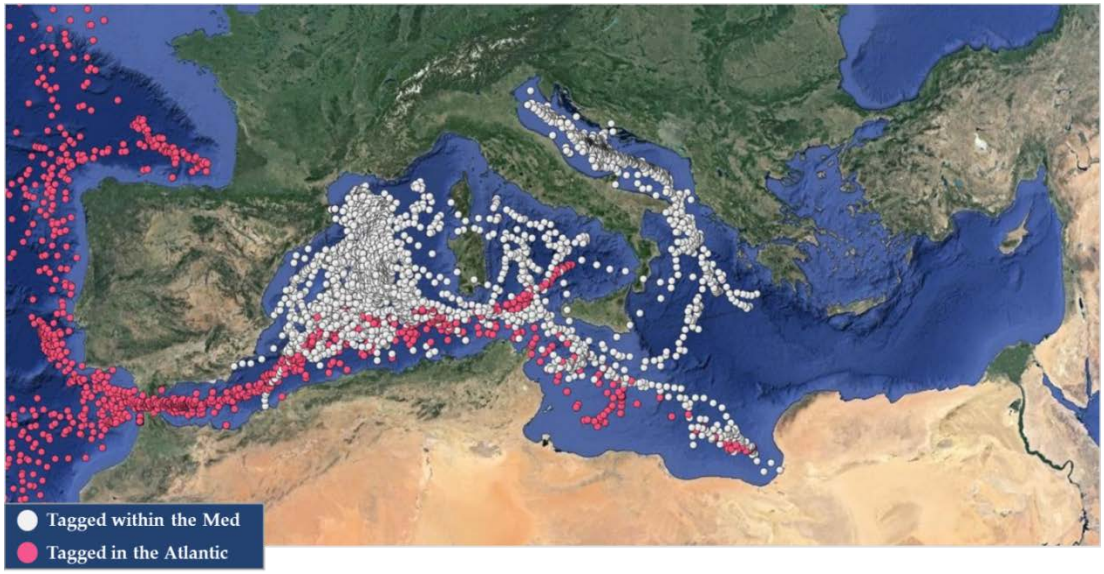

Figure 5. Daily positions of the 54 tunas tagged both in the Mediterranean (N = 34) and in the Atlantic coast of Morocco (N = 17), which visited the Mediterranean Sea at some point while having their tag attached.

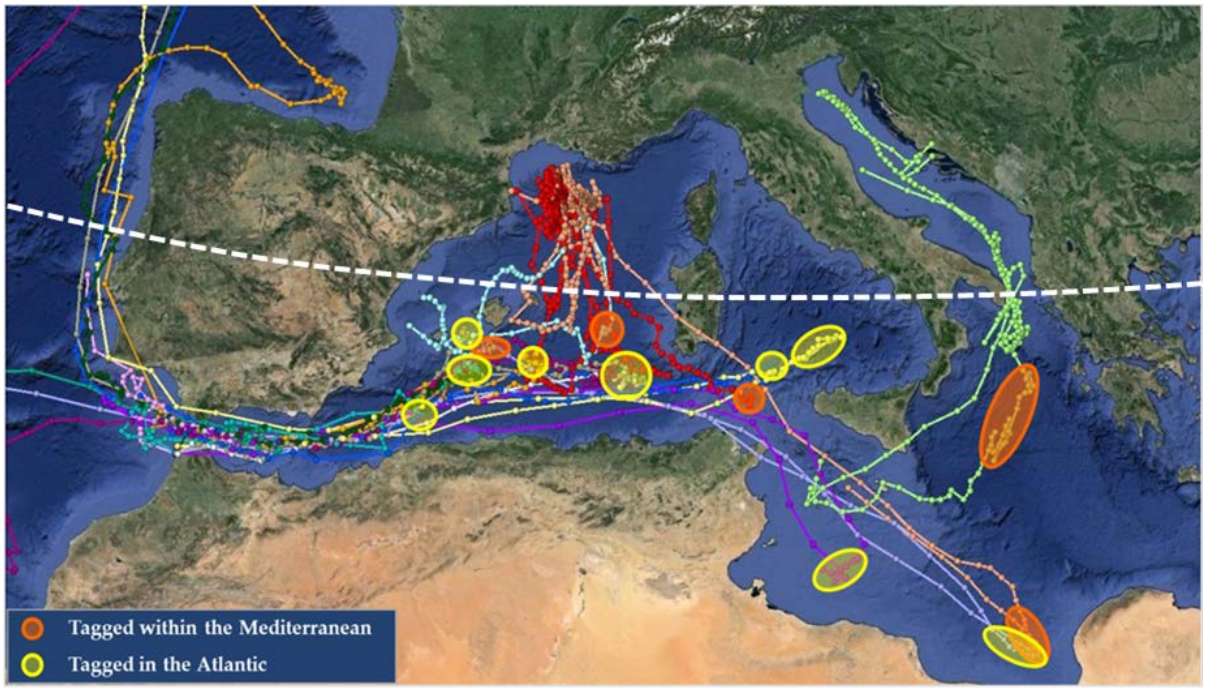

Figure 6. Places where tunas showed potential reproductive behavior. Orange areas represent those individuals tagged within the Mediterranean basin and yellow areas are for those tagged in the Atlantic coast of Morocco. Dashed white line is the 40^{o} N parallel.

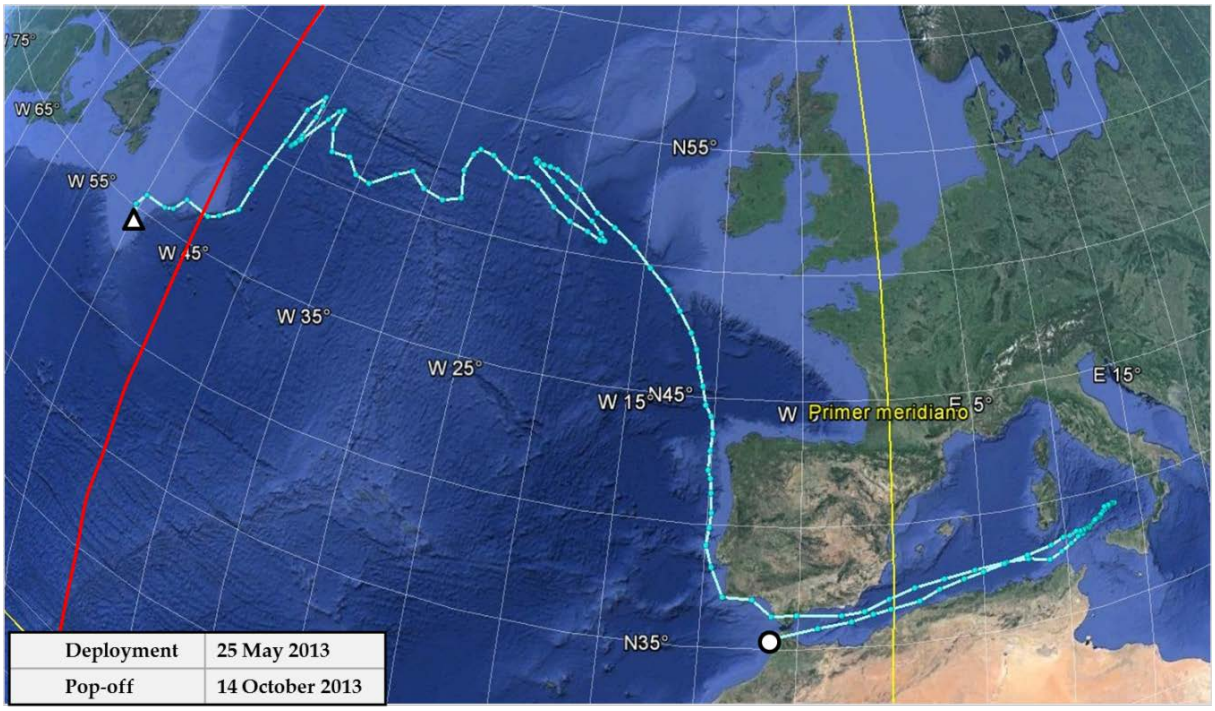

Figure 7. Trajectory of the tuna with ID # 11P0474 tagged in the Atlantic coast of Morocco on the 25th of May 2013.