Spedicato, M.T.; Lembo, G.; Marmulla, G. (eds.)
Aquatic telemetry: advances and applications. Proceedings of the Fifth Conference on Fish Telemetry held in Europe. Ustica, Italy, 9-13 June 2003.
Rome, FAO/COISPA. 2005. 295p.

Movements and migrations of North Atlantic Bluefin tuna tagged with pop-up satellite tags

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Key-words: Bluefin tuna, migrations, tagging, pop-up satellite tags, behaviour, feeding behaviour, feeding migrations, geographical distribution, oceanography.

Abstract

A total of 84 bluefin tuna were tagged with two types of electronic pop-up satellite tags and released in the Mediterranean and the Strait of Gibraltar between June 1998 and August 2000. Twenty-three tags (30%) were located by the Argos satellite system and the location rates were 21% and 52%, respectively for pop-up single-point tags (PTT-100 tag made by Microwave Telemetry Inc., Columbia, Maryland, USA) and pop-up archival tags (PAT tag made by Wildlife Computers Inc., Redmond, Washington, USA). Most tags surfaced in the western Mediterranean and eastern Atlantic, but one archival tag transmitted from a position south of Iceland and one single-point tag transmitted from the Greenland Sea. No transatlantic migrations were observed. Most tags released in the western Mediterranean surfaced near the tagging location, suggesting local residency. Residency and spawning site fidelity (which was also indicated by our data) offer the potential for overexploitation, if the industry progressively catches more large bluefin tuna for fattening. Tag experiments using pop-up archival satellite tags were conducted in collaboration with the Tuna Research and Conservation Centre, USA.

Introduction

Stock assessments of North Atlantic bluefin tuna (*Thunnus thynnus* L.) are currently carried out on the assumption that there are two stocks, the eastern Atlantic & Mediterranean and the western Atlantic, separated by a conventional boundary at 45° W. This two-stock hypothesis is supported by the presence of small to large bluefin tuna on both sides of the Atlantic, the occurrence of spawning in the Gulf of Mexico and in the Mediterranean at different times of the year, and the morphometric differences of bluefin tuna from the two grounds.
Analyses of conventional tagging data, which show a low mixing rate between west and east, with most tags recaptured in the area of release, also support the existence of two separate groups of bluefin tuna in the North Atlantic.
Recently, however, several electronic tagging programmes have been initiated to improve our knowledge of the migrations of North Atlantic bluefin tuna and investigate the occurrence of transatlantic movement (Block *et al*., 1998; 2001; Lutcavage *et al*., 1999).
In Europe, experiments with pop-up satellite-detected tags were carried out in the eastern Atlantic and Mediterranean between June 1998 and August 2000 as part of an EU FAIR Project. The aims of the project were: a) to identify and describe migrations and movements of bluefin tuna, both within the Mediterranean and between the Mediterranean and the Atlantic Ocean, in rela-

tion to spawning and nursery areas; b) to evaluate the practicalities of using pop-up satellite-detected tags; and to gain experience for future projects with large pelagic fish (De Metrio *et al*., 1999; 2001; 2002).

The present paper provides an overview of the results obtained during the EU FAIR Project. The findings, which have been partially reported to the international fisheries research community in several short ICCAT papers, are presented here for the benefit of the wider scientific community.

Material and methods

A total of 84 bluefin tuna were tagged with pop-up satellite-detected electronic tags in the Mediterranean and Eastern Atlantic, between June 1998 and September 2000. Types and number of tag used were: 61 PTT-100 pop-up single-point tags (Microwave Telemetry Inc., Columbia, Maryland, USA), which recorded a limited number of temperature measurements, and 23 PAT pop-up archival tags (Wildlife Computers, Redmond, Washington, USA), which recorded temperature, depth and daily longitude. Experiments with PAT tags were conducted in collaboration with the Tuna Research and Conservation Centre, Monterey, California, as part of the United States co-ordinated TAG programme.

Three bluefin tuna were tagged with PTT-100 tags, using an underwater gun, at the Stintino trap (Sardinia, Italy) in June 1998. Thirty-two bluefin tuna were tagged with PTT-100 tags by underwater gun or hand-held harpoon in the large bluefin tuna trap at Barbate (Spain), to the west of the Strait of Gibraltar, in July 1998 (9 fish) and in July 1999 (23 fish). Twenty-two bluefin tuna captured in the local sport fishery were tagged, either alongside the boat using a hand-held tagging stick (12 fish) or on deck (10 fish), in the Bocche di Bonifacio between Corsica and Sardinia during September 1999 and September 2000. Fifteen bluefin tuna were tagged (13 fish with PAT tags and 2 fish with PTT-100 tags) by hand-held harpoon and underwater gun in the aquaculture pens at Puerto Mazarròn (Cartagena, Spain) on 1st August 2000. Twelve bluefin tuna were tagged with PTT-100 tags in the Aegean Sea (Greece) in April and December 1999 and January and March 2000, using a short hand-held stick.

All tags were attached by a monofilament nylon leader to a nylon dart (PTT-100 tags) or a titanium anchor (PAT tags) embedded in the dorsal muscles of the bluefin tuna. For bluefin tuna tagged in the water, the nylon dart was embedded directly in the muscles. For bluefin tuna tagged on deck the titanium anchors were passed through the base of the second dorsal fin ray.

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, 1999). Data for the first area were analysed for the period September 2000 to February 2001, obtaining a fairly homogeneous temporal coverage (about three good satellite acquisitions per month) apart from January.

A series of trials were made with five unused PTT-100 tags 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 and transmitter competition on the Argos radio frequency) and the eastern North Atlantic. A complementary analysis was carried out with the data received from the 12 PTT-100 tags that were both detected and located by Argos.

Results

Six tags were recovered from recaptured bluefin tuna, leaving 78 available to surface and transmit radio signals (Table 1). Twenty-three tags were located by satellite, giving an overall location rate of about 30% (23/78): all 23 transmitted valid data. Sporadic radio signals were received from a further six tags (four PTT-100 & two PAT tags) raising the overall detection rate to about 37% (Table 1). These six tags were, however, not located by Argos. Good temperature data were received from the four PTT-100 tags but no data were received from the two PAT tags.

Table 1 – Detection and location rates of tags attached to bluefin tuna in the Mediterranean Sea and eastern Atlantic Ocean between 1998 and 2000.

Tag type	Tagging location	No. of tags deployed n	No. of tags recovered from captured fish n	No. of tags available to surface on programmed date n	No. of tags detected n	No. of tags located n	Detection rate %	Location rate %
PTT-100	Barbate trap '98	9		9	4	4	44.4	44.4
	Stintino trap '98	3		3	2	2	66.7	66.7
	Total '98	*12*		*12*	*6*	*6*	*50.0*	*50.0*
	Barbate trap '99	23	1	22	4	3	18.2	13.6
	Bocche di Bonifacio '99	12	2	10	5	2	50.0	20.0
	Aegean Sea '99	5		5	1	1	20.0	20.0
	Total '99	*40*	*3*	*37*	*10*	*6*	*27.0*	*16.2*
	Puerto Mazarron cage '00	2	1	1				
	Aegean Sea '00	7		7				
	Total '00	*9*	*1*	*8*				
	Total PTT-100 tags	61	4	57	16	12	28.1	21.1
PAT	Puerto Mazarron cage '00	13	1	12	4	4	33.3	33.3
	Bocche di Bonifacio '00	10	1	9	9	7	100.0	77.8
	Total PAT tags	23	2	21	13	11	61.9	52.4
TOTAL (PTT-100 + PAT tags)		84	6	78	29	23	37.2	29.5

Location rates were about 21% (12/57) for the PTT-100 tags and 52% (11/21) for the PAT tags, which appeared to be less influenced by the high level of background noise and high density of Argos transmitters in the Mediterranean area than the PTT-100 tags. Detection and location rates of PTT-100 tags varied markedly between release sites and years (Table 1). In 1998, 4 (44%) of the 9 tags released at Barbate were detected and located, compared with 2 (67%) of the 3 tags released at Stintino. In 1999, however, the rate of detection for tags released at Barbate fell to 18% and the rate of location was only 14%. A slightly higher rate of location (20%) was experienced with tags released in the Bocche di Bonifacio and Aegean Sea in 1999, although at 50% the detection rate for tags released in the Bocche di Bonifacio was considerably greater. In 2000, none of the nine tags released at Puerto Mazarròn and in the Aegean Sea was detected.

Detection and location rates of the PAT tags also differed markedly between release sites. Only 4 (about 33%) of the 13 tags deployed on bluefin tuna in a holding pen at Puerto Mazarròn in the year 2000 were detected (and located) by satellite, although a further tag was recovered from a recaptured bluefin tuna before it was due to detach from the fish. In contrast, in Corsica in the same year the detection rate was 100%, with radio signals received from all 9 of the tags still available to surface on the programmed day. As mentioned above, however, two of these tags could not be located, possibly because they drifted ashore shortly after surfacing. A tenth tag was recov-

ered from a recaptured bluefin tuna, again before it was due to detach from the fish, and the overall location rate from the releases in the Bocche di Bonifacio in 2000 was thus about 78%.

Most tags were located in the western Mediterranean or in the eastern North Atlantic off the coast of North Africa; one PAT tag surfaced south of Iceland and one PTT-100 tag transmitted from the Greenland Sea (Fig. 1). No tags were located in the western Atlantic suggesting no transatlantic migrations among the tagged fish.

Details of the tags that surfaced in the Mediterranean Sea and eastern Atlantic Ocean are given in Table 2, which summarises the dates and locations of deployment and pop-up, as well as the size of the tagged bluefin tuna.

Several tags showed interesting results. One PTT-100 tag deployed near the Strait of Gibraltar was detected in the Greenland Sea; another from the same release transmitted from the eastern Atlantic close to the southern limit of the eastern bluefin stock (Medina *et al*., 2002). A PAT tag deployed in the Mediterranean, close to Cartagena, was detected in the North Atlantic south of Iceland after 62 days at liberty. In contrast, most of the PAT tags deployed in the area of the Bocche di Bonifacio (Corsica) surfaced in the release area. Daily longitudes recorded by the tags indicated that all but one of these bluefin tuna remained close to the release area between longitudes 8° and 14°E. Maximum depths indicated that, while some bluefin tuna moved off into deep water (e.g. the Tyrrhenian Sea), the others most probably remained in the shallow water on the continental shelf around the islands of Corsica and Sardinia. The single tag that did not surface in the release area was located in the Golfe du Lion, to which the fish moved rapidly during its last few days at liberty.

Comparison of pop-up positions with the temporal set of chlorophyll-a maps shows a correspondence with higher pigment concentration areas. In particular, the central Mediterranean and the northern Tyrrhenian Sea show higher concentrations of chlorophyll-a than the other parts of the western Mediterranean and eastern Atlantic. Given the occurrence of persistent areas of high production in the areas where most of the tags were detected, especially to the east of Corsica, these may be feeding areas for both pre- and post-spawning bluefin tuna.

The rate of tag detection was much lower than expected from previous studies with the same type of tag in the western and central North Atlantic, where rates of 56 to 93% have been reported (Block *et al*., 1998; Lutcavage *et al*., 1999; Lutcavage, pers. comm.). Because of this, and also because of the large difference in location rates (44% and 14%, respectively) between the tag deployments in Barbate in 1998 and 1999, a series of tests was conducted to compare the performance of five unused PTT-100 tags at a number of locations in Europe, Madeira and the United States. The results revealed a detection problem in the western Mediterranean Sea, where some of our tags were expected to surface. This problem could well have resulted in non-detection of tags that surfaced successfully in this area at the programmed time. The analysis of the data transmitted by the 12 PTT-100 tags located by Argos indicated the same problem. Tags that surfaced in the western Mediterranean had much lower detection and location rates (0.5-4.4 locations per day) than tags that surfaced in the North Atlantic (10-20 locations per day).

Discussion

Reasons for the low detection rate of the PTT-100 tags may include post-tagging mortality, bluefin tuna capture, premature tag release, failure of the tag as a result of exposure to high pressure and low signal-to-noise ratio during transmission. Whilst it is difficult to quantify some of these factors, our test results clearly indicate that the strength of the transmitted signal was sufficiently low to have compromised our ability to detect tags over a significant area of the western Mediterranean and north-western Europe. The ability to detect tags that surfaced in the Atlantic should, however, have been the same as that for tags of the same type attached to bluefin tuna in United States 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, but were confined to the eastern management area with no evidence of transatlantic migrations.

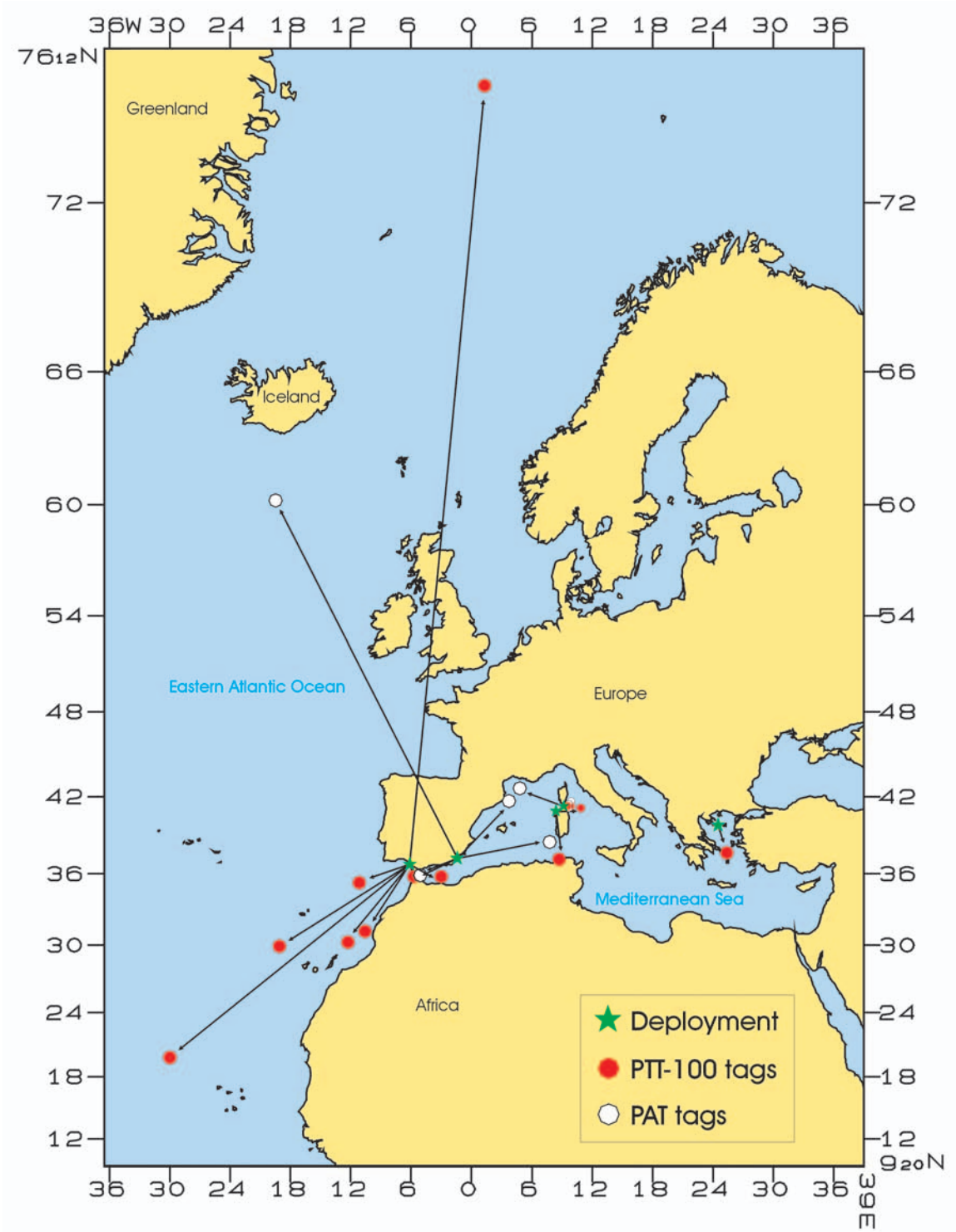

Fig. 1 – Pop-up locations of tags attached to bluefin tuna in the Mediterranean and eastern Atlantic from 1998 to 2000. Red circles, PTT-100 pop-up single-point tags; white circles, PAT pop-up archival tags.

Table 2 – Summary data for the tags located in the Mediterranean Sea and eastern Atlantic Ocean between 1998 and 2000. Dates and locations of deployment and pop-up are given, together with the size of the tagged bluefin tuna.

	Type and IDs of tags		Fish biometry		Deployment dates and sites		Pop-up dates and sites		Days at liberty	Area
			W (kg)	FL (cm)						
1	PTT-100	09118	100	169	07/06/98	Tuna-trap of Stintino (Sardinia)	17/06/98	Central Tyrrhenian Sea	10	Mediterranean Sea
2	PTT-100	09119	100	170	07/06/98	Tuna-trap of Stintino (Sardinia)	29/06/98	Coast of North Africa	22	
3	PTT-100	09117	150	194	27/07/98	Tuna-trap of Barbate (Spain)	01/08/98	Alboran Sea	5	
4	PTT-100	23343	80	157	03/04/99	Aegean Sea	02/05/99	Aegean Sea	29	
5	PTT-100	06086	70	151	27/09/99	Bocche di Bonifacio (Corsica, France)	26/03/00	Bocche di Bonifacio	181	
6	PTT-100	07779	80	157	27/11/99	Bocche di Bonifacio (Corsica, France)	28/07/00	Bocche di Bonifacio	239	
7	PAT	99-759	100	172	01/08/00	Tuna-cages of Puerto Mazarròn (Spain)	01/01/01	Sardinia Channel	154	
8	PAT	99-531	160	198	01/08/00	Tuna-cages of Puerto Mazarròn (Spain)	01/10/00	Strait of Gibraltar	62	
9	PAT	99-526	170	202	01/08/00	Tuna-cages of Puerto Mazarròn (Spain)	01/09/00	Golfe du Lion	32	
10	PAT	99-679	78	156	09/09/00	Bocche di Bonifacio (Corsica, France)	04/10/00	Bocche di Bonifacio	30	
11	PAT	99-721	46	135	10/09/00	Bocche di Bonifacio (Corsica, France)	03/12/00	Bocche di Bonifacio	90	
12	PAT	99-736	75	154	12/09/00	Bocche di Bonifacio (Corsica, France)	02/01/01	Bocche di Bonifacio	120	
13	PAT	99-754	84	160	12/09/00	Bocche di Bonifacio (Corsica, France)	04/02/01	Central Tyrrhenian Sea	150	
14	PAT	99-735	42	131	14/09/00	Bocche di Bonifacio (Corsica, France)	06/12/00	Golfe du Lion	90	
15	PAT	99-716	48	137	14/09/00	Bocche di Bonifacio (Corsica, France)	06/12/00	Bocche di Bonifacio	90	
16	PAT	99-720	54	142	14/09/00	Bocche di Bonifacio (Corsica, France)	06/11/00	Bocche di Bonifacio	60	
17	PTT-100	23011	150	190	27/07/98	Tuna-trap of Barbate (Spain)	24/09/98	Madeira Island	59	Eastern Atlantic
18	PTT-100	23014	150	193	27/07/98	Tuna-trap of Barbate (Spain)	20/01/99	Cape Verde Islands	177	
19	PTT-100	23328	150	194	27/07/98	Tuna-trap of Barbate (Spain)	23/03/99	Greenland Sea	239	
20	PTT-100	23344	150	194	23/07/99	Tuna-trap of Barbate (Spain)	21/09/99	Eastern Atlantic Ocean	60	
21	PTT-100	23345	150	195	23/07/99	Tuna-trap of Barbate (Spain)	19/10/99	Canary Islands	88	
22	PTT-100	23327	150	195	23/07/99	Tuna-trap of Barbate (Spain)	16/01/00	Canary Islands	177	
23	PAT	99-606	230	223	01/08/00	Tuna-cages of Puerto Mazarròn (Spain)	01/10/00	Iceland Sea	62	

It was also noticeable that most of the tags deployed in the Mediterranean surfaced close to the original tagging location. This was especially true of the bluefin tuna released between Corsica and Sardinia, suggesting the existence of residency associated with the high productivity, together with other environmental characteristics of this area.
The recapture of a big bluefin tuna (290 kg) tagged with a PTT-100 tag at Barbate on July 1999 is of particular interest. This bluefin tuna - to which the (pressure-damaged) tag was still attached - was caught near the Balearic Islands in June 2001, suggesting fidelity to the western Mediterranean spawning area.
Spawning site fidelity and Mediterranean residency clearly offer the scope for overexploitation if the industry continues to catch more and more large bluefin tuna for fattening in cages, instead of starting to rear new fish from eggs.
Domestication of bluefin, which is the aim of the new EU funded Project "REPRO-DOTT", would need to extend to the control of all stages of the life history, including reproduction in captivity, rearing and weaning of larvae, and growth to market size, to be sure of avoiding this risk. In this new context, further researches on the bluefin tuna migrations need to be carried out in order to better understand the relations between environmental parameters and the behaviour and physiology of this species. Electronic tags offer an ideal tool for this purpose.

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. They thank Prof. Barbara Block and colleagues at Hopkins Marine Station, Stanford University, for assistance in tagging bluefin tuna in Corsica in 2000 and for providing several PAT tags. They also thank Prof. Salvatore Rubino, Professor at the University of Sassari (Italy) and Mr. Agostino Diana, captain of the bluefin tuna trap at Stintino (Sardinia, Italy); Mr. Aniceto Ramirez and Mr. Vicente Zaragoza, respectively owner and captain of the bluefin tuna trap at Barbate (Spain); Mr. Jaques Renaud and Mr. Michel Camus, for their very important contribution for the success of the tagging operation in Corsica (France); Mr. Gines Mendez, owner of GINES MENDEZ COMPANY at Puerto Mazarròn (Spain); Mrs. Annunziata Marinelli, Mr. Enzo Pesola and Mr. Martino Cacucci for their contribution in field and laboratory.
Financial support was provided by EU grant CFP - FAIR Project No. 97/3975 "Study on movements and migrations of bluefin tuna (*Thunnus thynnus* L.) in the eastern Atlantic and Mediterranean using «Pop-up Satellite Tags»".

References

Block, B.A., Dewar, H., Farwell, C. & Prince, E.D. 1998. A new satellite technology for tracking the movements of Atlantic bluefin tuna. *Proceedings of the National Academy of Sciences*, USA, 95: 9384-9389.

Block, B.A., Dewar, H., Blackwell, S.B., Williams, T.D., Prince, E.D., Farwell, C.J., Boustany, A., Teo, S.L.H., Seitz, A., Walli, A. & Fudge, A. 2001. Migratory movements, depth preferences, and thermal biology of Atlantic bluefin tuna. *Science*, 293: 1310-1314.

De Metrio, G., Arnold, G.P., Cort, J.L., de la Serna, J.M., Yannopoulos, C., Megalofonou, P. & Labini G.S. 1999. Bluefin tuna tagging using "pop-up tags": first experiments in the Mediterranean and eastern Atlantic. *ICCAT, Col. Vol. Sci. Pap.*, 49 (1): 113-119.

De Metrio, G., Arnold, G.P., de La Serna, J.M., Yannopoulos, C., Megalofonou, P., Buckley, A.A. & Pappalepore, M. 2001. Further results of tagging Mediterranean bluefin tuna with pop-up satellite-detected tags. *ICCAT, Col. Vol. Sci. Pap.*, 52: 776-783.

De Metrio, G., Arnold, G.P., Block, B.A., de la Serna, J.M., Deflorio, M., Cataldo, M., Yannopoulos, C., Megalofonou, P., Beemer, S., Farwell, C. & Seitz, A. 2002. Behaviour of post-spawning Atlantic bluefin tuna tagged with pop-up satellite tags in the Mediterranean and eastern Atlantic. *ICCAT Col. Vol. Sci. Pap.*, 54 (2): 415-424.

IOCCG. 1999. Status and Plans for Satellite Ocean-Colour Missions: Considerations for Complementary Missions. Yoder, J. A. ed., Reports of the International Ocean-Colour Coordinating Group, No. 2, IOCCG, Dartmouth, Canada. 47 pp.

Lutcavage, M.E., Brill, R.W., Skomal, G.B., Chase, B.C. & Howey., P.W. 1999. Results of pop-up satellite tagging of spawning size class fish in the Gulf of Maine: do North Atlantic bluefin tuna spawn in mid-Atlantic? *Can. J. Fish. Aquat. Sci.*, 56: 173-177.

Medina, A., Abascal, F.J., Megina, C., García, A. 2002. Stereological assessment of the reproductive status of female Atlantic northern bluefin tuna during migration to Mediterranean spawning grounds through the Strait of Gibraltar. *J. Fish. Biol.*, 60 (1): 203-217.

Parrish, R.H. 1996. Time, space and fish scales: applications of retrospective environmental data to fisheries research. *NOAA-TM-NMFS-SWFSC*, 239: 24-29.