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# DISTRIBUTION OF WESTERN TAGGED ATLANTIC BLUEFIN TUNA DETERMINED FROM ARCHIVAL AND POP-UP SATELLITE TAGS*

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*SUMMARY*

*The successful deployment in recent years of electronic tag technology on Atlantic bluefin tuna has improved our ability to examine their movements throughout the North Atlantic and Mediterranean Sea. This has rapidly improved the ability to distinguish where the bluefin tuna feed and breed. When biological and physical data from the tags are combined with information about sea surface temperature and ocean color from remote sensing technologies, the relationship between the movements and behaviors of the fish can be linked to oceanographic processes. This paper focuses on the results of electronic tagging of bluefin tuna in the western North Atlantic.*

*RÉSUMÉ*

*Ces dernières années, le déploiement positif de marques électroniques sur le thon rouge atlantique a amélioré notre capacité à examiner ses déplacements dans l'Atlantique nord et la mer Méditerranée. Ceci a rapidement amélioré la capacité de déterminer les aires trophiques et de frai du thon rouge. Lorsque les données biologiques et physiques provenant des marques sont associées à l'information sur la température à la surface de la mer et la couleur de l'océan obtenue des technologies de télé-détection, les rapports entre les déplacements et les comportements du poisson peuvent être liés à des processus océanographiques. Le présent document se concentre sur les résultats du marquage électronique du thon rouge à l'ouest de l'Atlantique nord.*

*RESUMEN*

*En los últimos años, el despliegue fructífero de tecnología de marcas electrónicas colocadas en atunes rojos ha mejorado nuestra capacidad de examinar sus movimientos a través del Atlántico norte y del Mediterráneo. De este modo se ha mejorado rápidamente la capacidad de distinguir las zonas tróficas y de cría del atún rojo. Cuando los datos físicos y biológicos de las marcas se combinan con la información sobre la temperatura de la superficie del mar y el color del océano a partir de tecnológicas de detección remota, la relación entre los movimientos y conductas de los peces puede relacionarse con procesos oceanográficos. Este documento se centra en los resultados del marcado electrónico de atún rojo en el Atlántico Noroccidental*

## 1. INTRODUCTION

The successful deployment in recent years of implantable and pop-up satellite archival tags has rapidly enabled researchers to examine the movements of large pelagic fishes (Metcalfe and Arnold, 1997, Block *et al.*, 1998(a), Block *et al.* 1998(b), Lutcavage *et al.* 1999, Kitigawa *et al.* 2000, Marcinek *et al.* 2002, Block *et al.* 2001, Gunn and Block, 2002, Boustany *et al.* 2002, Seitz *et al.* 2002). These new techniques are providing the major advances that will be necessary to understand

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the distribution of oceanic organisms in relation to their changing physical and biological environments. ICCAT scientists and managers can use the new electronic tagging data to stimulate the development of models that allow an accurate estimate of the dynamic distribution of bluefin tuna based on age, season and primary productivity. As more environmental information is gathered and delivered from the tagged animals, new insights will be obtained about their individual behaviors, as well as how they respond to environmental variability on daily, seasonal, and inter-annual time scales.

This paper reports on the results of the on going electronic tag program in the western Atlantic called the Tag-A-Giant (TAG) program. This program is a collaboration between scientists from Stanford University, the Monterey Bay Aquarium and the National Marine Fisheries Service. To date 560 electronic tags have been deployed on Atlantic bluefin tuna at four locations in feeding regions (offshore waters of North Carolina and Massachusetts) and on breeding grounds (the Gulf of Mexico and the Mediterranean Sea). This report focuses on the electronic tags deployed in the western Atlantic from 1996-2001. In the TAG research program most bluefin tuna are measured when tagged in the western Atlantic feeding regions (Carolina and New England). Long-term deployments (> 2 months) have been on fish ranging in size from 163 to 287 cm curved fork length **(Tables 1 and 2)**. The mean age upon release of electronic tagged fish was above 8 years of age based on measured curved length (n= 490 measured).

The results in this brief report are intended to provide insight into the electronic tagging data from the TAG program that was initiated in the western Atlantic in 1996 to examine the migrations and biology of bluefin tuna (Block *et al.* 1998(a,b) 2001). The TAG program utilizes several types of archival tags produced from three engineering manufacturers (Block *et al.* 1998 (a,b) 2001). In this report we describe results from implantable archival tags that were surgically inserted in 279 tunas off the coast of North Carolina between 1996 and 1999. Additional Lotek archival tags with more memory and new algorithms for light based geolocation were deployed in January 2002. All implantable archival tags collected data from the organism and its surrounding environment. Pressure and internal temperature sensors are located in the tag, which is surgically implanted in the peritoneal cavity of the tuna. Light and ambient temperature sensors are located externally on an 8-23 cm stalk (longer in later generations of tags) protruding from the fish. Recent generations of archival tags are built with more sensitive light sensors (7-9 decades) and are capable of detecting moonlight. Two conventional tags placed externally notify fishers of the archival tag inside the fish and a $1000 reward upon return of the electronic tag. Of the 279 tags placed in the ocean from 1996 to 1999, 64 tags (23%) have been recaptured as of December 2002. The majority of tags have been recaptured where commercial fisheries are most intensive. The number one site for recapture of a North Carolina released archival tagged fish remains New England. Twenty-three bluefin tuna tagged in North Carolina have been recovered east of the stock boundary at the 45° meridian. Many of these tags have been recovered from the Mediterranean Sea. Excellent cooperation has also been obtained from high seas Japanese longline fishers who reliably return archival tags from the west, central and east Atlantic fisheries **(Table 1)**.

The most important contribution of the archival tag to fisheries biology is the ability to estimate location using light-level data collected while the animal carrying the tag remains submerged (Hill and Braun 2002). Calibration tests on fixed oceanographic moorings indicate that the longitude estimates have an accuracy of 0.25°-1.2° (Welch *et al.* 1999). In this report, longitude data is first filtered for any outliers (locations where movement exceeds 2° of longitude per day are discarded). We estimate latitude by comparing the *in situ* SST measurements made by the fish when at the surface and logged on the archival tag and AVHRR-derived SST estimates, along the filtered longitudes for each day. An algorithm developed in the laboratory, finds along the light-based longitude the best fit with the corresponding AVHRR satellite derived SST data (Teo *et al.* in preparation). To date, comparisons of endpoints at recapture (using GPS) with estimated positions indicate position estimates inclusive of latitude calculated in this manner are an accurate representation (within 0.25-1.5°) of the true distribution of electronically tagged bluefin tuna.

In **Figure 1**, the aggregate daily geolocation estimates for 13 archival tagged bluefin tuna (1- 3 year tracks) released from North Carolina, are presented for years encompassing 1996 (1 individual) through 2001. Most of the data corresponds to daily positions of Carolina tagged bluefin in 1997 and 1999. The aggregate daily position information provides a record of where bluefin appear most often in our data set. Recapture positions (from information provided by fishers) for all sixty-five archival tags are shown with triangles. In New England one triangle represents a location (in close proximity to BB-buoy) where over forty individual fish were recaptured in the vicinity of the buoy. Similarly in the east- near Gibraltar several recaptures have occurred in the strait. The major aspects of the data set remain unchanged from the Block *et al.* 2001 report and are primarily enhanced by the visualization of latitude. Major results from recovered tags are: (1) 23% of the implantable archival tagged bluefin tuna have been recaptured, (2) the number one location for recovering an archival tagged fish released off North Carolina is New England waters, and (3) over 30% of the recovered tags are found east of the stock boundary with numerous tags within the Mediterranean. The individual archival tag geolocation estimates indicate that bluefin tuna released in the North Carolina winter fishery are found most often along the North American continental shelf **(Figures 1-3)**. The offshore waters of New England, Canada and the Carolinas form the regions where most of the geolocation estimates are found. Bluefin tuna are also located seasonally in the Gulf Stream and large fish, as discussed below, aggregate in a region east of the Flemish Cap from May-December. Importantly, these fish leave the Carolinas and move directly to the Flemish Cap without associating with the New England region. The fish that move to the north central Atlantic have all been recaptured in the Eastern Atlantic or the Mediterranean Sea.

Adolescent (7) and young potentially mature bluefin tuna (8-9, based on measured length) have a distinct seasonal cycle that is associated with the calendar year. In the first year after release, fish that were tagged in the Carolinas have the highest probability of being west of the stock boundary and along or on the continental shelf of North America in the winter (Carolina), or to points south of Carolina (Bahamas). In spring and early summer these bluefin tuna are most often positioned along the northern edge of the Gulf Stream or in warm core rings (Block *et al.* 1998, 2001). By summer and early fall the fish are primarily on the continental shelf off New England and Nova Scotia. These fish return to Carolina in the November to February period (Block *et al.* 2001) and often stay until early spring. Fish of slightly larger body size (8.5 to 10 years of age) released in Carolina have shown a second migration pattern, distinct from the one described above, in which no visitation to the North American shelf or slope waters occurs in summer and the fish move directly from North Carolina in winter to a region of high primary productivity east of the Flemish Cap in spring, summer and fall. It remains possible that if we tagged these fish earlier in their life history, they too would have remained on the continental shelf. There appears to be a minimum size required to move into the northern colder feeding grounds most likely associated with increased ability to maintain elevated body temperatures in larger fish. Remarkably, retention of fish in the region to the east of the Flemish Cap occurs for up to 7 months (Walli *et al.* in preparation). Fish move from the region of high primary productivity east and later in the summer to the north of the Flemish Cap and often into the eastern Atlantic. Two fish (485, 779) have returned in winter months from the oceanographic regions to the east of the Flemish Cap to regions that are recognized as western Atlantic breeding areas.

Four longitude/latitude tracks that are representative of the data set are shown in **Figures 2A-D**. Three of the four tracks (A-C) were presented as shown here (2A and B) or longitude only (2C) in Block *et al.* (2001). The fourth track (2D, bluefin 779) is a new track that presents one of the longest records (1999-2001) acquired to date from a bluefin released in January 1999. In **Figure 2A**, fish 521 (218 CFL at release in 1999) shows a western resident track characteristic of many of the recovered fish in year one post release (aggregation in Carolina in winter and New England in summer), followed by a migration south the second winter to a western breeding ground. The fish moved to the eastern Atlantic in 2000 where it was recaptured. **Figure 2B** shows a similar pattern of western continental shelf residency, with some offshore Gulf Stream occupancy for three years for bluefin tuna 408 (203 cm CFL at release in 1997). This three-year pattern was followed by a rapid movement to the Mediterranean in early summer. The fish was close to a known Mediterranean spawning ground and recaptured in June 2000. **Figure 2C** is the track of bluefin 512 (207 cm CFL upon release), a female tagged in January 1999 off the coast of Carolina. This fish moved north after tagging to the regions offshore of the mid-Atlantic bight. The tuna remained in the Gulf Stream during this period. In June, the bluefin swam south to the Gulf of Mexico. The bluefin remained in the Gulf for approximately 26 days. During this period a distinctive diel behavior with oscillatory diving was noted and we suggested that it might be indicative of spawning behavior (Block *et al.* 2001). The bluefin moved from the Gulf of Mexico at the end of June to the feeding grounds off New England where it was recaptured.

The fourth track (Figure 2D) is of bluefin tuna 779 (218 cm CFL upon release) released off North Carolina in January 1999. This fish moved from North Carolina to a region east of the Flemish Cap. This oceanographic region places the tuna to the east of the stock boundary in May of 1999. Remote sensing data (SeaWiFs, ocean color) indicates that the fish was located along a frontal zone enriched in chlorophyll. The frontal region remains a consistent oceanographic feature east of the Flemish Cap and is most likely associated with the confluence of the Labrador Current and northern Gulf Stream waters. Importantly, the ICCAT stock boundary is placed to the west of the region of peak primary productivity observed to aggregate Atlantic bluefin on their northern feeding grounds. During the summer feeding season in 1999, bluefin 779 moved back and forth across the stock boundary numerous times. Bluefin 779 moved in the winter of 1999 south to the eastern Atlantic and then north toward the Gibraltar Straits. This fish returned in May of 2000 to the same region east of the Flemish Cap where it appeared to be feeding the previous summer. The bluefin remained in this area of high productivity until early December of 2000. This fish then moved south to the Bahamas where it remained for a brief period in January and February. The fish then crossed the Atlantic in 29 days where it was recaptured inside the Mediterranean by a French purse seiner (triangle) and was moved to a Spanish pen. The repeated positions from the pen have been removed in this representation of the fish movements.

In **Figure 3**, a pop-up satellite derived data set independent from the information provided in **Figures 1 and 2** is shown. These data are comprised of pop-off satellite end point positions calculated by radio transmissions from the pop-off satellite archival tags (PSAT) to the ARGOS satellites (Block *et al.* 1998a, 2001). The endpoint positions represent the final pop-off positions of bluefin tuna released from three locations. The points in most cases represent a position that is within 0.3° of a bluefin's position prior to release of the tag. The ARGOS positions plotted are color coded for the location that the bluefin tuna were released from (North Carolina, yellow; New England, blue; Gulf of Mexico, black). All North Carolina fish were released at the same season and location as archival tagged fish (December-March, 1997, 2000, 2001, 2002).

The general movement patterns of the Carolina-tagged fish can be represented by the end point positions of the tags that popped off 0.1 to 9 months post release. They describe in their pattern of endpoints, a seasonal movement from Carolina in winter, into the Gulf Stream in spring and to New England waters in summer. This corroborates the first year western resident pattern observed in many implantable archival tagged North Carolina-released fish. The New England released PSAT tagged fish were tagged in the months of September and October (1998, 2000, 2001: N=33). The bluefin tuna primarily migrated south along the North American shelf and slope waters upon release and popped-up in the early winter months off Carolina and in winter in the Gulf of Mexico. Several tags were located in the mid-Atlantic region. Longline caught bluefin tuna, tagged and released in the Gulf of Mexico (March, April and May 1999, 2000, 2001 and 2002) surface close to the points of release (due to premature release in many cases) that were to the west of the Loop Current, and to points north and east of the Loop Current. In addition, pop-off endpoints record the positions of fish exiting from the Gulf of Mexico and moving through the Straits of Florida and along the North American continental shelf.

For most of the PSAT tagged fish, a light and SST based geolocation record from release to pop-off is also present in the record (n=95).. Light based geolocation on PSAT tags is limited by the extensive on-board compression of data required for satellite transmission of data sets. In contrast, an implantable archival tag stores in memory all the light data recorded during the mission, which improves the daily polynomial fits associated with estimating the position from dawn and dusk curves. Additionally, pressure sensor data required to correct every light point to the surface is readily available for post-processing and further analysis. It would be next to impossible to calculate position data on a *diving* vertebrate without a pressure corrected data set. Bluefin are now known to dive daily at dawn and dusk further complicating the procedures. To date, the peer-review literature has not had a report of the accuracy of light-based geolocations from pop-up satellite archival tags. A calibration of the techniques used to calculate position (double tagging with ARGOS versus PSAT tags) is underway and we hope to add 6000 new geolocation estimates of the daily positions with an error estimate for bluefin tuna in the Atlantic (Boustany *et al.* in preparation). Preliminary data from PSAT light based geolocation (n= 95 individual tracks) estimated from tags with pressure sensors (not shown) corroborates that North Carolina released fish most often show a pattern of western residency the year after release with limited movement to the east Atlantic. The PSAT data set also confirms a small percentage (<5%) of Carolina fish follow the migration pathway outlined above, a movement of large bluefin tuna from the Carolinas to the oceanographic area east of the Flemish Cap and ICCAT stock boundary.

Results from satellite tagged bluefin tuna released in New England waters corroborate the implantable archival tag data presented above. Seventy five percent of the fish have been measured on the decks of TAG sport fishing vessels in this region and many fish overlap the same size classes of fish being tagged in the North Carolina region (7-12 years of age). New England fish represent in many cases a larger class of fish (>12 years) that are not accessible in North Carolina. This result is consistent with our archival tagging data, which indicates strong linkages between the two feeding areas for fish from 7-10 years of age. These size classes of fish make up a large proportion of the western fishery and bluefin appear to remain along the continental shelf during their adolescent and potentially their early breeding years. Three New England fish have shown a directed movement to the Gulf of Mexico and Bahamas breeding regions and in one case fidelity back to New England waters (Stokesbury *et al* in preparation). The tracks are similar to the implantable archival tagged bluefin shown in Figure 2C. Unfortunately, due to premature release we thus far were unable in many cases to track the New England bluefin tuna long enough to obtain records to breeding areas.

PSAT tagged fish occasionally get recaptured and when they do, a full archival record is on board the tag. To date in the West Atlantic three tags have been recaptured by longliners and are currently being decoded. We have experienced different recapture rates based on location of release (West Atlantic versus Mediterranean Sea). Fish released in North Carolina winter and New England fall have had a low recapture rate with only 3 out of a total of 206 deployed PSATs (1.5%) being recaptured (1-9 months post release). Tagging operations occur in New England at the end of the commercial season and the North Carolina fishery has been closed during the tagging period to commercial harvest. Thus the chance of recapture for PSAT released bluefin in the West Atlantic was limited for six months in all locations by the regulations imposed on the commercial fishery.

External pop-up satellite archival tag success remains a challenge primarily due to the issues of keeping the majority of externally placed tags on fast moving fish. Premature release of the PSAT is a major problem associated with these data sets. To date in the TAG program, tracks of one year have been difficult to obtain with external tagging and most of the PSAT tracks extend from 2 to 9 months durations. Tags presumed to be drifters (pre-mature release) from Carolina or New England releases are not plotted in **Figure 3**. Such tags, most often float to the central Atlantic at mid-latitudes and provide an informative view as to where drifting tags go. In **Figure 3**, two such potential "drifter" tags are included- and they are shown as open circles. These two tags are first generation single point tags that remained on New England released bluefin tuna beyond the point where temperature data was recorded. The two tags, placed on New England released fish in 1998, lack a pressure sensor to verify if the tag remained on the fish 5 and 7 months post-tagging. We have found the low resolution of temperature on this first generation of tag is in sufficient to discern if the tags remained on the fish. Satellite tags and data sets derived from this early generation of tags (Block *et al.* 1998(a), Lutcavage *et al.* 1999) must be viewed with caution in light of the challenges associated with understanding the quality of the data output. Pop-up satellite archival tags require a pressure sensor to confirm that the tags remained on fish and calibration experiments of the light or SST-based estimates to ensure the reported positions are accurate. Any use of the data without these features is prone to error (Gunn and Block 2001).

The TAG program is continuing forward with plans to implant archival tags in more bluefin tuna in the western Atlantic. The multi-year tracks are extremely informative on ocean basin scales. Integration of remote sensing data provides strong evidence that bluefin are concentrated in regions of peak oceanic primary productivity on winter and summer feeding grounds. Pop-up satellite archival tags are useful for fisheries independent data sets and provide a means of estimating bluefin tuna survivorship and fishing pressure in management areas. Increased efforts to improve the reliability of the instruments for long-term deployments should improve the data return from this type of electronic tag.

Much of the success of the TAG implantable archival tag program is due to the high level of cooperation among international fishers in North Atlantic and the Mediterranean Sea. An effort to continuously educate fishers of the current use of archival tags, the proper recovery of implantable and external placed tags, and the importance of returning the tags to fisheries agencies, should be associated with ICCAT. Continued successful recovery of archival and pop-up satellite tags ensures a rich data set for future management.

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**Table 1.** Release and Recapture Information on Archival Tagged Bluefin Tuna

| Tag | Release Date | LAT1 | LON1 | CFL (cm) | Recovery Date | LAT2 | LON2 | Days | Years | Rec. Location | Vessel Type | Tag Returned? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NMT X | mar-97 | 35.00 | -75.00 | | 01-jun-97 | 36.87 | 12.85 | | | Sicily Med | Italy Longline | No |
| WC 97-112 | 21-mar-97 | 35.05 | -75.32 | 210 | 28-ago-97 | 42.08 | -65.55 | 160 | 0.4 | Cape Cod | R&R-CAN | Yes |
| WC 97-041 | 08-mar-97 | 35.10 | -75.29 | 196 | 13-sep-97 | 43.12 | -70.07 | 189 | 0.5 | Jeffries Ledge | US R&R | Yes |
| WC 97-030 | 07-mar-97 | 35.02 | -75.45 | 202 | 03-may-98 | 40.96 | -48.36 | 422 | 1.2 | Grand Banks | Japanese LL | Yes |
| WC 97-X | mar-97 | 35.00 | -75.00 | | 03-jun-98 | 36.57 | 12.53 | | | Sicily Med | Italy Longline | No |
| NMT 275 | 07-mar-97 | 35.03 | -75.40 | 192 | 04-jul-98 | 39.91 | -70.62 | 484 | 1.3 | E. of Block Canyon | US Longline | Yes |
| WC 97-043 | 20-mar-97 | 35.11 | -75.23 | 180 | 17-sep-98 | 41.45 | -69.23 | 546 | 1.5 | Cape Cod | Purse Seine | Yes |
| NMT 267 | 21-feb-97 | 35.02 | -75.42 | 176 | 25-sep-98 | 41.27 | -69.14 | 581 | 1.6 | Cape Cod | Purse Seine | Yes |
| WC 97-102 | 17-mar-97 | 35.05 | -75.35 | 210 | 07-oct-98 | 45.19 | -61.01 | 569 | 1.6 | Canadian EEZ | R&R-CAN | Yes |
| WC 97-019 | 07-mar-97 | 35.02 | -75.41 | 193 | 14-nov-98 | 37.37 | -74.42 | 617 | 1.7 | Washington Canyon | US Longline | Yes |
| WC 97-036 | 08-mar-97 | 35.11 | -75.29 | 197 | 24-dic-98 | 43.37 | -52.00 | 656 | 1.8 | Grand Banks | Japanese LL | No |
| WC 97-027 | 07-mar-97 | 35.02 | -75.44 | 171 | 16-abr-99 | 24.00 | -83.00 | 770 | 2.1 | Off Cuba | Taiwanese LL | Yes |
| WC 97-X | mar-97 | 35.00 | -75.00 | | 01-jun-99 | 34.97 | 14.13 | | | Italy | Purse Seine | No |
| NMT 268 | 16-mar-97 | 35.02 | -75.33 | 190 | 16-jun-99 | 34.89 | 14.08 | 822 | 2.3 | Messina Italy | Italian PS | No |
| NMT 719 | 30-ene-99 | 34.42 | -76.67 | 208 | 10-jul-99 | 41.16 | -70.67 | 161 | 0.4 | Cape Cod | US R&R | No |
| NMT 350 | 07-mar-97 | 35.03 | -75.41 | 198 | 15-ago-99 | 42.06 | -65.58 | 891 | 2.4 | Prince Edward Island | R&R-CAN | Yes |
| NMT 720 | 07-feb-99 | 34.46 | -76.61 | 216 | 20-ago-99 | 42.26 | -69.95 | 194 | 0.5 | Stellwagen Bank | Purse Seine | No |
| WC 98-491 | 16-ene-99 | 34.52 | -76.67 | 210 | 29-ago-99 | 42.16 | -69.57 | 225 | 0.6 | Stellwagen Bank | Purse Seine | No |
| NMT 396 | 04-mar-97 | 35.11 | -75.28 | 197 | 17-sep-99 | 58.52 | -27.24 | 927 | 2.5 | East Atlantic | Japanese LL | Yes |
| NMT 602 | 21-ene-99 | 34.55 | -76.64 | 211 | 21-sep-99 | 41.27 | -69.25 | 243 | 0.7 | New England | US R&R | No |
| NMT 153 | 23-mar-96 | 34.56 | -75.75 | 183 | 27-sep-99 | 41.29 | -69.22 | 1283 | 3.5 | Cape Cod | US R&R | Yes |
| WC 97-089 | 17-mar-97 | 35.03 | -75.37 | 203 | 28-sep-99 | 41.17 | -69.13 | 925 | 2.5 | New England | US Purse Seine | Yes |
| WC 97-048 | 07-mar-97 | 35.02 | -75.45 | 200 | 08-oct-99 | 53.88 | -44.88 | 945 | 2.6 | Canada | Japanese LL | Yes |
| WC 97-022 | 17-mar-97 | 35.05 | -75.35 | 186 | 08-oct-99 | 41.25 | -69.07 | 935 | 2.6 | New England | US Purse Seine | Yes |
| WC 98-521 | 01-ene-99 | 34.58 | -76.37 | 218 | 06-abr-00 | 37.41 | -19.72 | 461 | 1.3 | East Atlantic | Japanese LL | Yes |
| NMT 382 | 07-mar-97 | 35.02 | -75.45 | 190 | 01-may-00 | 24.00 | -83.00 | 1151 | 3.2 | Cuba | Phillipine LL | Yes |
| WC 98-500 | 31-dic-98 | 34.53 | -76.43 | 249 | 08-may-00 | 36.34 | 13.59 | 494 | 1.4 | Malta Sea | Russian | No |
| WC 97-063 | 21-mar-97 | 35.11 | -75.23 | 200 | 15-may-00 | 33.42 | -15.03 | 1151 | 3.2 | East Atlantic | Japanese LL | No |
| NMT 1233 | 09-feb-99 | 34.39 | -76.58 | 224 | 24-may-00 | 35.22 | -6.20 | 470 | 1.3 | Straits of Gibraltar | HandLine | Yes |
| NMT 408 | 03-mar-97 | 35.09 | -75.26 | 203 | 15-jun-00 | 35.37 | 12.53 | 1200 | 3.3 | Off Malta | Italian PS | Yes |
| NMT 667 | 20-ene-99 | 34.52 | -76.66 | 226 | 12-jul-00 | 41.40 | -69.29 | 539 | 1.5 | New England | US harpoon | Yes |
| NMT 363 | 07-mar-97 | 35.04 | -75.40 | 208 | 30-jul-00 | 42.41 | -70.47 | 1241 | 3.4 | Stellwagon Bank | US Harpoon | No |
| WC 97-038 | 07-mar-97 | 35.03 | -75.43 | 195 | 01-ago-00 | 42.00 | -70.00 | 1243 | 3.4 | New England | US R&R | Yes |
| WC 98-507 | 16-ene-99 | 34.51 | -76.64 | 216 | 08-ago-00 | 42.00 | -70.00 | 570 | 1.6 | New England | US Harpoon | Yes |
| WC 98-512 | 17-ene-99 | 34.53 | -76.63 | 207 | 22-ago-00 | 41.18 | -69.10 | 583 | 1.6 | New England | US Purse Seine | Yes |
| WC 97-051 | 20-mar-97 | 35.10 | -75.23 | 198 | 09-sep-00 | 41.25 | -69.25 | 1269 | 3.5 | New England | US R&R | Yes |
| WC 97-016 | 07-mar-97 | 35.02 | -75.42 | | 10-sep-00 | 41.16 | -70.67 | 1283 | 3.5 | New England | US Purse Seine | Yes |
| WC 97-017 | 07-mar-97 | 35.02 | -75.45 | 200 | 12-sep-00 | 41.68 | -69.97 | 1285 | 3.5 | New England | US R&R | Yes |
| WC 97-037 | 07-mar-97 | 35.03 | -75.44 | 195 | 17-sep-00 | 41.25 | -69.25 | 1290 | 3.5 | New England | US R&R | Yes |
| WC 98-492 | 06-ene-99 | 34.39 | -76.28 | 229 | 22-sep-00 | 41.25 | -69.25 | 625 | 1.7 | New England | US R&R | Yes |
| NMT 277 | 04-mar-97 | 35.12 | -75.28 | 178 | 02-oct-00 | 41.25 | -69.25 | 1308 | 3.6 | New England | US R&R | Yes |
| NMT 715 | 27-ene-99 | 34.89 | -75.73 | 202 | 04-oct-00 | 41.25 | -69.25 | 616 | 1.7 | New England | US Purse Seine | Yes |

**Table 1.** Release and Recapture Information on Archival Tagged Bluefin Tuna

| Tag | Release Date | LAT1 | LON1 | CFL (cm) | Recovery Date | LAT2 | LON2 | Days | Years | Rec. Location | Vessel Type | Tag Returned? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WC 97-067 | 08-mar-97 | 35.10 | -75.32 | 202 | 08-oct-00 | 41.25 | -69.25 | 1310 | 3.6 | New England | US R&R | Yes |
| WC 98-485 | 21-ene-99 | 34.51 | -76.66 | 207 | 15-oct-00 | 52.03 | -32.14 | 633 | 1.7 | Central Atlantic | Japanese LL | Yes |
| WC 98-502 | 14-ene-99 | 34.63 | -76.30 | 214 | 26-abr-01 | 29.32 | -13.09 | 833 | 2.3 | Canary Islands | Spanish Bait Boat | Yes |
| WC 98-504 | 31-dic-98 | 34.55 | -76.37 | 226 | 05-may-01 | 35.47 | -6.17 | 856 | 2.3 | Morocco | Handline | Yes |
| WC 98-508 | 17-ene-99 | 34.54 | -76.65 | 198 | 15-jun-01 | 34.97 | 14.13 | 880 | 2.4 | Southern Italy | Purse Seine | Yes |
| WC 97-091 | 17-mar-97 | 35.03 | -75.37 | 190 | 26-jun-01 | 43.21 | -69.67 | 1562 | 4.3 | Maine | US R&R | Yes |
| WC 98-480 | 21-ene-99 | 34.50 | -76.66 | 211 | 04-ago-01 | 42.25 | -70.25 | 926 | 2.5 | New England | US Harpoon | Yes |
| NMT 391 | 07-mar-97 | 35.03 | -75.40 | 193 | 16-ago-01 | 42.07 | -65.61 | 1623 | 4.4 | Gulf of Maine | US R&R | Yes |
| NMT 921 | 17-ene-99 | 34.50 | -76.63 | 183 | 28-ago-01 | 42.72 | -69.83 | 954 | 2.6 | New England | Purse Seine | Yes |
| WC 97-045 | 20-mar-97 | 35.11 | -75.23 | 200 | 08-ago-01 | 43.23 | -51.63 | 1602 | 4.4 | Central Atlantic | Japanese LL | Yes |
| NMT 942 | 20-ene-99 | 34.52 | -76.65 | 229 | 01-sep-01 | 41.16 | -70.67 | 955 | 2.6 | BB Buoy | US R&R | Yes |
| WC 98-495 | 15-feb-99 | 34.38 | -76.58 | 213 | 15-jun-01 | 35.20 | -6.20 | 851 | 2.3 | Morocco | Trap | Yes |
| NMT 779 | 20-ene-99 | 34.50 | -76.24 | 218 | 03-jun-01 | 38.36 | 2.27 | 865 | 2.4 | Spain | French PS | Yes |
| WC 98-511 | 06-ene-99 | 34.37 | -76.28 | 201 | 15-jun-01 | 33.98 | 14.00 | 891 | 2.4 | Malta Sea | Spanish Trap | No |
| NMT 273 | 05-mar-97 | 34.97 | -75.41 | 169 | 27-mar-00 | 33.40 | -21.25 | 1118 | 3.1 | East Atlantic | Japanese LL | No |
| WC 98-518 | 16-ene-99 | 34.52 | -76.64 | 209 | 30-ago-02 | 41.25 | -69.25 | 1322 | 3.6 | New England | US R&R | Yes |
| WC 98-510 | 14-ene-99 | 34.63 | -76.30 | 218 | 01-oct-02 | 32.54 | 16.70 | 1356 | 3.7 | Libya | Libyan LL | Yes |
| NMT 705 | 11-feb-99 | 34.40 | -76.59 | 222 | 31-ago-02 | 35.95 | -5.55 | 1297 | 3.6 | Spain | HandLine | Yes |
| NMT 952 | 11-feb-99 | 34.36 | -76.58 | 178 | 16-oct-02 | 41.25 | -69.25 | 1343 | 3.7 | New England | US R&R | Yes |
| NMT 1143 | 09-feb-99 | 34.40 | -76.59 | 210 | 22-sep-02 | 41.25 | -69.25 | 1321 | 3.6 | New England | US R&R | Yes |
| WC 97-028 | 07-mar-97 | 35.02 | -75.44 | | 23-oct-02 | 41.15 | 69.05 | 2056 | 5.6 | New England | US R&R | Yes |
| WC 97-103 | 17-mar-97 | 35.03 | -75.21 | 185 | 24-oct-03 | 41.15 | 69.05 | 2412 | 6.6 | New England | US R&R | Yes |

**Table 2.** North Carolina Electronic Tagged Fish Measured Curved Fork Length

| Year & TAG Type | 2002 PSAT | 2001 PSAT | 2000 PSAT | 1999 Archival | 1997 PSAT | 1997 Archival |
|---|---|---|---|---|---|---|
| N | 55 | 61 | 29 | 108 | 37 | 171 |
| Maximum | 241 | 234 | 234 | 249 | 220 | 240 |
| Minimum | 186 | 173 | 185 | 179 | 154* | 163 |
| Mean | 202 | 207 | 209 | 208 | 190 | 191 |

* Several short term (1-3 day) tests of the tagging technology were conducted and pop-up satellite tags were placed on any bluefin available.

Figure 1

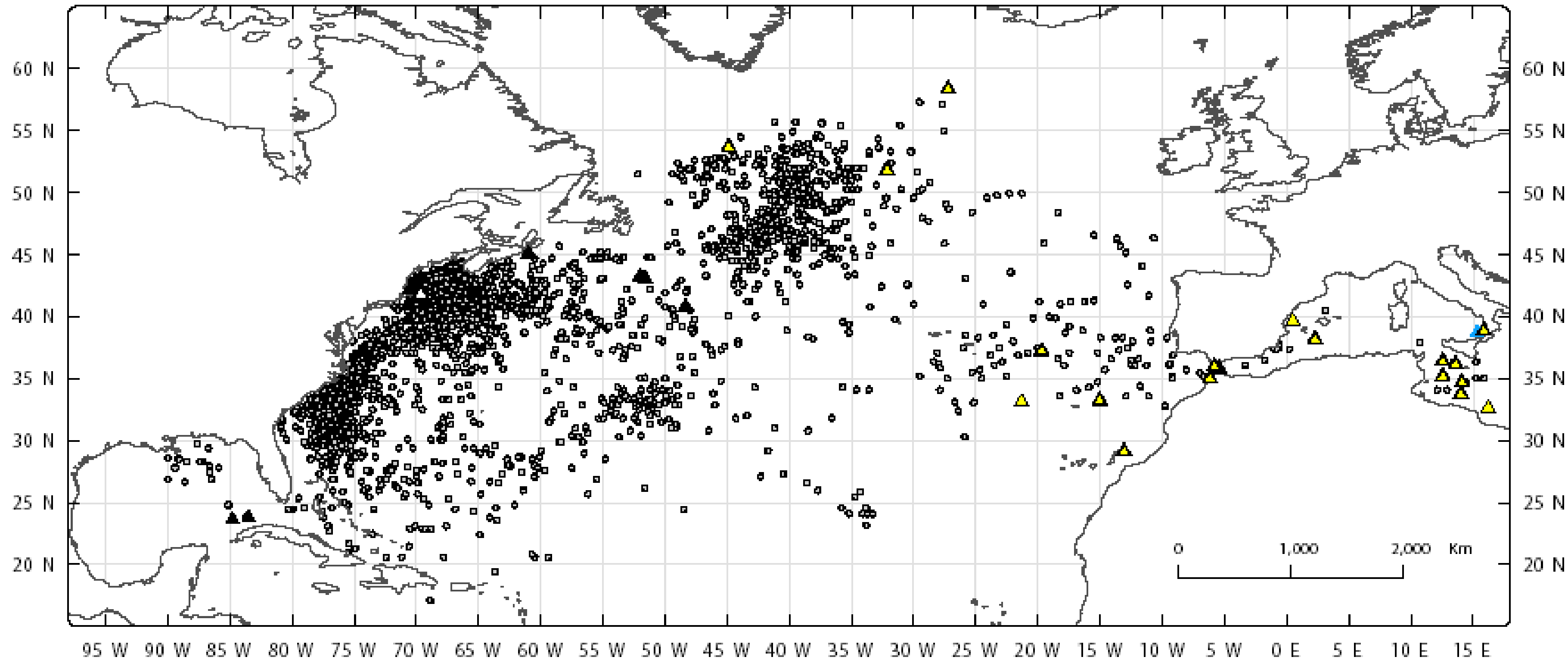


**Figure 1**. Distribution of archival recaptured bluefin tuna (triangles). Black triangles indicate western recoveries and light triangles indicate bluefin recaptured east of the stock boundary. Circles are daily calculated positions of 13 archival tagged bluefin tuna from 1997-2001 (see text for details). Individual tracks range from 1-3 years of data. Numerous points overlie one another in this figure along the continental shelf. The bluefin released from Carolina often have a year of western residency prior to movements into the eastern Atlantic or Mediterranean Sea. In many cases, the tags of early generations stopped logging data (memory was filled) by the time the fish moved into the eastern Atlantic. Future records from archival tags with more memory, will most likely reveal more information about the eastern Atlantic locations occupied by bluefin tuna tagged in the western Atlantic. A recent record not shown here does have 3 years of Atlantic bluefin movements in the east Atlantic and Mediterranean sea with a heavy concentration of locations near the coasts of Spain and Portugal. Feeding concentrations are located in Carolina in winter, New England, and the oceanographic region to the east of the Flemish Cap in summer. Longitude and some latitude data were presented in Block *et al.* 2001. Dark triangles are locations for 2 reported archival tags with complete conventional tag information but no return of any portion of the archival tag to the US.

Figure 2

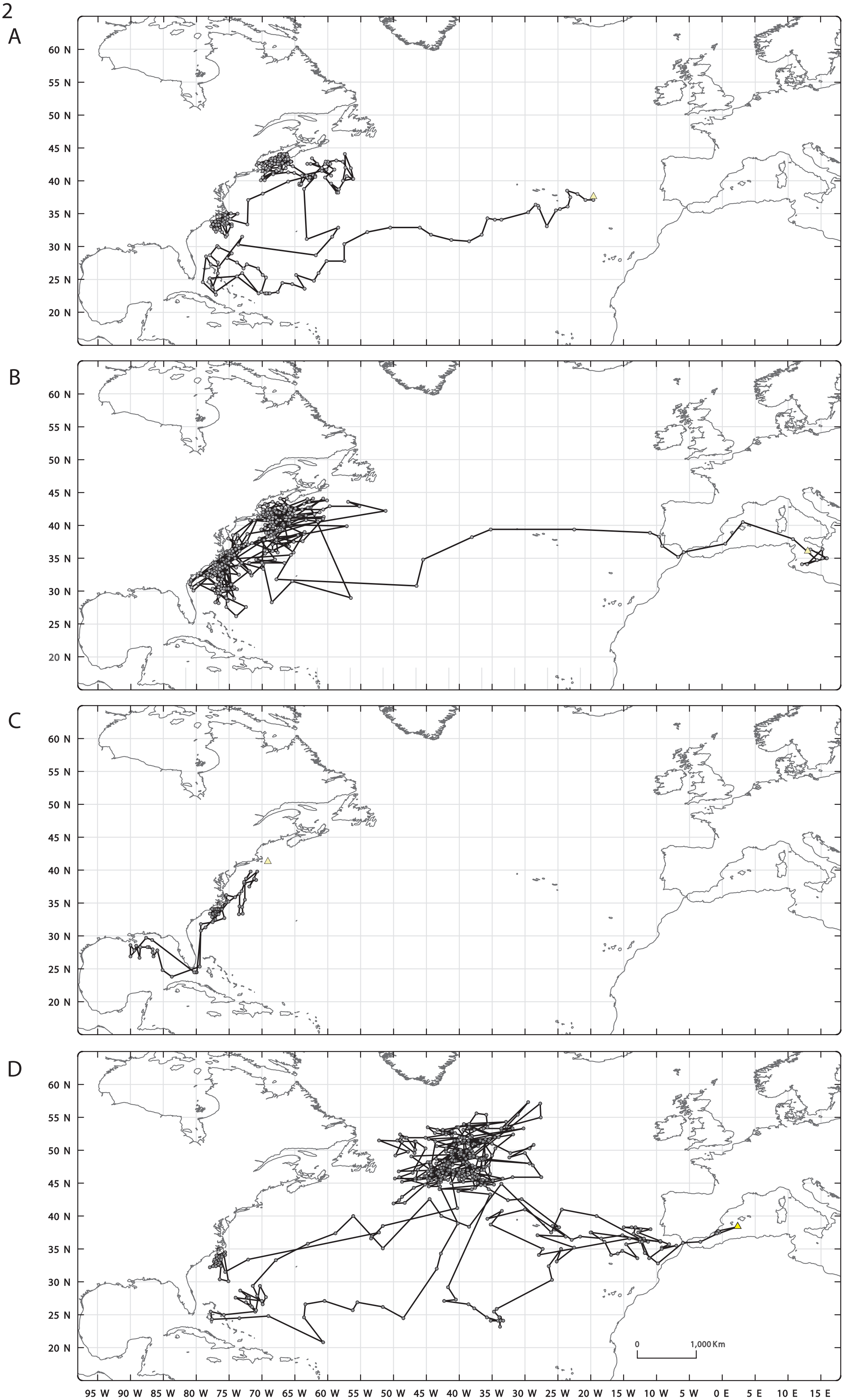
A
B
C
D
60 N
55 N
50 N
45 N
40 N
35 N
30 N
25 N
20 N
0
1,000 Km
95 W
90 W
85 W
80 W
75 W
70 W
65 W
60 W
55 W
50 W
45 W
40 W
35 W
30 W
25 W
20 W
15 W
10 W
5 W
0 E
5 E
10 E
15 E

**Figure 2.** Implantable archival position records from the tracks of bluefin tuna tagged and released offshore of North Carolina, USA with implantable archival tags in 1997 and 1999. A. Fish 521 (released 01 Jan. 1999, 218 cm CFL) shows a western resident track in year one typical of many archival tagged fish, followed by a migration from the west Atlantic to the east Atlantic in year two, from Block *et al.* 2001. B. Fish 408 (released 03 March, 1997, 203 cm CFL) shows fidelity for three years to the west Atlantic continental shelf and then rapid movement to the Mediterranean sea in late May and early June 2000, from Block *et al*. 2001. C. Track of a female bluefin tuna (released 17, Jan. 1999, 207 cm CFL) that went into the Gulf of Mexico at a time that coincides with the breeding season (June 1-26, 1999), from Block *et al.* 2001. D. Tag 779 (released 20 Jan, 1999, 218 cm CFL), which shows no association with the North American coastline after the first winter of release and a strong association with the oceanographic region to the east of the Flemish Cap. This bluefin tuna displayed several transatlantic crossings before eventual recapture in the Mediterranean. A period of aggregation in February north of the Bahamas most likely represents the breeding period of this individual.

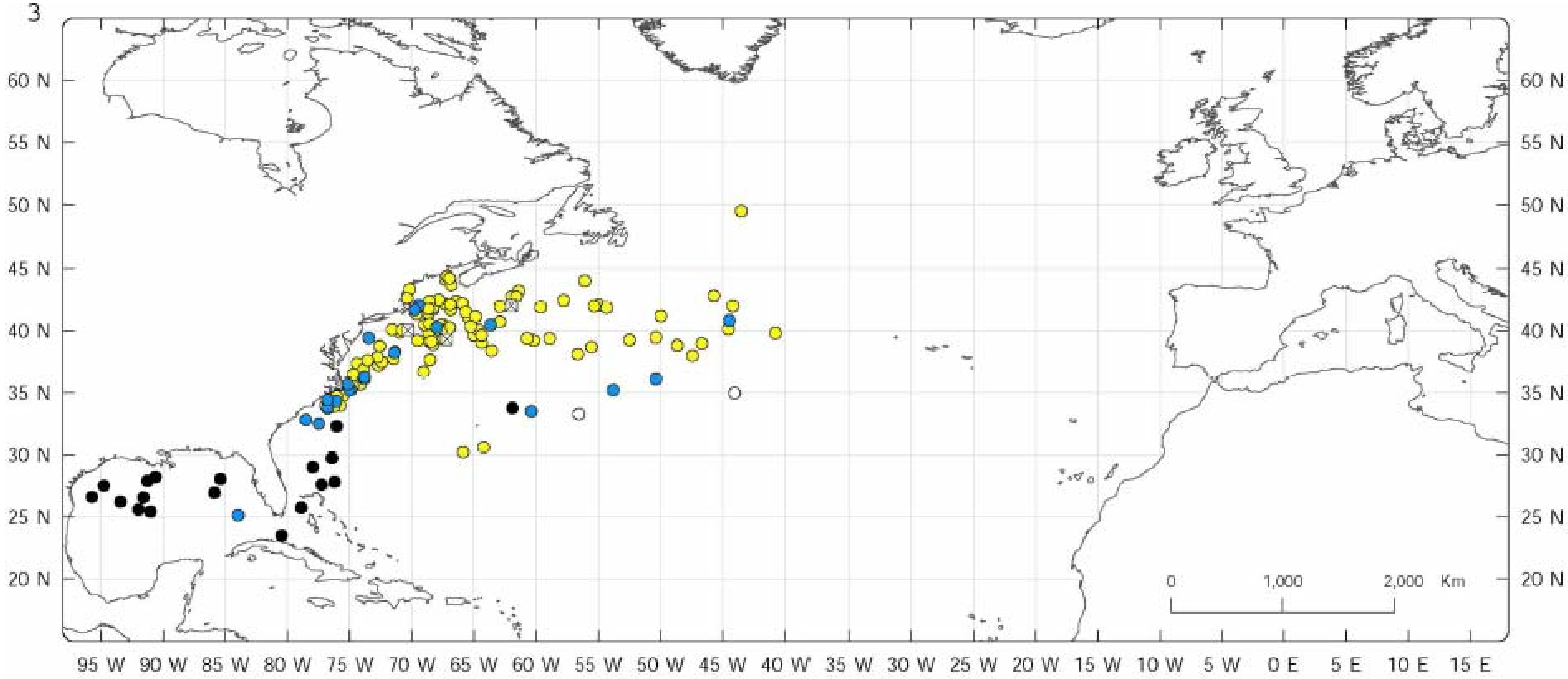


**Figure 3.** Pop-up satellite archival tag end points of western tagged Atlantic bluefin tuna (circles). Three longline recaptured PSAT tags are represented in squares. The color coding of the circles represents the deployment location. Light circles are fish released in Carolina, dark circles, are fish released from New England or the Gulf of Mexico. Open circles represent PSATs that are presumed to be 'drifters'. Data is from Block *et al.* 1998a 2001, and unpublished data from New England releases of Stokesbury *et al.*in preparation, Carolina releases, Boustany *et al.* in preparation and Gulf of Mexico data from Block *et al.* and Teo *et al.* in preparation).