# UPDATE OF ELECTRONIC TAGGING DATA AND METHODOLOGIES FOR ATLANTIC BLUEFIN TUNA IN ORDER TO PLAN FUTURE TAGGING ACTIVITIES

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*SUMMARY*

*This document presents the current electronic tagging information available for management strategy evaluation. This information also allows to identify gaps, in sizes and geographical areas, that should be taken into account to plan future tagging activities. It also describes the status of current electronic tag databases, advantages and disadvantages of electronic tags used on Atlantic bluefin tuna and outlines the technological advances that will allow the use of different types of tags (pop-up satellite archival, archival internal and acoustic tags) to improve the description of movements of this species. The conclusions section summarizes the progress needed to develop the use of electronic tagging on Atlantic bluefin tuna.*

*RÉSUMÉ*

*Ce document présente les informations actuelles sur le marquage électronique disponibles pour l'évaluation de la stratégie de gestion. Ces informations permettent également d'identifier les lacunes, en termes de tailles et de zones géographiques, qui doivent être prises en compte pour planifier les futures activités de marquage. Il décrit également l'état des bases de données actuelles sur les marques électroniques, les avantages et les inconvénients des marques électroniques utilisées sur le thon rouge de l'Atlantique et expose les progrès technologiques qui permettront d'utiliser différents types de marques (marques-archives pop-up par satellite, marques-archives internes et acoustiques) pour améliorer la description des mouvements de cette espèce. La section des conclusions résume les progrès nécessaires pour développer l'utilisation du marquage électronique sur le thon rouge de l'Atlantique.*

*RESUMEN*

*Este documento presenta la información actual de marcado electrónico disponible para la evaluación de estrategias de ordenación. Esta información también permite identificar lagunas, en las tallas y zonas geográficas, que deben tenerse en cuenta para planificar futuras actividades de marcado. También describe la situación de las actuales bases de datos de marcas electrónicas, las ventajas y desventajas de las marcas electrónicas utilizadas en el atún rojo del Atlántico y expone los avances tecnológicos que permitirán el uso de diferentes tipos de marcas (archivo satelital pop-up, archivo interno y marcas acústicas) para mejorar la descripción de los movimientos de esta especie. La sección de conclusiones resume los avances necesarios para desarrollar la utilización del marcado electrónico en atún rojo atlántico.*

*KEYWORDS*

*Electronic tagging, stock identification, data bases,* Thunnus thynnus

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## 1. Introduction

The use of electronic tags has proven to be a powerful and effective technology for studying fish movements, migrations, habitat use and physiology, including feeding and spawning behaviour. Several types of electronic tags have been used to study the ecology of Atlantic bluefin tuna (*Thunnus thynnus*, ABFT), mainly pop-up satellite archival tags (PSATs, or PATs), with external attachments, but also internal archival or data storage tags (DSTs) with surgical implantation in the body cavity, (Block *et al.,* 2005; Cermeño *et al.,* 2015; Arregui *et al.*, 2018). Improvements in technology (i.e. higher capacity batteries) and deployments methodology, is allowing to get longer release time tags and more detailed data, which besides the development of acoustic tagging programs, will provide better information on the movements of this species.

The continuous recording of the location of the specimen through electronic tags is an important contribution to know the movements of the fish, which is crucial for the proper management of a species such as ABFT which is capable of large transatlantic migrations. In addition, this species has spawning areas in both sides of the Atlantic, the Gulf of Mexico and the Slope Sea in the West, and the Mediterranean Sea, and probably other less important spawning areas as Bay of Biscay, in the East. The spawning site fidelity to these West or East areas have resulted in the current recognition of two different populations or stocks. It is therefore essential to know to which stock each tagged fish corresponds in order to see the movement capacity from both spawning grounds and the extent of mixing in the Atlantic Ocean. The best way for stock identification is through biopsy and genetic analysis, combined with microchemical analyses of otoliths. Where this has not been possible, their presence in one of the two main spawning areas, Gulf of Mexico or Mediterranean, has been used as an identifier of ABFT location of origin, as it is very uncommon for the same specimen to visit both areas (Block *et al.*, 2005). The identification of the stock of origin is essential to know the mixing that occurs between the two stocks and hence to properly manage their harvesting. Unfortunately, more than 50% of the tags deployed in ABFT are not allocated to one or the other stock, which is essential to model both stocks with methods that take into account the mixing, such as the management strategy evaluation.

The aim of this paper is to know what electronic tagging data on bluefin tuna are currently available, in order to identify knowledge gaps that should be taken into account to plan future tagging activities, aiming at properly estimating the movements between spatial strata, required by the management strategy evaluation (MSE) process, and in general to enhance the description of movements throughout the ABFT distribution area. Another objective is to briefly review the pros and cons of different types of e-tags, as well the recent technological developments and improvements in deployment methodologies, that should be taken into account to design a global e-tagging program for this species, that could take advantage of the complementarity among the different types of tags to contribute to the achievement of the aforementioned objectives.

### *Section 1. Current situation of e-tags data management in ICCAT*

The International Commission for the Conservation of Atlantic Tunas (ICCAT) began collecting metadata on electronic tags deployed on ABFT and other species around 2005, and over the last decade has directly supported electronic tagging activities in the framework of several research programmes, in the case of ABFT, the Atlantic Bluefin Tuna Research Project (GBYP). The original e tags inventory has been updated and nowadays contains metadata on 4 339 electronic tags, (internal, pop-up and acoustic ones), deployed from 1997 to 2019, and mostly on ABFT (3 740). This inventory is available at ICCAT webpage: https://www.iccat.int/en/accesingdb.html. Unfortunately, it is not yet fully operative, as some countries and research teams have not correctly communicated the metadata as requested (https://www.iccat.int/Forms/TG01-03_en.7z).

In addition to these metadata, in the case of ABFT, raw binary data from 1 053 individuals are also available at ICCAT Secretariat, both from internal (77) and pop up tags (976). Those data come from GBYP tagging (371) and data recovery programs (605), but in general the raw binary files are spread across various laboratories and/or scientists. Moreover, these raw data files are archived using various structures and formats, which can be inconsistent in time (changes in software, data policies, etc.), which prevent a global and fully standardized joint processing of such raw data sets.

To overcome this lack of data standardization, it has been decided to develop an e-tags data relational database at the ICCAT Secretariat, with the support of the GBYP, taking advantage of the system already developed by the Large Pelagic Research Center (LPRC, www.tunalab.org/index.htm) and the Oceanographic In-situ Data Interoperability Project (OIIP) to manage and analyse electronic tagging data.

However, since this global ICCAT information system on e-tags is not yet operative, to accomplish with MSE process e-tags info requirements, it was decided to centralize all the already available spatial data (tracks) resulting from the analyses of raw data from ABFT electronic tags in a single DB managed by the SCRS expert Dr. Matt Lauretta. Thus, several institutions sent to Dr. Lauretta, in addition to those provided by ICCAT Secretariat, further available files containing the data on daily geolocations, till getting a total of 1 279 individuals, as detailed in section 5.

***Section 2: Pop-up satellite archival tags (PSAT)***

Pop-up satellite archival tags (PSATs) are data loggers, attached externally to the body fish by means of different types of darts and tethers, which typically register depth, temperature and light data following pre-programmed settings. These tags, which started to be used on Atlantic bluefin tuna in the nineties (Block et al. 1998), are equipped with a release section which allow the tag to detach itself at a programmed date, and once floating at surface it transmits the collected data via the Argos satellite system. This allows data to be obtained without the need to physically recover the tag.

Unfortunately, in spite of this advantage, they show also several limitations. So, they are relatively big (125–215 mm and 36-108g) and hence are not suitable for small bluefin. Moreover, given that the transmission of data via satellite requires a high energy consumption, the number of messages that can be transmitted must be limited to grant a percentage of successfully received data enough to estimate at least the track of the fish. So, even choosing the settings to get only the minimum data required to estimate such track, the maximum time lapse covered by this type of tags is two years, and typically only one. Other weaknesses of using satellite tags are their depth limitations (2000m), their high cost (up to 4000$), their vulnerability to problems in data transmission due to biofouling, several potential technical problems as battery failures or malfunctioning of the release unit and, over all, the premature release for different reasons (predation by other fish, death of fish due to tagging stress, accidental detachment of the tag due to infections or inadequate insertion of the darts and tethers etc). The latter is a very important problem, that has heavily affected the ABFT satellite tagging programs, mainly those developed on the East stock, since if the duration of the tracks is less than a complete year cycle the derived movement matrices can be highly biased, since they could be mainly driven by the spatial and temporal distribution of tags deployments. As an example, the mean time on fish of satellite tags deployed within GBYP program before 2018 was only 49 days in tags programmed to last one year.

However, in spite of these potential limitations, this type of tags is the most widely used for ABFT spatial patterns determination. Fortunately, some of the aforementioned drawbacks can be solved or at least minimized in several ways. So, technological improvements by manufacturers have resulted in less losses due to premature detachments caused by technical issues, as pin-broke, or data transmission failures attributable to battery failures. In addition, improvements in tag deployment methodologies, taking advantage of the know-how from more experienced teams working from decades ago in the West Atlantic area, have allowed to increase significantly the time on fish of pop-up tags in the Eastern Atlantic deployments. So, as an example, in **Figure 2.1** it can be observed a sharp increase in time spent on fish of pop-up tags deployed within GBYP program in the years 2019 and 2020, after introducing some improvements in tagging equipment and methodologies (new types of darts and reinforced tethers; ad hoc workshop, including practical activities in the field, on pop-up tags attachment methods). In addition, the limitations affecting the quality of data received from satellite pop up tags, can be also overcome if they are physically recovered, since then it is possible to download directly from the tags 100% of recorded data. Some specific actions to enhance the physical recovery of these tags, as the maintenance and reinforcement of GBYP rewards program, including payment of high rewards for e-tags recovery, even those deployed by other institutions; maintenance of awareness programs, including contacts with farming companies; talks given to ICCAT observers on the importance of e-tags recovery; inclusion in the manuals addressed to ICCAT observers of instructions on how to proceed when a tag is detected, and the use of goniometers to detect and allocate precisely recently detached pop up tags, allowing its recovery in the open sea, has allowed to increase significantly the number of electronic tag recoveries along the last two years, as can be seen in **Figure 2.2.**

***Section 3: Archival internal tags***

Internal archival tags typically implanted in the peritoneal cavity of tunas, record depth, internal temperature, external temperature, and light, allowing posterior geolocation.

They are a lot smaller than PSATs, allowing to tag early juveniles (as early as age 1) which is impractical with PSATs. While current PSATs provide information for up to one year, archival tags can record multiple years of information in their memories, allowing for multiyear tracks and investigation of ontogenetic changes in behavior in each individual fish tagged. In the case of ABFT, this is particularly important to resolve uncertainty around age at first maturity, skip spawning behavior and shifts in resident/migratory behaviors. In addition, archival tags provide very detailed datasets (e.g. with records every few seconds), that allow searching for specific behaviors like spawning events (Aranda et al. 2013). In the case of ABFT, this is also something very important to understand when and where they spawn (e.g. if they spawn out of the Gulf of Mexico and the Mediterranean Sea, and how often), and their reproductive potential (e.g. number of spawning events within a season). This can also be investigated using PSATs when they are physically recovered.

The main disadvantage is that they need to be physically recovered if they are to provide any information, so it is important to consider potential recovery rates when designing archival tagging surveys, and promote recoveries through tag-awareness campaigns and high rewards. In addition, it has been observed in the field that some sensors can lose accuracy (or even stop measuring) through time, or that memories were filled after certain amount of years, which is linked to how the tag is specified regarding frequency of data recording. For example, Arregui *et al.,* (2018) had 7 recaptures with 35.5 years at liberty, from which they were able to retrieve information from 17.3 years (2.5 years per tag). So, although archival tags are in principle able to provide multiyear tracks, it is important to consider, at the onset, whether this is the main aim of the study, and program tags accordingly. And in parallel, it would be ideal to improve the performance of the tag sensors to make sure they are able to records reliably throughout multiple years.

When tagging juveniles with archival tags, it is important to take biopsies to allow for genetic identification of stock of origin. This is particularly important with juveniles, because they are less likely to visit spawning areas that would allow to identify origin based on the behavior (the current practice in the ABFT MSE).

***Section 4. Acoustic tracking as promising tool for the long-term monitoring of Atlantic Bluefin Tuna***

Acoustic telemetry (AT) is widely used to track animals in the aquatic environment. Stationary or mobile receivers are used to detect presence and/or location of animals via encoded acoustic signals originating from uniquely ID-coded transmitters (i.e., tags) attached internally or externally to animals. Such technology has revolutionized the understanding of aquatic animal movement in recent decades (Hussey *et al.*, 2015). Continuing hardware improvement, transmitters miniaturization, advancing sensor technology, increased longevity and sophisticated software developments are allowing longer and more reliable deployments, providing continuing greater flexibility in species and the life-stages that can be tracked and more detailed movement information (Hussey *et al.*, 2015; Matley *et al.*, 2022).

These advances have enabled a switch from traditional presence/absence approach of acoustic telemetry towards high-resolution data movement behaviours (e.g., Baktoft *et al.*, 2017; Aspillaga *et al.*, 2021). They have also opened the possibility to understand animal behaviour in the context of the surrounding environment (e.g., Marcinek *et al.,* 2001) but also estimation of animal physiology (e.g., Wright *et al.,* 2014) and predation interactions (e.g., Halfyard *et al.,* 2017) in the wild. AT is also a very promising tool to effectively address central fishery management questions such as natural mortality (Block *et al.,* 2019) and fishing mortality (Heupel and Simpfendorfer, 2002).

The main limitation of the technology is in the limited range of the acoustic signals propagated from the tags. Receivers detection range is typically between 60 and 950 m depending on local geography, bathymetry, and environmental conditions (Huveneers et al. 2016) necessitating multiple receivers (arrays) depending on the hypotheses at hand. The absence of larger acoustic arrays has reduced the value of acoustic tracking of large highly migratory species (Heupel *et al.*, 2006), among them the ABFT (Block *et al.,* 2001). Hence, acoustic tagging are omitted in the large-scale tagging programs of the Tuna Regional Fishery Management Organizations (RFMOs), like those carried out under GBYP (https://www.iccat.int/GBYP/en/) and AOTTP (https://www.iccat.int/aottp/en/) of the International Atlantic Commission for the conservation of Atlantic Tuna (ICCAT). These programs, aiming to estimate key life-history aspects (e.g., natural mortality, growth, abundance, spatio-temporal distribution) and fishery parameters (e.g., catchability, mortality by fishing) that feed population dynamics models (Hilborn & Walters, 1992), use currently only conventional, archival and pop up satellite tags (PSAT). These tags have advantages and provide pivotal information to the sustainable management of tuna species (Eveson, 2015), but also important handicaps and limitations. Large number of fish (thousands) must be tagged with conventional or archival tags to obtain good results given the low tag-reporting rate and are fishery dependent. Pop up satellite tagging have a much higher reporting rate and are fishery independent, but have also limitations (Lutcavage *et al.*, 2015), as detailed in section 2.

In the last decade there has been and increase broad-scale integrated networks composed by acoustic arrays deployed by individual or coordinated research groups around the world (e.g., the Ocean Tracking Network; O'Dor *et al.,* 2008; Hussey *et al.,* 2015). Shared and open Protocols ensure equipment interoperability (any transmitter can be detected on any receiver; Reubens *et al.,* 2021) and data are stored in a central facility where researchers can access them. These types of network expand the study area of the individual researcher potentially up to the continental scale. The European Animal Tracking Network (ETN - https://www.europeantrackingnetwork.org/en) is a recently created biotelemetry network, where key sites are already covered (~2000 integrated arrays are deployed across European waters (**Figure 4.1A**) and with an aim to deploy several strategic arrays (Abecasis *et al.,* 2018). Some of these key arrays have been already developed (as the Danish Straits and North Channel; **Figure 4.1.B-C**) and others, like the Gibraltar Strait, is being working on its implementation. The Strait is one of the most important natural gates for the marine animal migrations not the least for Bluefin Tuna (Mather *et al.,* 1995; Carruthers *et al.,* 2018). Hence, AT may now benefit the current tagging programs providing a number of advantages including:

- The methodology has the potential to provide relevant results without the need to tag a very large number of animals.
- Physical recapture of the animal to get data is not necessary (e.g., Cabanellas-Reboredo *et al.,* 2012).
- Acoustic tags are less costly compared to other biotelemetry tags (Whoriskey, 2015; Zeh *et al.,* 2015).
- Acoustic tags can last up to 10 years.
- Fish down to a few hundred grams can be tagged.
- Acoustic tags can serve as ground truthing for other tags like PSAT (in case of double tagging)

The potential for long time deployment, relatively cheap tags, tagging small fish and fishery independent detections holds promise of estimation of essential dynamic population parameters limiting present fishery management models. Also, acoustic detections would have the potential to serve as reference position with which improve the accuracy of the trajectories derived from light-based positions of archival and satellite tags (often incomplete or impaired by large observation errors, increasing the value of these taggings (Sibert and Fournier, 2001; Royer *et al.,* 2005).

To demonstrate the potential advantages and proof of concept, a pilot study was undertaken in summer 2021. Seven acoustic receivers were deployed in and around the Gibraltar Strait from May to September at strategic places (including the un-preceded collaboration with fishing sector attaching some receivers at the Tuna Traps; **Figure 4.1F**). Despite the low acoustic coverage, a total 14 acoustically tagged ABFT were detected (10 individuals from 2019-2020 tagging in Skagerrak; ICCAT reports, and 4 individuals from 2016-2020 tagging in Canada). All the fish were detected in the first half of July probably returning to the Atlantic after spawning in Mediterranean waters (Mather *et al.,* 1995; Reglero *et al.,* 2017).

These records strongly demonstrate the potential of acoustic telemetry to address important questions related to the ecology of ABFT, not least in terms of multiyear survival and spawning as well transatlantic migration. In consequence, acoustic telemetry may play a key role in the proper fishery conservation of this high-valued marine resource.

***Section 5: Updated information on e-tags for MSE data input***

A total of 1 279 electronic tags recorded data to estimate daily geolocations of ABFT released between 1996 and 2021. Of those, 136 fish were tagged within or entered the Gulf of Mexico (GoM), and 388 fish were tagged within or entered the Mediterranean Sea (MED) or were tagged in the Bay of Biscay as juveniles. The fish that entered the GoM or MED were assigned to a stock-of-origin accordingly (Bay of Biscay juveniles also assigned to MED), and the remaining 755 fish were not assigned to a stock. Overall, the majority of data (58% of tracked days) corresponded to fish of unknown stock-of-origin. Of the GoM assigned fish, all fish were tagged at a size >200 cm straight fork length. MED assigned fish ranged 64 to 270 cm in size at tagging, and unassigned fish ranged 59 to 313 cm. Size-at-tagging frequency distributions are shown in **Figure 5.1**.

The number of days tracked per fish averaged 166 days for GoM assigned fish (minimum = 9 days, maximum = 746 days), 129 days for MED assigned fish (minimum = 1 day, maximum = 1,628 days), and 136 days for unassigned fish (minimum = 1 day, maximum = 1,253 days) (**Figure 5.2**). **Table 5.1** shows the number of days observed per area by quarter and stock aggregated across all tagged fish. The area delineations are plotted in **Figure 5.3**. GoM assigned fish primarily resided in the West Atlantic, Caribbean, Gulf of St. Lawrence, and Gulf of Mexico but were not observed in the North Atlantic, East Atlantic, or Mediterranean spatial areas. MED assigned fish were observed in all spatial areas with exception of the Gulf of Mexico.

## Conclusions

- There is a need to improve the electronic database of electronic tags.
- The identification of the stock of electronic tagged specimens needs to be improved. Nearly 60% of the tags are not assigned to a stock-of-origin.
- Tagging of fish less than 200 cm in length in the West Atlantic is required
- It is necessary to tag more specimens in the eastern Atlantic and the Mediterranean Sea, especially in the Eastern Mediterranean.
- Technological advances and experience in the tagging technique are enabling higher tag retention rates and the achievement of a greater number of tracked days at liberty.
- Advances in acoustic telemetry and the increase in deployed acoustic arrays allow this type of electronic tagging to be considered as a promising tagging alternative.

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**Table 5.1** Summary of bluefin tuna days tracked per area by quarter, stock (assigned by spawning ground entry) and size class at time of tagging.

| | | GOM | | | | MED | | | | UNK | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size | Area | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
| <128cm | GOM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CAR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | GSL | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | W_ATL | 0 | 0 | 0 | 0 | 147 | 199 | 178 | 92 | 0 | 0 | 0 | 0 |
| | N_ATL | 0 | 0 | 0 | 0 | 55 | 68 | 0 | 20 | 0 | 0 | 0 | 0 |
| | E_ATL | 0 | 0 | 0 | 0 | 586 | 333 | 594 | 1292 | 62 | 91 | 782 | 348 |
| | S_ATL | 0 | 0 | 0 | 0 | 888 | 341 | 85 | 407 | 28 | 0 | 23 | 16 |
| | W_MED | 0 | 0 | 0 | 0 | 964 | 573 | 1680 | 2397 | 0 | 0 | 0 | 0 |
| | E_MED | 0 | 0 | 0 | 0 | 9 | 16 | 11 | 50 | 0 | 0 | 0 | 0 |
| 128-195cm | GOM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CAR | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 7 | 108 | 11 | 0 | 5 |
| | GSL | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 133 | 73 |
| | W_ATL | 0 | 0 | 0 | 0 | 158 | 136 | 92 | 85 | 4256 | 3868 | 2167 | 2089 |
| | N_ATL | 0 | 0 | 0 | 0 | 57 | 1 | 61 | 141 | 43 | 75 | 102 | 6 |
| | E_ATL | 0 | 0 | 0 | 0 | 217 | 218 | 343 | 316 | 41 | 151 | 1027 | 327 |
| | S_ATL | 0 | 0 | 0 | 0 | 176 | 113 | 48 | 23 | 7 | 55 | 262 | 29 |
| | W_MED | 0 | 0 | 0 | 0 | 2386 | 1403 | 2815 | 4708 | 0 | 0 | 0 | 0 |
| | E_MED | 0 | 0 | 0 | 0 | 460 | 249 | 236 | 387 | 0 | 0 | 0 | 0 |
| >195cm | GOM | 2726 | 3305 | 1 | 524 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CAR | 929 | 389 | 9 | 539 | 81 | 0 | 0 | 17 | 1662 | 140 | 0 | 495 |
| | GSL | 0 | 28 | 426 | 613 | 0 | 0 | 54 | 81 | 0 | 16 | 418 | 600 |
| | W_ATL | 1900 | 1652 | 1331 | 3741 | 1213 | 574 | 419 | 920 | 13438 | 10350 | 4175 | 5717 |
| | N_ATL | 0 | 1 | 0 | 0 | 750 | 216 | 659 | 1169 | 727 | 498 | 901 | 1111 |
| | E_ATL | 0 | 0 | 0 | 0 | 1077 | 592 | 1487 | 1317 | 573 | 1249 | 2061 | 1620 |
| | S_ATL | 12 | 64 | 0 | 0 | 758 | 1313 | 359 | 285 | 1068 | 1439 | 408 | 318 |
| | W_MED | 0 | 0 | 0 | 0 | 342 | 2100 | 1210 | 861 | 0 | 0 | 0 | 0 |
| | E_MED | 0 | 0 | 0 | 0 | 0 | 353 | 44 | 0 | 0 | 0 | 0 | 0 |
| Unk | GOM | 752 | 594 | 0 | 67 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CAR | 523 | 60 | 0 | 111 | 0 | 0 | 0 | 0 | 409 | 78 | 2 | 260 |
| | GSL | 0 | 0 | 8 | 52 | 0 | 0 | 0 | 6 | 8 | 3 | 319 | 542 |
| | W_ATL | 346 | 36 | 378 | 1424 | 251 | 51 | 0 | 75 | 6717 | 3506 | 9082 | 14737 |
| | N_ATL | 0 | 0 | 0 | 0 | 135 | 68 | 54 | 96 | 326 | 76 | 132 | 196 |
| | E_ATL | 0 | 0 | 0 | 0 | 54 | 270 | 687 | 421 | 179 | 134 | 0 | 29 |
| | S_ATL | 0 | 0 | 0 | 0 | 287 | 300 | 93 | 18 | 251 | 156 | 31 | 28 |
| | W_MED | 0 | 0 | 0 | 0 | 360 | 922 | 1040 | 807 | 0 | 0 | 0 | 0 |
| | E_MED | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

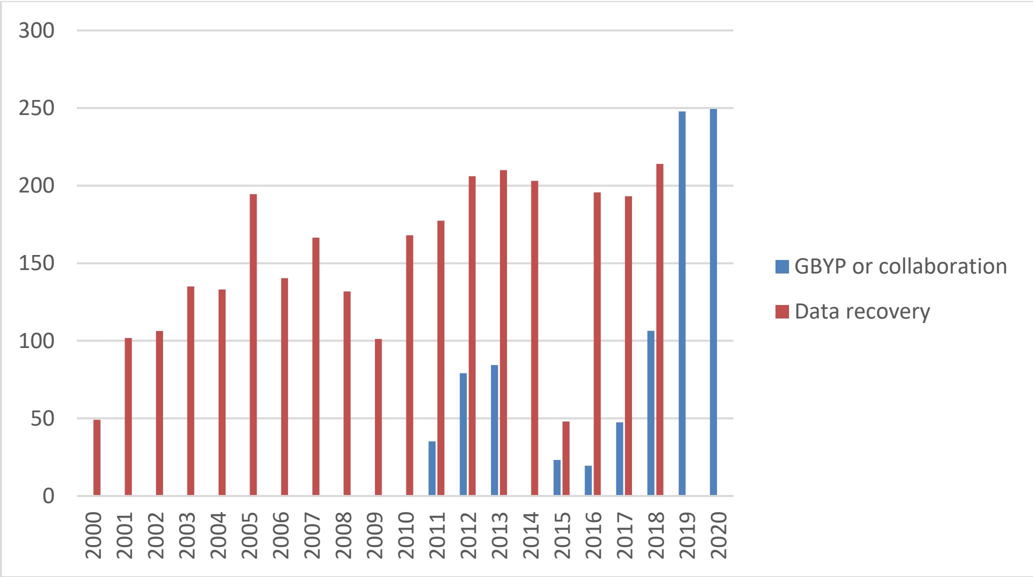


**Figure 2.1** Temporal evolution of the mean number of days on fish of pop up tags deployed in Western Atlantic (from GBYP data recovery program) and East Atlantic (tags deployed under GBYP contracts or Memorandum of Understanding).

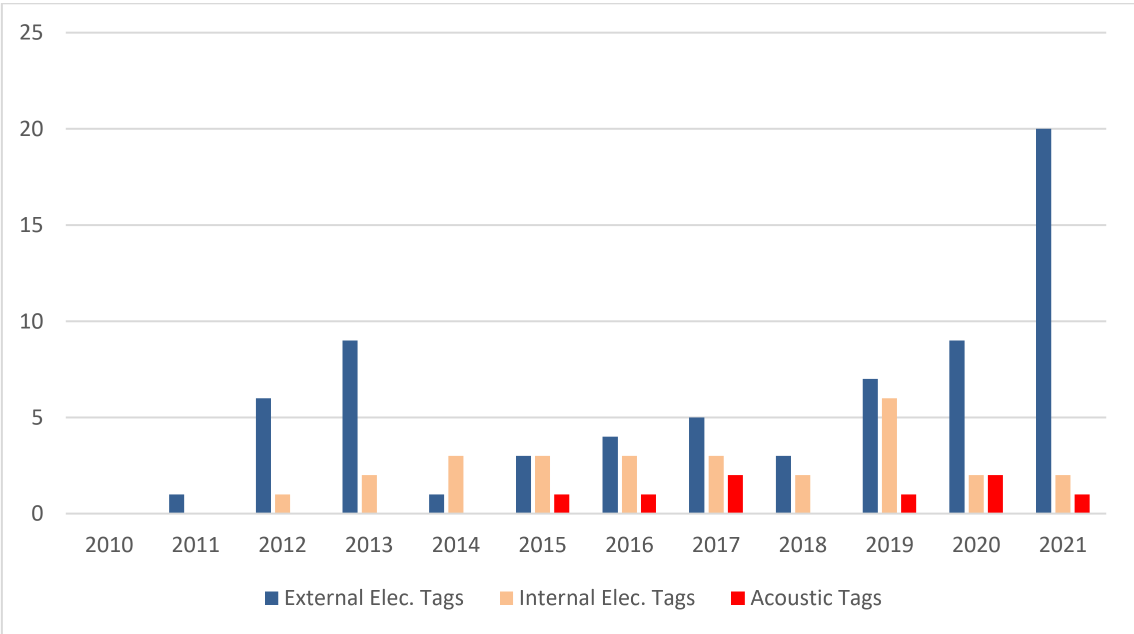


**Figure 2.2** Temporal evolution of e-tags recoveries in relation to GBYP program.

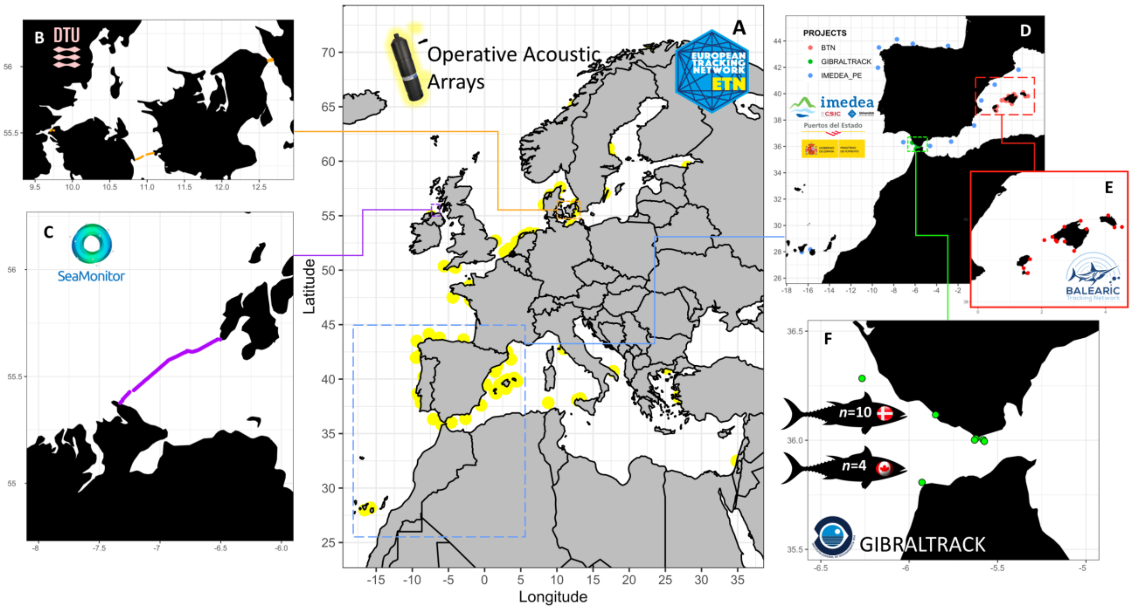


**Figure 4.1** Potential European tracking network with detail of some key arrays implemented in the North Europe and Spanish waters to monitor Bluefin Tuna and other large-migratory species: A) Operative arrays from the European Tracking Network across European waters, B) Danish Straits array deployed by the Technical University of Denmark, C) North Channel array deployed by Sea Monitor project led by the Loughs Agency, D) Fifteen oceanic places of the Atlantic and Western Mediterranean Sea (blue points) covered by receivers attached to oceanography buoys under a collaboration between IMEDEA-UIB-CSIC and Spanish Minister (Puertos del Estado), E) Fifteen key locations around Balearic Islands (red points; under the umbrella of the Balearic Tracking Network- https://trackingfish.com/como-funciona/) one of the most important spawning grounds of Bluefin Tuna (Álvarez-Berastegui *et al.*, 2016; Reglero *et al.*, 2017) and F) seven strategically locations at the Gibraltar Strait (green points) deployed during a pilot project in 2021.

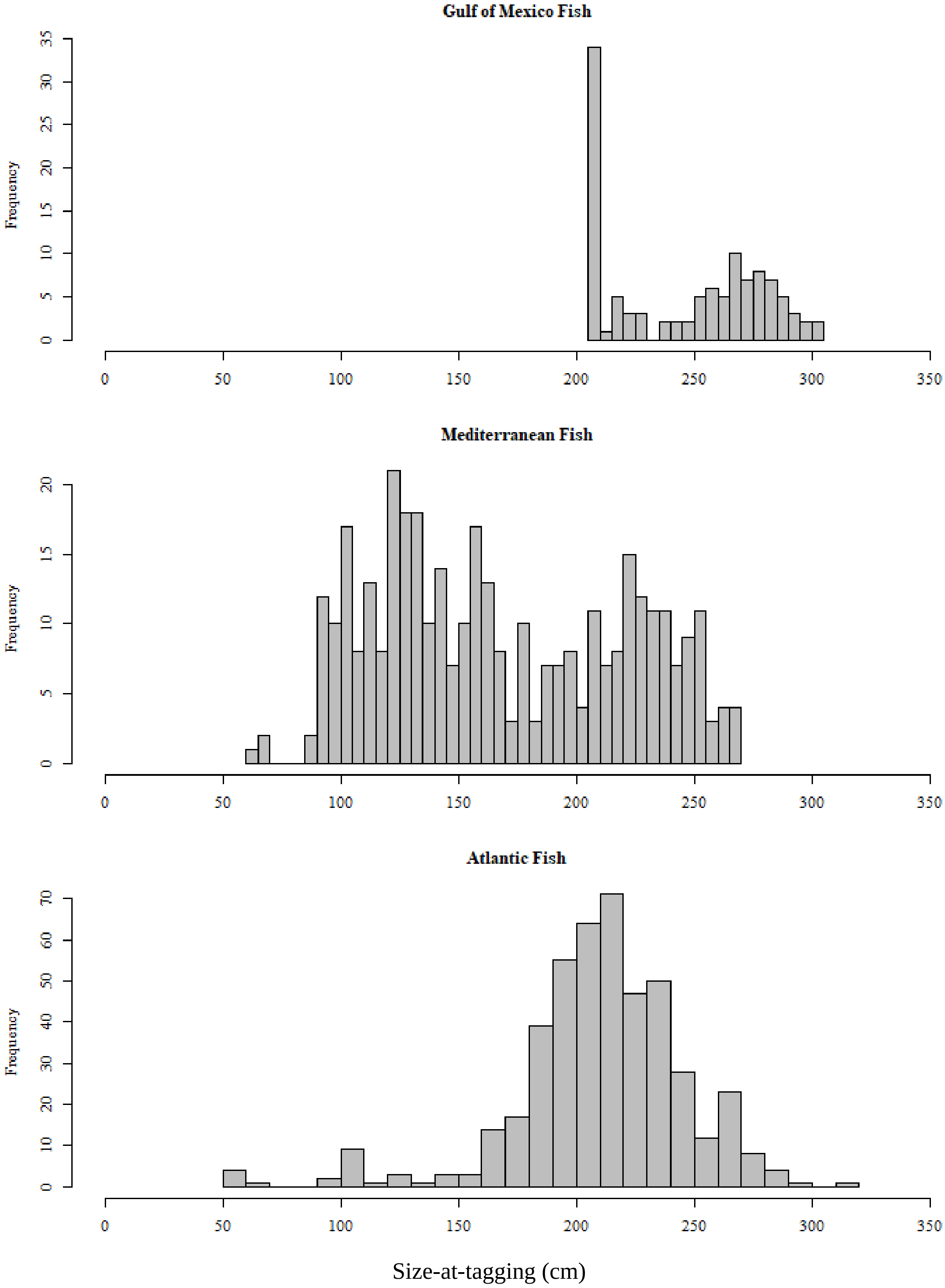


**Figure 5.1** Size-at-release of electronically tagged bluefin tuna.

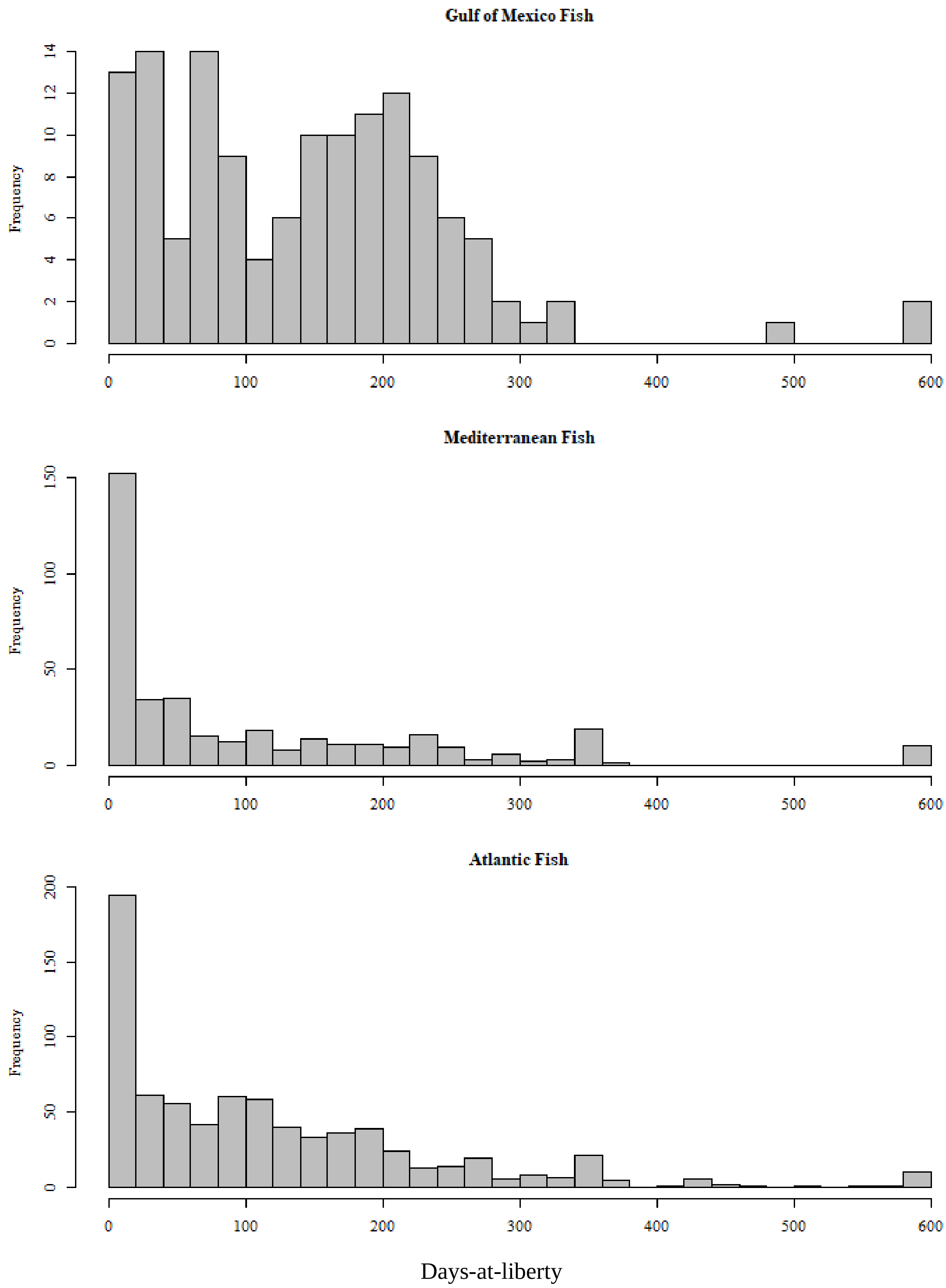


**Figure 5.2** Distribution of tracked days-at-liberty of electronically tagged bluefin tuna. The upper bin indicates fish at liberty 600 days or greater.

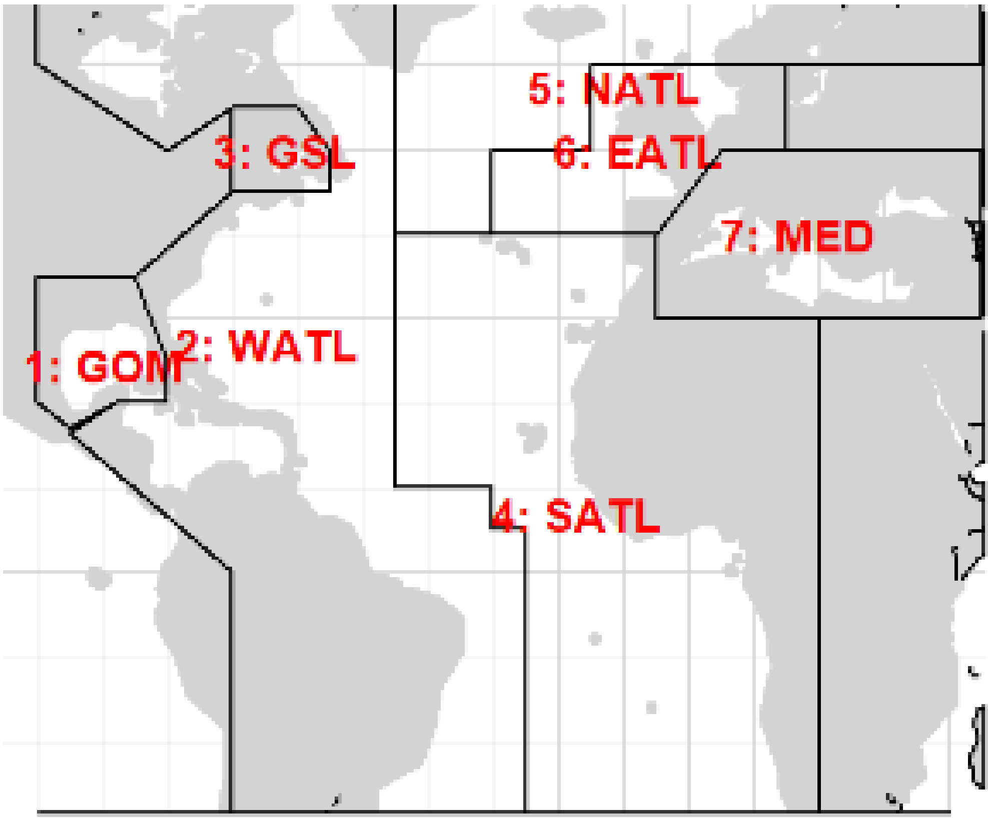


**Figure 5.3** Bluefin tuna spatial area delineations.