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Distribution and movements of western Mediterranean bluefin tuna (*Thunnus thynnus*) and implications for domestication

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SUMMARY – We tagged 84 bluefin tuna with electronic pop-up tags and released them in the Mediterranean and the Strait of Gibraltar between June 1998 and August 2000; 25 (32%) were located by the Argos satellite system. Location rates were 21% and 62%, respectively, for single-point tags (61 released) and archival tags (23 released). 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 tuna for fattening. Domestication needs to obviate this risk. PAT tag experiments were conducted in collaboration with the Tuna Research and Conservation Center, USA.

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

RESUME – *"Distribution et mouvements du thon rouge de la Méditerranée Occidentale (*Thunnus thynnus*) et implications pour la domestication". Nous avons identifié 84 thons rouges avec des marques pop-up électroniques et nous les avons relâchés en Méditerranée et dans le détroit de Gibraltar entre juin 1998 et août 2000 ; 25 individus (32%) ont été localisés par le système satellitaire Argos. Les taux de localisation ont été de 21% et 62%, respectivement, pour les marques à point simple (61 animaux lâchés) et les marques archives (23 animaux lâchés). La plupart des marques sont réapparues en Méditerranée occidentale et Atlantique Est, mais une marque archive émettait à partir d'une position au sud de l'Islande et une marque à point simple émettait depuis la mer du Groënland. On n'a pas observé de migrations transatlantiques. La plupart des individus marqués lâchés en Méditerranée occidentale sont apparus près du lieu de marquage, ce qui fait supposer qu'ils résident localement. La fidélité au site de résidence et de ponte (ce qui était également indiqué par nos données) permettrait potentiellement la surexploitation, si l'industrie capture progressivement des thons plus grands pour l'engraissement. Aux fins de domestication, il est nécessaire d'ignorer ce risque. Des expériences avec marques PAT ont été menées en collaboration avec le Centre de Recherches et de Conservation des Thonidés, aux USA.*

Mots-clés : *Thon rouge, migration, marquage, marques satellitaires pop-up, marques archives pop-up, comportement, comportement alimentaire, migrations alimentaires, distribution géographique, océanographie.*

Introduction

Stock assessments of North Atlantic bluefin tuna are currently carried out on the assumption that there are two stocks (eastern Atlantic and Mediterranean; western Atlantic) separated by a conventional boundary at 45°W. This two-stock hypothesis is supported by the presence of small to large specimens on both sides of the Atlantic, the occurrence of spawning in the Gulf of Mexico and the Mediterranean at different times of the year, and morphometric differences between fish from different areas. 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 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 (No. 97/3975). The aims of the project were: 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; 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, 2000).

Materials and methods

We tagged a total of 84 bluefin tuna – 52 giants, 17 smaller adults and 15 juveniles – with pop-up satellite-detected electronic tags in the Mediterranean and Eastern Atlantic, between June 1998 and September 2000. Two types of tag were used: PTT-100 single-point pop-up tags (Microwave Telemetry Inc., Columbia, Maryland, USA), which recorded a limited number of temperature measurements, and PAT archival pop-up tags (Wildlife Computers, Redmond, Washington, USA), which recorded temperature, depth and daily longitude. PAT tag experiments were conducted in collaboration with the Tuna Research and Conservation Center, Monterey, California, as part of the US co-ordinated TAG programme. We used 61 PTT-100 tags and 23 PAT tags. Three giants were tagged with PTT-100 tags, using an underwater gun, at the Stintino trap (Sardinia, Italy) in June 1998. Thirty-two fish were tagged with PTT-100 tags by underwater gun or hand-held harpoon in the large tuna trap at Barbate (Spain), to the west of the Strait of Gibraltar, in July 1998 and 1999. Twenty-two bluefin, captured in the local sport fishery, were tagged in the Bocche di Bonifacio (between Corsica and Sardinia) in September 1999 and 2000, either alongside the boat using a hand-held tagging stick and PTT-100 tags (12 fish), or on deck using PAT tags (10 fish). Fifteen fish were tagged (13 with PAT tags) by hand-held harpoon and underwater gun in aquaculture pens at Puerto Mazarron (Cartagena, Spain) in August 2000. Twelve tuna were tagged in the Aegean Sea (Greece) 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 fish. For the 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, 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. Some 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. Comparative trials were also undertaken in Madeira and Columbia, Maryland, using the same five tags.

Results and discussion

Twenty-three of the 84 pop-up tags were located by satellite, giving an overall location rate of 32% (25/78). All of these tags transmitted valid data (Fig. 1). Six more tags were recovered from recaptured fish. Location rates were 21% (12/57) for the PTT-100 tags and 62% (13/21) 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. Sporadic signals, which were too weak to allow either location or data transmission, were received from a further 6 PTT-100 tags on or close to the expected pop-up day, increasing the detection rate for these tags to nearly 32% (18/57) and for all the tags to 38% (31/78). Most tags were detected in the western Mediterranean or eastern North Atlantic, off the coast of North Africa. However, one PAT tag surfaced south of Iceland and one PTT-100 tag transmitted from the Greenland Sea. No tags were detected in the western Atlantic.

Location rates of PTT-100 tags varied markedly between release sites and years. For example, in the Aegean Sea in 1998 and 1999 the location rate was only 8%, compared to 23% for Barbate in southern Spain in the same years, and 67% for releases at Stintino, Sardinia in 1998. However, only 14% (3) of the 23 tags released at Barbate in southern Spain in 1999 were located by satellite (a further tag was recovered from a recaptured fish) compared to 44% (4) of the 9 tags released from the same trap in 1998. Location rates of the PAT tags also differed markedly between release sites. Only 4 (33%) 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, although a further tag was recovered

from a recaptured fish before it was due to detach from the fish. In contrast, 100% of the 10 PAT tags deployed on smaller (40-90 kg) fish in Corsica, during September 2000, were located by satellite, although no valid data were recovered from two tags that appear to have drifted ashore shortly after surfacing, and a tenth tag was recovered from a recaptured fish, again before it was due to detach from the fish. 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. A PAT tag deployed in the Mediterranean, close to Cartagena, was detected in the North Atlantic south of Iceland; in contrast, most of the PAT tags deployed in the area of Bocche di Bonifacio (Corsica) surfaced in the release area. Daily longitudes recorded by the tags indicated that these fish had all remained in the area between Corsica and longitude 14°E. Maximum depths indicated that, while some fish moved off into deep water in the Tyrrhenian Sea, others remained solely in the shallow water on the continental shelf around the island. 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 northern Tyrrhenian Sea showed higher concentrations of chlorophyll-a than other parts of the western Mediterranean and eastern Atlantic (Fig. 2). Given the occurrence of a persistent areas of high production in the areas where most of the tags were detected, especially to the east of Corsica, we suggest that these may be feeding areas for both pre- and post-spawning fish.

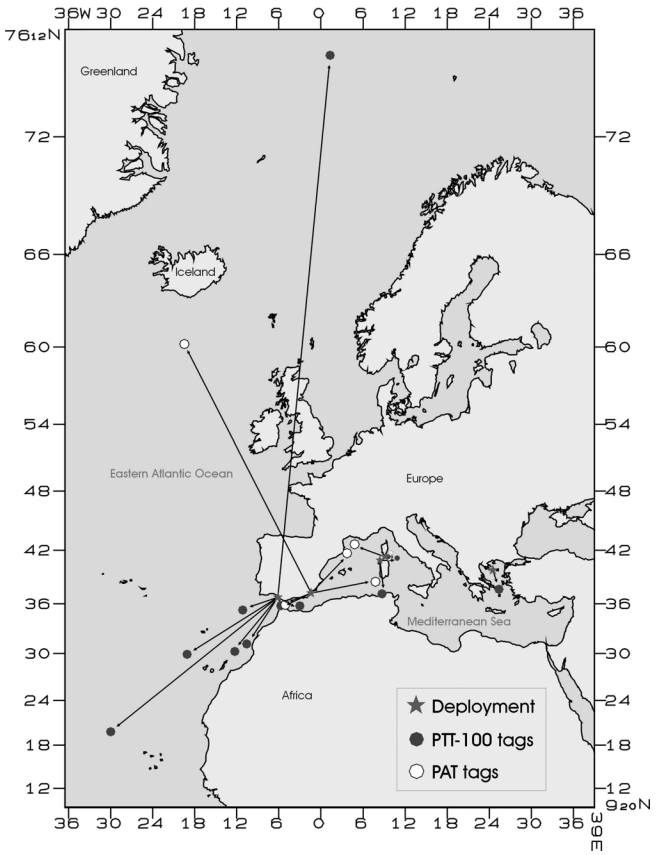

Fig. 1. Pop-up locations of tags attached to tuna in the Mediterranean and eastern Atlantic from 1998 to 2000. Coloured circles: PTT-100 single-point pop-up tags; white circles: PAT archival pop-up tags.

The rate of tag detection and location 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; M.E. Lutcavage, pers. comm.). Because the difference was so large, we conducted a series of tests to compare the performance of five unused PTT-100 tags at a number of locations in Europe Madeira and the USA. The results our tests clearly indicated that there is a detection problem in parts of the Mediterranean Sea, where we expected some of our tags to surface. It seems likely, therefore, that a low signal-to-noise ratio in the affected

areas may have resulted in non-detection of tags that may otherwise have 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.

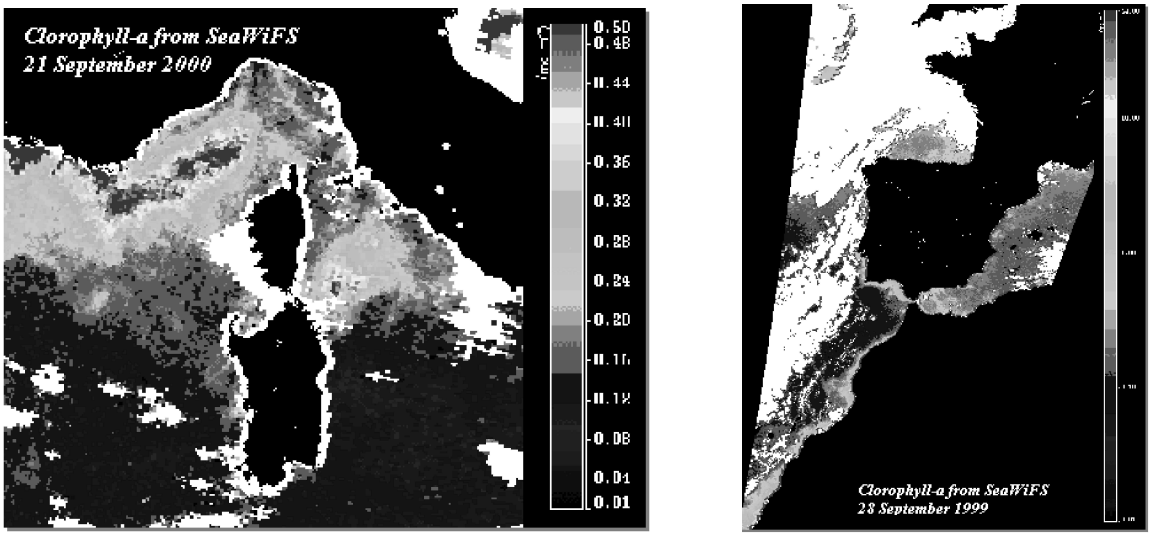

Fig. 2. Chlorophyll-a concentration from SeaWiFS in the central Mediterranean (on the left) and western Mediterranean and eastern Atlantic (on the right).

Conclusions

Reasons for the low detection rate of the PTT-100 tags may include post-tagging mortality, fish capture, premature tag release, failure of the tag as a result of exposure to high pressure and low signal-to-noise ratio. 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. According to Argos, the problem, which results from a high level of background noise and competition from more powerful transmitters is, however, confined to Europe. The 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, but were confined to the eastern management area with no evidence of transatlantic migrations. 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 fish released off Corsica, suggesting the existence of residency associated with the high productivity, or other environmental characteristics of this area. The recapture of a big tuna (290 kg) tagged with a PTT-100 tag at Barbate trap on July 1999 is of particular interest. This fish – to which the 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 for fattening in cages, instead of starting to rear "new fish" from eggs. Domestication of bluefin 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.

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