BEHAVIOUR OF POST-SPAWNING ATLANTIC BLUEFIN TUNA TAGGED WITH POP-UP SATELLITE TAGS IN THE MEDITERRANEAN AND EASTERN ATLANTIC

G. De Metrio[1], G.P. Arnold[2], B.A. Block[3], J.M. de la Serna[4], M. Deflorio[1], M. Cataldo[5], C. Yannopoulos[6], P. Megalofonou[6], S. Beemer[3], C. Farwell[3], A. Seitz[3]

SUMMARY

A total of 84 bluefin tuna were tagged using 61 PTT-100 single point and 23 PAT archival satellite tags - PAT tag experiments were conducted in collaboration with the Tuna Research and Conservation Center, USA – in the Mediterranean and the Eastern Atlantic between June 1998 and August 2000. Considering both types of tag, the overall return rate obtained in the two areas during the whole period was 31.3%. The return rates from PTT-100 and PAT tags were 20.3% and 61.9%, respectively. No transatlantic migrations were observed. Several of the tags have shown interesting results: two PTT-100 tags deployed off the Strait of Gibraltar was detected in the Greenland Sea and in an area close to the southern limit of the eastern Atlantic bluefin tuna stock; a PAT tag deployed in the Mediterranean was detected in the Iceland Sea; most of the tags deployed in the area of Bocche di Bonifacio (Corsica) popped up in the same area. Inspection of SeaWiFS satellite data (for chlorophyll-a concentration extraction) showed that higher concentrations of chlorophyll-a appeared in the areas where most of the tags were detected. These areas of high productivity may therefore be feeding areas for both pre- and post-spawning fish. Tag trials were made at different sites in order to test the ability of the Argos satellite system to detect tags in the western Mediterranean and the eastern North Atlantic.

RÉSUMÉ

Des thons rouges au nombre de 84 ont été marqués dans la Méditerranée et dans l'Atlantique est entre juin 1998 et août 2000 au moyen de 61 marques PTT-100 single-point et de 23 marques archives PAT reliées à un satellite; les expériences de marquage PAT se sont déroulées en collaboration avec le Tuna Conservation Center des Etats-Unis. Si l'on considère les deux types de marques, le taux global de récupération obtenu dans ces deux zones sur l'ensemble de la période était de 31,3%. Le taux de récupération était respectivement de 20,3% pour les marques PTT-100 et de 61,9% pour les marques PAT. Aucune migration transatlantique n'a été observée. Plusieurs marques ont donné des résultats intéressants: deux marques PTT-100 apposées au large du détroit de Gibraltar ont été détectées dans la mer du Groenland et dans un secteur proche de la limite méridionale du stock est-atlantique de thon rouge; une marque PAT apposée en Méditerranée a été détectée dans la mer d'Islande; la plupart des marques apposées dans la zone de Bocche di Bonifacio (Corse) sont apparues dans le même secteur. L'inspection des données SeaWiFS par satellite (pour l'extraction de la concentration en chlorophylle) ont montré que les plus fortes concentrations en chlorophylle-a se trouvaient dans les secteurs où la plupart des marques étaient détectées. Ces zones de forte productivité sont donc peut-être des zones trophiques pour les poissons pré-ponte comme post-ponte. Des essais de marquage ont été faits à différents endroits pour tester la capacité du système satellitaire Argos de détecter les marques dans l'ouest de la Méditerranée et dans l'Atlantique nord-est.

[1] Department of Animal Health and Welfare - University of Bari (Italy) – g.demetrio@veterinaria.uniba.it
[2] CEFAS Lowestoft, Suffolk (UK).
[3] Hopkin Marine Station, Tuna Research and Conservation Center - Stanford University (USA).
[4] IEO Fuengirola, Malaga (Spain).
[5] PLANETEK ITALIA Bari (Italy).
[6] Department of Zoology, Marine Biology - University of Athens (Greece).

RESUMEN

Se marcó un total de 84 atunes rojos utilizando 61 marcas PTT- 100 de punto único y 23 marcas archivo por satélite PAT -los experimentos de marcas PAT se realizaron en colaboración con el Tuna Research and Conservation Center de Estados Unidos-, en el Mediterráneo y en el Atlántico este entre junio de 1998 y agosto de 2000. Considerando ambos tipos de marca, la tasa de recuperación global obtenida en las dos zonas durante todo el período ascendió al 31,3%. Las tasas de recuperación de PTT-100 y PAT fueron del 20,3% y del 61,9%, respectivamente. No se observaron migraciones trasatlánticas. Muchas marcas presentaron resultados interesantes: dos marcas PTT-100 colocadas en las aguas del Estrecho de Gibraltar se localizaron en el mar de Groenlandia y en una zona cercana al límite meridional del stock de atún rojo del Atlántico este; una marca PAT colocada en el Mediterráneo se detectó en el mar de Islandia; la mayor parte de las marcas colocadas en la zona de Bocche di Bonifacio (Córcega) se desprendieron en la misma zona. La inspección de los datos del satélite SeaWiFS (para la extracción de la concentración de clorofila "a") mostraba que las concentraciones más altas de clorofila "a" se había producido en las zonas en las que se detectaron más marcas. Por consiguiente, estas zonas de alta productividad podrían ser zonas tróficas o para los peces en períodos inmediatamente anteriores y posteriores al desove. Se realizaron pruebas con marcas en diferentes puntos con el fin de comprobar la capacidad del sistema por satélite Argos para detectar marcas en el Mediterráneo oeste y en el Atlántico nordeste.

KEYWORDS

Bluefin tuna, Migrations, Tagging, Pop-up tags, Pop-up archival tags, Behaviour, Environmental conditions, Experimental research, Feeding behaviour, Feeding migrations, Fishery management, Geographical distribution, Oceanography.

1. INTRODUCTION

As is well known, ICCAT has for many years assessed Atlantic bluefin tuna (*Thunnus thynnus*, L.) on the hypothesis that there are two separated stocks - the Eastern-Atlantic stock, including the Mediterranean, and the Western-Atlantic stock - with limited rates of exchange. However, the hypothesis is untested and exchange rates between the Western and Eastern Atlantic, as well as those between the Western and Eastern Mediterranean remain unknown.

TUNASAT, an EU-funded research programme involving Italy, Spain, Greece and the UK, which was carried out during the three-year period 1998-2000, aimed to help solve this problem. Specifically the project set out to identify and describe migrations and movements of bluefin tuna both within the Mediterranean and between the Mediterranean and the Atlantic Ocean in relation to spawning and nursery areas. It also aimed to evaluate the practicalities of using pop-up satellite-detected tags, and gain experience for future projects with large pelagic fish (*De Metrio et al.*, 1999, 2000).

Tagging in 2000 was carried out in conjunction with the Tuna Research and Conservation Centre, as part of the US co-ordinated TAG programme.

2. MATERIAL AND METHODS

A total of 84 bluefin tuna - 52 giants, 17 smaller adults and 15 juveniles - were tagged with pop-up tags in Mediterranean and Eastern Atlantic, between June 1998 and September 2000 (figure 1).

Sixty-one of these tuna were tagged with PTT-100 single-point pop-up satellite tags, manufactured by Microwave Telemetry (Columbia, Maryland, USA) and programmed to detach themselves from the fish and float to the surface after intervals of between 5 and 300 days. The PTT-100 tags recorded 61

average hourly, or daily, sea temperatures that were transmitted through the Argos satellite system, which determined the pop-up position of each tag. Twenty-three fish were tagged with pop-up archival satellite tags, which were constructed by Wildlife Computers Inc (Redmond, WA, USA). These PAT tags were programmed to detach themselves from the fish and float to the surface after intervals of between 32 and 185 days, providing a full archive of light, temperature and pressure at 2 minutes intervals. A selection of the archived data - including daily longitudes, times of sunrise and sunset, depth and temperature histograms - was transmitted through the Argos satellite system, which again determined the pop-up position of the tag. The full set of archived data could be downloaded from tags that were subsequently recovered. The PAT tag experiments were conducted in collaboration with the Tuna Research and Conservation Centre, as part of the US co-ordinated TAG programme.

Thirty-two bluefin tuna were tagged with PTT-100 tags by underwater gun and hand-held harpoon in the large tuna trap at Barbate (Spain) to the west of the Strait of Gibraltar in July 1998 and 1999. Fifteen fish were tagged (13 with PAT and 2 with PTT-100 tags) by hand-held harpoon and underwater gun in aquaculture cages at Puerto Mazarron (Cartagena, Spain) in August 2000. Three fish (giants) were tagged with PTT-100 tags using an underwater gun at the Stintino trap (Sardinia, Italy) in June 1998. Twenty-two fish, captured in the local sport fishery, were tagged by hand-held harpoon in the Bocche di Bonifacio (Corsica, France) in September 1999 and 2000 (figure 2). Of these 22 tuna, 12 were tagged with PTT-100 tags, bringing the fish close to the boat, and 10 with PAT tags, bringing the fish on board using a plastic cradle with two handles. Twelve bluefin tuna were tagged in the Aegean Sea (Greece) using a short hand-held stick.

The tags were attached by a monofilament nylon leader to medical grade nylon dart (PTT-100 tags) or a titanium anchor (PAT tags) embedded in the dorsal muscles. For 12 fish tagged with PAT tags in the Corsican sports fishery, the titanium anchor was passed through the base of the second dorsal fin rays.

A series of charts of chlorophyll-a concentration were plotted for the Tyrrhenian Sea close to Corsica and Sardinia (central Mediterranean) and the eastern Atlantic to the south of the Strait of Gibraltar, the two areas in which most of the tags surfaced. Data were extracted from the SeaWiFS database (Parrish, 1996; IOCCG Reports, 1999). Data for the first area was analysed for the period September 2000 to February 2001, obtaining a quite homogeneous temporal coverage (about three good satellite acquisitions per month) apart from January.

Cloud coverage proved to be more of a problem for the Atlantic area in the period July - October 1999 (when the Barbate campaign took place). Consequently, the threshold for rejecting data, according to cloud coverage, was different in the two cases. Selected data were processed to derive chlorophyll-a projected maps centred on the most interesting areas.

Some trials were made with five unused PTT-100 tags in order to test the ability of the Argos satellite system to detect these tags in the western Mediterranean, where there is now known to be substantial background noise on the Argos radio frequency, and the eastern North Atlantic.

Plastic buckets filled with seawater deep enough for the tags to float upright were used to carry out the tests. The buckets were placed 1-2 meters apart and the tags set to transmit during a period from 10 minutes before the satellite came into range for the first time to 10 minutes afterwards. An RMD02 receiver, which identifies the source (tag ID number) of each received signal, was used to monitor the signals ("beeps") received from the five The trials were carried out in the USA by Microwave Telemetry and at various European locations by members of the Tunasat team.

3. RESULTS

3.1 Detection rates

Table 1 shows the number of tags deployed at each location and the numbers of these that were successfully detected by satellite. From the total of 84 pop-up tags, 29 returns were obtained, of which 23 were located by satellite and 2 transmitted no-valid data giving a total detection rate of about 31%. Four more tags were recovered from recaptured fish.

From the 61 PTT-100 single point pop-up tags, 12 (20.3%) were successfully located by satellite; another two fish were caught in the commercial fishery before the tags were due to release. Detection rates varied between the release sites from about 8% in the Aegean Sea, for the two years 1998 and 1999, to about 67% at Stintino in Sardinia in 1998. The overall detection rate for the 32 bluefin tuna tagged with PTT-100 tags at Barbate in July 1998 and 1999 was 21.9% but there was a marked difference between the two years. In 1998 the detection rate was 50% (12 tags released, 6 tags detected); in 1999 the rate was only 15.4% (40 tags released, 6 tags detected, 1 tag recovered from recaptured fish); in 2000 no returns were obtained (9 tags released, 1 tag recovered from a recaptured fish). Sporadic radio signals, which were received from a further 6 tags on or close to the expected pop-up day, were of insufficient strength, or number to provide geographical location or transmit temperature data.

From the 23 PAT tags, 13 were detected by satellite, for a total return rate of 61.9%. However, two of these tags, which appeared to have drifted ashore very quickly after release, transmitted no valid data. A further 2 tags were recovered from recaptured fish and the full set of archived data recovered. The detection rate for the PAT tags differed markedly between the two release sites. Only 4 (33.3%) of the 13 tags deployed on bluefin tuna (11 giants and 2 smaller adults) in a holding pen at Puerto Mazarron in August 2000 were detected by satellite; a further tag was recovered from a recaptured fish. In contrast, 9 (100%) of the PAT tags deployed on smaller (40-90 kg) fish in Corsica, during September 2000, were detected by satellite, including the two tags that drifted ashore; the tenth tag was recovered from a recaptured fish.

3.2 Pop-up locations

The positions at which the various tags were first detected by the Argos satellite system are shown in figure 1. Despite several long-distance movements, no tags were detected in the western North Atlantic. Most tags from Spain surfaced between Gibraltar, Madeira and the Cape Verde Islands, although tags from two giant bluefin surfaced south of Iceland (60.114°N 19.480°W) and in the Greenland Sea (75.123°N 1.095°E) after 62 and 239 days at liberty, respectively. Assuming that the tag was still attached to the fish on the programmed release date, the position in the Greenland Sea is the most northerly reported position for a bluefin tuna. Recorded temperatures were consistent with pop-up positions. Successive daily longitudes from the PAT tag indicated that the first of these two fish followed a relatively direct track towards Iceland after leaving the Mediterranean.

An analysis of the temperature record indicates that the second fish, which was tagged with a PTT-100 single-point tag, must have similarly followed a fairly direct course to an area south of Iceland during its first 30 days at liberty. The speed of movement was too fast to be accounted for by prevailing ocean currents. Thereafter, however, the rate of progress was much slower and could be accounted for by passive drift at the surface, if the tag had become prematurely detached from the fish. Equally, the tag could have remained on the fish until the programmed date and detached when the fish was in the Greenland Sea.

Most of the tags that were deployed in the Mediterranean surfaced close to the tagging location, especially those from fish that were released off Corsica. One of the PAT tags was detected in the Golf du Lion (figure 1) but the others surfaced close to the Bocche di Bonifacio, or in the northern Tyrrhenian Sea to the east of Corsica (figure 2).

The daily longitudes recorded by the PAT tags indicate that all of these fish remained in the area between Corsica and longitude 14°E. Maximum depths recorded by the PAT tags similarly indicate that, while some fish moved off into deep water in the Tyrrhenian Sea, others remained in shallow water on the continental shelf around the island. Given the occurrence of a persistent area of high production in the area to the east of Corsica (figure 3), this may be a feeding area for both pre- and post-spawning fish.

The data acquired from the SeaWiFS sensor for the central Mediterranean (Tyrrhenian Sea) and the eastern Atlantic and western Mediterranean are shown in figures 3 and 4 respectively. The chlorophyll-a concentration in mg/m^3 is represented using a pseudo-colour look up table. Clouds are shown in white.

3.3 Tag detection trials

The rate of detection of the PTT-100 tags was only about 20% overall, which was much lower than expected from previous experience with the same type of tag in the western and central North Atlantic (*Block et al.*, 1998; *Lutcavage et al.*, 1999; *Lutcavage*, pers. comm.). Because this difference was so large, it was conducted a series of tests to estimate the detection rate in Europe compared with that obtained in the USA and Madeira.

Five PTT-100 tags, which performed almost perfectly in Columbia, Maryland, USA, were tested sequentially in Lowestoft, Bari, Athens, Malaga and Madeira. The power radiated by each tag was then measured in Lowestoft and shown to be still within the manufacturer's specification, as was the transmission frequency.

The results of the detection tests, which are summarised in table 2, clearly indicate that there is a problem with detecting these tags in parts of the Mediterranean Sea, where they were expected tags to pop up. It seems likely, therefore, that a low signal to noise ratio in the affected areas may have resulted in the non-detection of tags that may otherwise successfully surfaced when programmed to detach themselves from the fish.

Corroborative evidence is available from six tags, from which sporadic signals were received on, or close to, the expected pop-up day. No temperature data were obtained from these six tags and the signals were too weak, or too few, for the Argos system to determine the location of the tag.

4. DISCUSSION AND CONCLUSIONS

The overall detection rate (~ 20%) of the PTT-100 tags was much lower than that (56 to 93%) achieved with single-point tags of the same design in the western Atlantic (*Block et al.*, 1998; *Lutcavage et al.*, 1999; *Lutcavage*, pers. comm.; *De Metrio et al.*, 2000). Whilst the reasons for this low detection rate may include post-tagging mortality and premature tag release, it has now demonstrated that the strength of the radio signal transmitted by the tags is a significant factor in parts of the Mediterranean and northern Europe.

Although it cannot says how many tags were not detected because of this signal to noise ratio problem, it is clear that our ability to detect tags was compromised over a significant area. According to Argos, the problem, which results from a high level of background noise, is confined to Europe, however. Our ability to detect tags that surfaced in the Atlantic should therefore have been the same as that for tags attached to tuna in US waters. In this context it is interesting to note that none of the pop-up positions of our tags were located in the central or western North Atlantic.

High non-reported fishing mortality of giant bluefin in the eastern North Atlantic may be another factor responsible for low tag 'return' rates, with tags being recaptured - although not returned - before the programmed release date. Evidence that this may be occurring comes from the comparative

detection rates of the 23 PAT tags released in Cartagena and Corsica in August and September 2000. The satellite detection rate of the tags released on small bluefin (40-90 kg) in the sports fishery off Corsica was 100%. In contrast, only 4 (~33%) of the tags deployed on larger bluefin (11 giants and 2 smaller adults) in a holding pen at Cartagena were subsequently detected by the Argos satellite system. Two of these four tags were located in the western Mediterranean, one near the Strait of Gibraltar and one near Iceland.

Comparison of pop-up positions with the temporal set of chlorophyll-a maps shows a correspondence with higher pigment concentration areas. Higher concentration of chlorophyll-a appeared mainly in the areas where most of the tags were detected, especially in the central Mediterranean and northern Tyrrhenian Sea, where most of the Corsican tags surfaced. Given this correspondence, these areas of high production may well be feeding areas for both pre- and post-spawning fish.

5. REFERENCES

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6. ACKNOWLEDGEMENTS

The Authors are grateful to Molly Lutcavage and colleagues for advice and practical help with methods of attaching the PTT-100 tags and for access to unpublished data. The Authors thank them for their generous support.

Moreover, the Authors express their thanks to Prof. Salvatore Rubino, Professor of the Department of Medical Microbiology at the University of Sassari (Italy), and Mr. Agostino Diana, captain of the tuna trap at Stintino (Sardinia, Italy); to Mr. Aniceto Ramirez and Mr. Vicente Zaragoza, respectively owner and captain of the tuna trap at Barbate (Spain); to Mr. Jaques Renaud and Mr. Michel Camus, for their very important contribution for the success of the tagging operation in Corsica (France); to Mr. Gines Mendez, owner of GINES MENDEZ COMPANY at Puerto Mazarron (Spain); to Mrs. Annunziata Marinelli and Mr. Enzo Pesola for their contribution in laboratory.

Table 1. – Tag returns.

Type of tag	Tagging place	No tags deployed	No tags detected	Detected but no valid data	Detection rate	No tag recovered from recaptured fish
PTT-100	Barbate trap '98	9	4		44.4%	
	Stintino trap '98	3	2		66.7%	
	Total 1998	*12*	*6*		*50.0%*	
	Barbate trap '99	23	3		13.0%	
	Bocche di Bonifacio '99	12	2		18.2%	1
	Aegean Sea '99	5	1		20.0%	
	Total 1999	*40*	*6*		*15.4%*	*1*
	Puerto Mazarron cage '00	2			0.0%	1
	Aegean Sea '00	7			0.0%	
	Total 2000	*9*			*0.0%*	*1*
	Total	**61**	**12**		**20.3%**	**2**
PAT	Puerto Mazarron cage '00	13	4		33.3%	1
	Bocche di Bonifacio '00	10	7	2	100.0%	1
	Total	**23**	**11**	**2**	**61.9%**	**2**
Total (PTT-100 + PAT tag)		**84**	**23**	**2**	**31.3%**	**4**

Table 2. – Comparison of location rates for the PTT-100 single-point pop-up satellite tags.

Location	No. of tests*	No. of locations	Location rate (%)
Lowestoft (1) (UK)	50	0	0
Columbia (USA)	20	19	95
Lowestoft (2) (UK)	60	3	5
Bari (1) (I)	65	0	0
Bari (2) (I)	90	18	20
Bari (3) (I)	75	10	13
Athens (GR)	50	15	30
Malaga (E)	45	21	47
Madeira (P)	40	31	78

* No. of tests = no. of tags (5) x no. of satellite passes

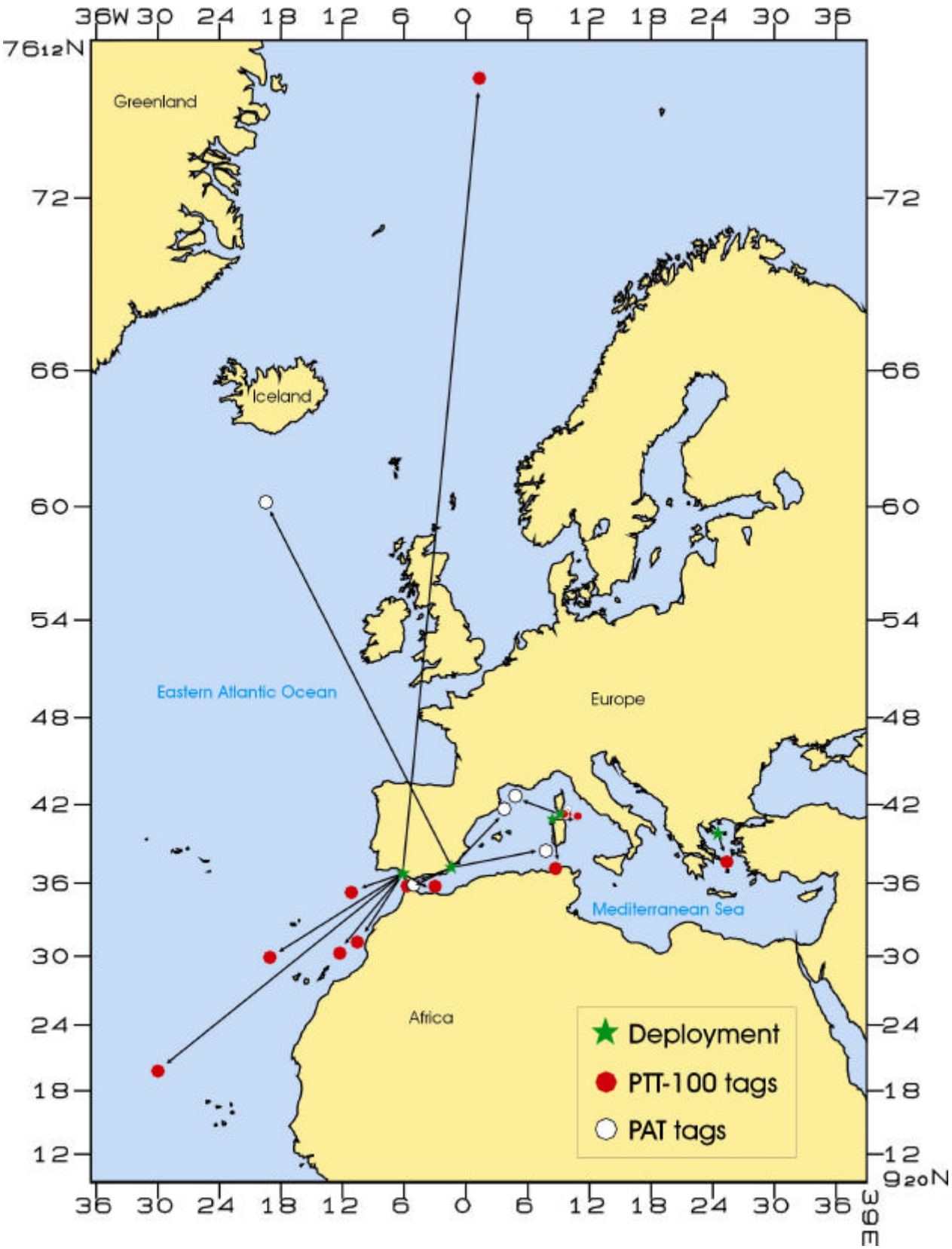

Figure 1 - Pop-up locations of tags attached to tuna in the Mediterranean and eastern Atlantic from 1998 to 2000. Red circles, PTT-100 single-point pop-up tags; white circles, PAT archival pop-up tags.

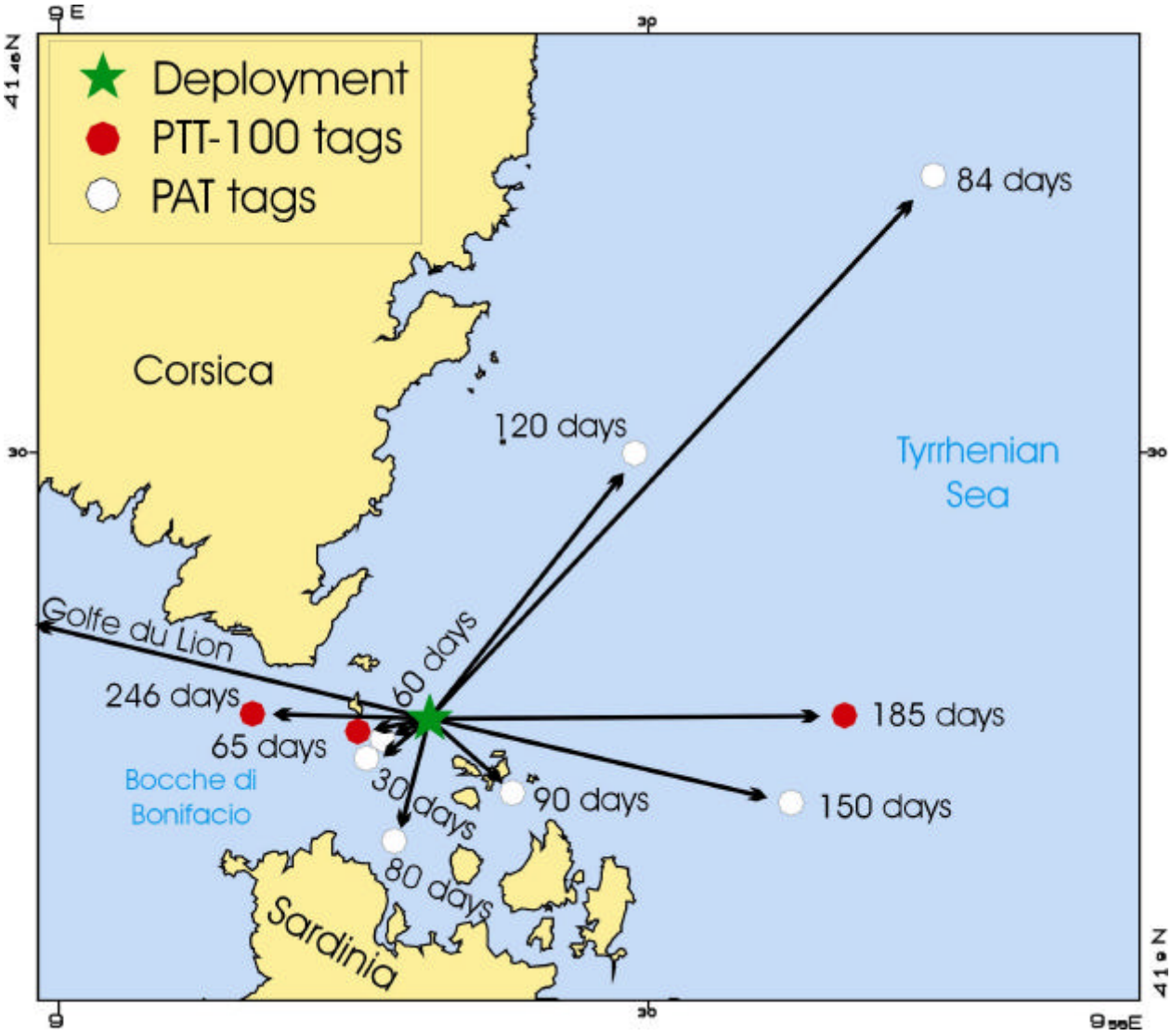

Figure 2 - Pop-up locations of tags attached to tuna in the Corsican sports fishery in 1999 and 2000. Red circles, PTT-100 single-point pop-up tags; white circles, PAT archival pop-up tags.

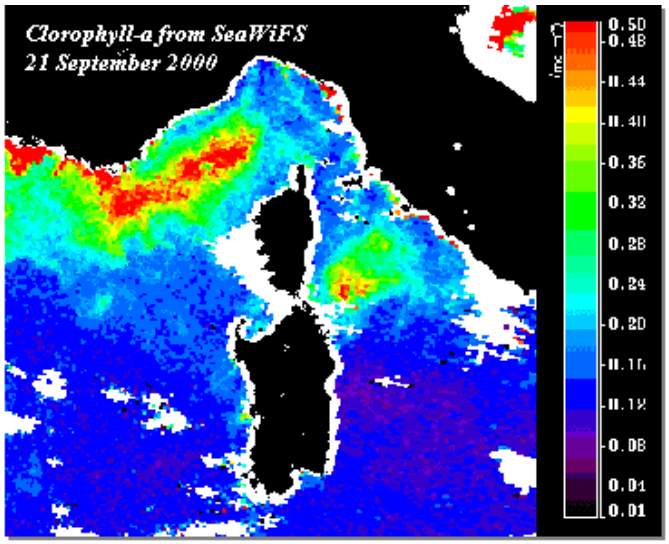

Figure 3 - Chlorophyll-a concentration from SeaWiFS in the central Mediterranean (Tyrrhenian Sea).

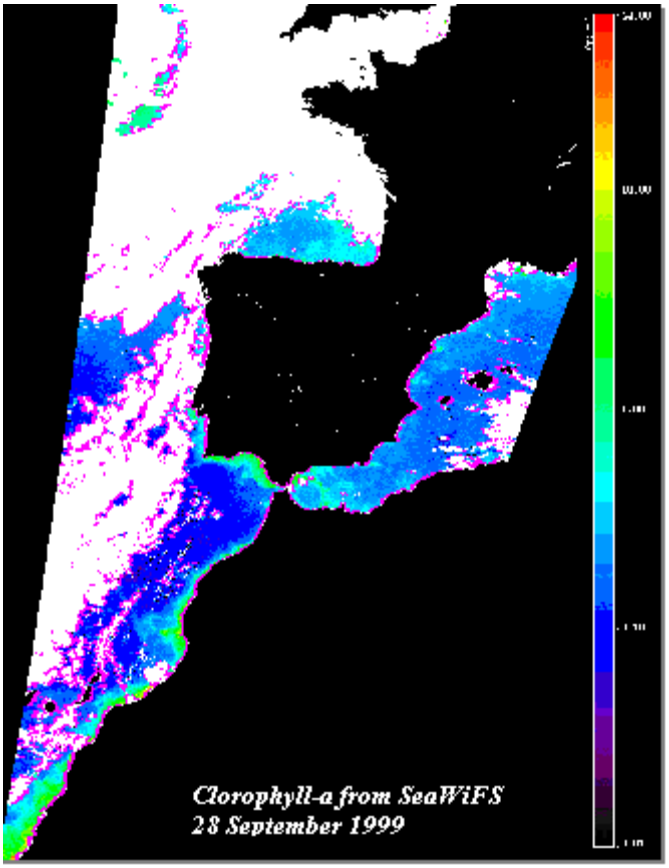

Figure 4 - Chlorophyll-a concentration from SeaWiFS in the western Mediterranean and eastern Atlantic.