INTERNATIONAL COMMISSION FOR THE CONSERVATION OF ATLANTIC TUNAS

COMMISSION INTERNATIONALE POUR LA CONSERVATION DES THONIDES DE L'ATLANTIQUE

COMISION INTERNACIONAL PARA LA CONSERVACION DEL ATUN ATLANTICO

ATLANTIC-WIDE RESEARCH PROGRAMME FOR BLUEFIN TUNA

(ICCAT GBYP)

PHASE 11

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GBYP SCIENTIFIC AND TECHNICAL FINAL REPORT FOR PHASE 11

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ATLANTIC-WIDE RESEARCH PROGRAMME FOR BLUEFIN TUNA (ICCAT GBYP)

PHASE 11

FINAL REPORT

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1. Introduction

1.1 Historical background

The Atlantic-Wide Research Programme for Bluefin Tuna was officially adopted by the ICCAT Commission in 2008, endorsing the SCRS Chair's report on Bluefin Tuna Research Priorities and Potential costs. In 2009 the SCRS advised the Commission that, in order to substantially improve the scientific advice, such program would focus on the improvement of basic data collection through data recovery, understanding of key biological and ecological processes, improvement of assessment models and provision of scientific advice on stock status.

During the Commission Meeting in 2009, a number of Contracting Parties expressed a willingness to make extra-budgetary contributions to such a Programme with a view towards initiation of activities related to different priorities: Programme coordination, data recovery, aerial surveys and tagging design studies, with additional research activities to be undertaken in the following years. The provision to accept additional contributions from various entities and private institutions or companies was also agreed.

GBYP (Grand Bluefin Tuna Year Programme) was then adopted as official acronym of the research programme. Given that budgetary contributions would be provided annually the Programme has been implemented by annual Phases. To facilitate its coordination and management a post of Programme Coordinator was created, and a Steering Committee (SC) was set.

It was initially envisaged as a 6-year programme, but in 2014 the GBYP Steering Committee (documents SCRS/2014/194 and SCI 005/2014) and the SCRS recommended extending the GBYP activities up to 2021 and this proposal was endorsed by the Commission during its November 2014 meeting, along with the SCRS report. A new plan for the GBYP activities to be done during these additional years was approved along with the extension. Consequently, the donors maintained their contributions, allowing the continuity of the programme. In its report for the biennial period 2020-2021, Part 2 (2021), adopted in the 27th regular meeting of the Commission, the SCRS request explicitly further funding of the GBYP for the period 2022-2026.

From 2015 GBYP is being complemented by a twin programme, the BTRP, funded by NOAA-NMFS and addressed to USA research teams, which focuses its research activities on the western Atlantic Ocean.

1.2 Objectives

At the beginning of the programme the GBYP Steering Committee defined as the main objective of the GBYP the improvement of the knowledge and understanding of the Atlantic bluefin tuna (*Thunnus thynnus*) stocks and populations. Aiming at the achievement of this strategic objective, a series of general objectives was set considering the priorities initially stated by SCRS (data collection, understanding of key biological and ecological processes and assessment improvement). These broad objectives have been maintained throughout the program, but along the successive phases they have been adapted to the evolution of the "state of the art" as regards scientific knowledge on bluefin tuna, in order to better match SRCS research needs and Commission recommendations. In addition, new general operational objectives have been considered from Phase 10.

Therefore, the general objectives set for Phase 11 were:

a) Improving basic data collection and management, through data recovery activities, developing a broad scale biological sampling program taking advantage of the synergies between CPCs and GBYP sampling programs and, finally, supporting the development at ICCAT Secretariat of new databases integrating data derived from GBYP and from CPCs relevant programs.

b) Improving understanding of key biological and ecological processes, mainly through electronic tagging trials, coordinated with national programs, to determine BFT spatial patterns and supporting broad scale standardized and coordinated analysis of available biological samples, including microchemical, genetic and sclerochronological analyses to investigate mixing and population structure.

c) Improving assessment models and provision of scientific advice on stock status, through improved modelling of key biological processes, development of fishery independent indices, further developing stock assessment models considering mixing among areas, and development and use of biologically realistic operating models for more rigorous management options testing.
d) Enhance coordination between GBYP activities and the monitoring and research activities on BFT carried out by other institutions, both at national and international level.
e) Implement within ICCAT Secretariat an information system on biological data

1.3. Programme management and financial aspects

The GBYP programme development is supervised by a Steering Committee, which has the role to guide and refine it. It is composed by the SCRS chair, W-BFT rapporteur, E-BFT rapporteur, one external member and the ICCAT Executive Secretary or his deputy.

The Steering Committee is regularly informed and consulted by the GBYP Coordinator for all relevant issues. The Steering Committee meets not less than once a year, to verify the activities done, refine the Programme, propose follow-up of the Programme and adopt the budget.

The GBYP coordination team carries out the day to day tasks related to the implementation of the project, including the elaboration of the calls for different types of contracts, Memorandum of Understanding and contracts proposals, the reports on the different GBYP activities directly organized or developed by GBYP staff, as GBYP workshops, and the programme annual and executive reports.

Furthermore, the GBYP coordination participates, or provides scientific support whenever requested, in national or international initiatives which are potentially able to increase the effectiveness of the GBYP and the achievement of its objectives. For example, since 2010 the Coordinator has been part of the Evaluation Committee of the NOAA BTRP and has participated regularly in the EU Regional Coordination Group on Large Pelagic meetings.

The GBYP is funded by voluntary contributions of CPCs and other entities, as Chinese Taipei and ICCAT Secretariat. Among CPCs, EU provides 80% of total budget. In addition, several private or public entities also provide few additional funds or in-kind support. The budget is set annually, by phase. The evolution of the total budget along the Programme, by type of activity, is shown in **Table 1** (in euro):

Table 1. GBYP Budget by type of activity, per Phase

	Phase 1	Phase 2	Phase 3	Phase 4	Phase5	Phase 6	Phase 7	Phase 8	Phase 9	Phase 10
Coordination	210,000	453,000	225,000	600,245	342,000	383,000	415,745	312,500	227,000	478,000
Data Recovery	200,000	149,000	30,000	40,250	20,000	165,000	25,000	58,000		
Aerial Survey	300,000	465,000		518,426	519,500		405,000	494,500	535,775	321,000
Biological Studies		505,000	430,000	364,000	363,000	556,000	580,000	583,000	710,000	750,000
Tagging	40,000	890,000	1,175,000	1,229,979	669,500	844,000	262,000	159,000	177,500	315,000
Modelling		40,000	65,000	122,100	211,000	177,000	121,240	143,000	99,725	136,000
FINAL	**750,000**	**2,502,000**	**1,925,000**	**2,875,000**	**2,125,000**	**2,125,000**	**1,808,985**	**1,750,000**	**1,750,000**	**2,000,000**

It must be pointed out that this annual and variable funding scheme, instead of a multi-year and more stable funding system, is one of the major problems for GBYP, because this fact makes difficult a mid- and long-term planning of the activities, which would be for sure more efficient. The GBYP Steering Committee and the SCRS have recommended several times the adoption of a more stable funding system, but all proposals submitted so far by the ICCAT Secretariat or some CPCs to the Commission (i.e.: scientific quota, CPCs contribution proportional to quota, etc.) were discussed but they were never approved. The uncertainties linked to the funding at each Phase are creating operational problems since the beginning of the programme, because it is difficult to plan all activities and provide all necessary contracts when the effective funding for a given Phase is confirmed only at the very end of the previous one. This fact implies a continuous attention to the effective budget availability at each step of the programme by the Coordination team and Steering Committee and the impossibility to operate with multi-year contracts for multi-year activities.

The general information about GBYP activities and its results from the very beginning of the programme till nowadays, as well on budgetary and other administrative issues, is available from ICCAT GBYP webpage (https://www.iccat.int/GBYP/en/). All the relevant documents related to the programme development, including final reports of every activity and derived scientific papers, annual reports to SCRC and European Union, as well GBYP workshops or Steering Committee meetings reports, are also easily available therefrom.

2. Budget in Phase 11

The eleventh Phase of the ICCAT GBYP officially started on 1 January 2021 following the signature of the Grant agreement for the co-financing of the ICCAT GBYP Phase 11 (SI2.839201) by the European Commission. Initial duration of the Phase was one year, but it was extended for eight months, thus officially ending on 31 August 2022.

Phase 11 has been amended twice. First amendment included extending the agreement duration till 30 June 2022. The main motivation for requesting the amendment was to fully implement the foreseen activities, given that many of them had been cancelled or delayed due to COVID 19 pandemic. The first amendment was approved by the European Union on 18 November 2021. The second amendment was requested in order to adjust the budget to the actual costs, in order to make a full and efficient use of the available funds. Moreover, an additional extension of two months was requested, in order to be able to implement various activities that were further delayed. It must be pointed out that such modifications and time extension did not imply any change in the total budget for GBYP Phase 11, which remained fixed at 1,600,000 €, with an EU contribution of 1,280,000 €. The second amendment was approved by the European Union on 1 April 2022, extending the agreement until 31 August 2022.

It is worth to mention that the GBYP Phase 11 overlapped with Phase 10 for seven months (January-July 2021. It has made a bit more complex the GBYP programme management, but it has been possible to develop in parallel the different phases without major problems, since each phase has a well-defined work-plan and budget, and hence every cost can be assigned univocally to the activities detailed in the respective Grant Agreements. In addition, in March 2022 a proposal was submitted for financing the Phase 12.

A report of the GBYP activities in Phase 11 up to September 2021 was provided to the BFT Species Group (Annex 1b, document no. 13 presented as SCRS/2021/138) and the SCRS (Annex 1a, document no. 22, Annex 1b, document no. 1). The final report of Phase 11 activities was submitted to SCRS in September 2022, and presented within the SCRS 2022 Plenary meeting.

In Phase 11, the budget had the following funders when the proposal was presented (in order of contribution already received):

European Union	1,280,000.00 €
Morocco	61,981.13 €
Japan	53,204.87 €
Tunisia	59,028.97 €
Turkey	50,506.30 €
Libya	23,164.16 €
Norway	19,000.00 €
Canada	18,843.04 €
Korea	8,717.90 €
United States of America	8,420.00 €
Albania	3,208.52 €
Chinese Taipei	2,000.00 €

China	1,925.11 €
TOTAL BUDGET	**1,600,000.00 €**

Further amounts were residuals of previous GBYP Phases, and they were used for better balancing the EU contribution and for compensating costs which were not covered by the EU funding in the various Phases. Additional eventual residuals from the amounts provided in Phase 11 or further contributions from other CPCs will be used for the following Phases of GBYP. It should be noted that some contributions for the current and previous GBYP Phases are still pending from several ICCAT CPCs.

3. Programme Coordination in Phase 11

3.1. Steering Committee

The Steering Committee in the Phase 11 was composed by the SCRS chair (Dr. Gary Melvin), the Western BFT rapporteur (Dr. John Walter), the Eastern BFT rapporteur (Dr. Enrique Rodríguez Marín), the ICCAT Executive Secretary (Mr. Camille Jean Pierre Manel) and the external expert. The contract for the external member of the Steering Committee was signed with Dr. Ana Parma, researcher at the Centre for the Study of Marine Systems – CONICET (Argentina).

During the Phase 11, three SC meetings have been held, in October, November and December 2021. The reports are available in Annex 1a (documents no. 8-10). Other decisions have been taken via email, following the regular correspondence held between the GBYP Coordinator and GBYP SC members for all relevant issues.

3.2. Coordination Team

In the Phase 11 the Coordination Team has been composed by the GBYP Coordinator (Dr. Francisco Alemany), the Assistant Coordinator (Mrs. Stasa Tensek) and the Database Specialist (Mr. Alfonso Pagá). It should be pointed out that the ICCAT Secretariat provided the technical and administrative support for all GBYP activities on a daily basis.

3.3. Project management activities

During Phase 11, a total of 6 calls for tenders and 6 official invitations have been released, which have resulted in a total of 13 contracts awarded to various entities (Annex 2). In addition, one call of expression of interest for collaborating with GBYP etagging program was published, which resulted in 10 memorandums of understanding. A total of 20 scientific papers have been produced in Phase 11 (list in Annex 1b), while others will be published in the following months. So far, the GBYP has produced in total, over the first 11 Phases, 422 activity reports and 327 scientific papers.

Other routine project management activities have been the actions related to GBYP Research Mortality Allowance, the Tag awareness and reward program, the regular communication with the Steering Committee members and the updating of the GBYP web page.

Regarding RMA, during 2021 the Research Mortality Allowance was used for covering the incidental death of 114 specimens of bluefin tuna, which equals to a total of 2000 kg, reported through 15 RMA forms. Considering the number of specimens, most of these correspond to sampling activities, while considering the weight, the most correspond to incidental deaths due to electronic tagging activities.

In addition to the coordination tasks related to activities developed under these contracts or agreements and other day to day communication tasks with different stakeholders, the GBYP coordination team has participated in all ICCAT meetings focused on bluefin tuna (reports available in Annex 1a, documents no. 25-37). In addition, the Coordinator participated in the following meetings:

-On line meeting on collaborative work to assess sea turtle bycatch in pelagic longline fleets (South Atlantic) ocean and Mediterranean sea of this same group held in May 2022

-On line EU Regional Coordination Group on Large pelagics annual meeting, held in June 2021.

-EU-RCG Liason meeting, held on September 2021

-Meeting on satellite data integration in ETN, organized by the European Tracking Network, held in February 2022

EU RCG-LP annual meeting held on-line in June 2022.

Moreover, the GBYP coordinator participated directly in the training course for ROP observers on 12 May 2022 in Valencia, revising and proposing new contents to the "Observer's Manual" and the presentations dealing with tagging, and in the e-tagging activities carried out in Türkiye in June 2022, taking care of overall coordination of the campaign and logistic issues.

4. Activities in Phase 11

The Phase11 activities, adapted to the current SCRS research needs and Commission requests, were structured considering the main lines of research established since the beginning of the programme, i.e. data recovery and management, biological studies, tagging, stock indices (aerial surveys) and modelling, All activities carried out throughout the GBYP Phase 11, as well their final or preliminary results and the related coordination activities, are summarised in this report.

In general, most of the activities were successfully implemented according to the planned timetable, However, some field studies, as biological sampling of adults in farms, and planned in-person meetings and workshops, have continued to be hampered by significant challenges that have arisen due to the contention measures imposed by governments to mitigate the effects of the COVID-19 pandemic, which have affected the functioning of many of the research institutions and companies participating in GBYP funded studies, producing delays and even cancellations of some activities. As a first measure to deal with these problems, a time extension for the development of GBYP Phase 11 was requested. As regards meetings, as an alternative, most of those directly organized and supported by GBYP have been held online, namely those related with the bluefin tuna MSE process and the GBYP Steering Committee meetings.

4.1. Data recovery and management

This activity involves the compilation, storage and review of all relevant scientific information, original and processed, produced by or received in GBYP, including the data update and the errors correction in the databases. It regularly provides updated and verified information to the SCRS and the Secretariat.

In Phase 11, as in previous Phases, a special budget was reserved for data recovery, to cover any activity that could provide additional information on bluefin tuna catches, length distribution or spatial distribution patterns. So, at the very end of the Phase 11, a contract was signed with Dr. Molly Lutcavage (Tuna2Oceans Ltd) for acquiring 138 electronical tag datasets from tags deployed in 2010, 2011 and 2013 by Large Pelagics Research Centre. The contractor was hired to submit the complete datasets, including raw data on temperature, depth and light, as well as the processed daily geolocation estimates. The report is available in Annex 1a, document no. 23.

However, following the strategic shift initiated in Phase 10, most of efforts in this line have been directed to the development of information systems allowing the proper storage and analysis of the data from GBYP funded research activities or other data relevant for BFT management not yet included in current ICCAT databases, and hence to make the better use of the huge amount of data generated within previous Phases. So, a considerable in-house work has been carried out by the GBYP Team, in close collaboration with the ICCAT Secretariat, namely the Department of Research and Statistics, and SCRS scientists, to this end.

Specifically, the actions carried out in this line within GBYP Phase 11 have been:

- Updating the information with the latest inputs and improving the data quality of a database (e.g., crosscheck validation and duplications removal), integrating the data related to BFT farming, including those from stereo camera measurements and harvesting operations, relating and complementing them with data from eBCD and VMS systems. Within this Phase, more than 200 files and 28000 individual BFT stereo cameras measurements have been incorporated and analysed. As a result of this task, a recommendation to modify the official forms was presented, as well as the results of some analyses.

- Updating and maintenance of a database on growth in farms, integrating the information obtained from the GBYP studies, for different farms and period from 2019 to 2021. Several coordination meetings with ICCAT Science and Statistics Department staff were also held in relation to this task. As a result, many reports and a database including more than 25000 BFT measurements, as well as data on daily feeding and environmental conditions are now available to use.

- The initial tasks aiming at the implementation of the work plan for the creation of a broad biological data information system. A detailed work plan has been agreed and established, in coordination with ICCAT Statistics Department staff, through several internal coordination meetings. As a first step, after some coordination meetings between the GBYP coordination team, the Statistics Department, Secretariat and the main biological studies contractor, AZTI Tecnalia, which is in its turn the responsible for the maintenance of the GBYP Tissue Bank, a detailed template to get relevant info about the biological sampling activities and storage procedures of biological samples was designed and then filled by AZTI team. Based on the received answer and information previously available from GBYP information system, a metadata inventory is being created, integrating the information from GBYP biological studies carried out in the successive Phases of the programme. Beside this, the data about biological information and biological sampling of species under ICCAT convention carried out by EU countries under the EU Data Collection Framework, which is submitted annually by these member states to the EU, is being downloaded from EU portal https://datacollection.jrc.ec.europa.eu/ars, and it is being processed for including it into the new ICCAT biological data and information system, to be used as a reference to improve the coordination between CPC and ICCAT special scientific programs sampling activities.

- Contribution to the design and build up a data repository to store the information from the aerial survey activity.

In addition, a new project was initiated in close collaboration with the ICCAT Secretariat Statistics Department, for developing an integrated electronic tagging management system capable of managing the data from all the electronic tags released by ICCAT, or provided by CPCs scientific teams, in all ICCAT managed species. The rationale behind this project is that existing and future electronic tagging information will be much more useful to the ICCAT scientific community if all the information is validated and stored in a centralised relational database, together with all the associated metadata. This system, called ETAGS, will be used to manage both the metadata on electronic tagging operations and the raw data generated by these electronic tags. For this purpose, a contract was signed with Dr. Chi Hin Lam (Big Fish Intelligence Company Limited), who has already developed a system to manage and analyse electronic tags data. Dr Lam adopted the existing system to ICCAT needs and provided necessary support and training on platform installation and use of the tools. The report is available in Annex 1a, document no. 11. Given the complexity of the overall project, including combination of various technologies needed and large amount of data in the inventory, the project is still ongoing and will be continued within future Phases.

4.2. Fishery independent stock indices (Aerial Surveys)

ICCAT GBYP Aerial survey on bluefin spawning aggregations (AS) was initially identified by the Commission as one of the three main research objectives of the Programme, in order to provide fishery-independent trends on the minimum SSB. However, due to different reasons, as budget and logistic limitations and different opinions about the best sampling strategies between successive SC members, this activity has not been developed regularly and has not followed homogenous methodologies and sampling strategies from the very beginning. Moreover, the AS has faced numerous logistical challenges, which have resulted in changes in survey design and data processing to standardize methodologies and improve the accuracy of the index.

In 2019, all historical GBYP aerial survey data were re-analysed for all the areas and years in a homogeneous way, correcting some errors that were not detected before and introducing also some methodological improvements in the data analysis process, resulting in new more accurate and fully standardised index time series. However, the new index time series exhibited substantial differences in relation to prior time series, and still showed a high interannual variability between and within areas, which raised new concerns about the estimation procedures and the overall efficacy of the survey. In addition, in 2020 an in-depth revision of the whole GBYP AS program was carried out by two external experts who detected some inconsistencies and presented several recommendations for its improvement. One of these recommendations was to start moving to digital observing and counting systems to substitute human observers-based system, and another was to extend, if possible, the surveyed areas. So, in 2021, still within GBYP Phase 10, a pilot aerial survey was carried out, aiming at evaluating the feasibility of using digital systems for the monitoring of BFT spawning aggregations and its accuracy and precision, as compared to the classic human observers-based system. Due to budgetary limitations, the survey was carried out only in the Balearic Sea area. The reasons to select this area was that it would allow to continue the AS index from that area, which was at the moment the only one considered for the MSE, and that this area was the most suitable, from the logistic and financial point of view, for carrying out the trial. Finally, in 2021, under GBYP Phase 10, a global reanalysis of the whole time series, applying both the design-based approach used from the beginning of the GBYP aerial surveys, but also exploring a new model-based approach aiming at overcoming the potential impact of interannual environmental variability on BFT spawners distribution and hence on index accuracy, was carried out.

4.2.1. Aerial survey campaigns in 2022

Considering the results from the aforementioned pilot survey and those from the global revision and reanalysis of the time series carried out in 2021, as well logistic constraints and available budget, the GBYP Steering Committee decided to resume, within GBYP Phase 11, the aerial survey for bluefin tuna spawning aggregations in the core areas of the Western and Central Mediterranean Sea in 2022, following the standard human observers based methodology, but including again the use of digital systems for automatic recording of images along the transects. The three sub-areas to be surveyed were the following: Balearic Sea (Area A), Southern Tyrrhenian Sea (Area C) and Central-southern Mediterranean Sea (Area E). It was decided that the Levantine Sea sub-area (Area G) would not be surveyed because the results obtained in previous campaigns suggest that one of the basic assumptions to apply this methodology, it is that the BFT spawners be fully available for aerial observations, is not accomplished.

With this aim, a call for tenders was released (05/2022) and several bids were received. Nevertheless, considering the scientific and technical aspects of the bids and the available budget for this activity, it was decided that further feasibility studies towards implementation of digital systems could not be done this year. Moreover, given that not all the areas were covered with the bids and one bidder withdrew its offer in the last moment, two more calls for tenders (06/2022 and 07/2022) had to be released in order to cover the entire survey area. As a result, three contracts were awarded for this activity. Air Perigord (France) was awarded for carrying out the survey of Area A and Unimar and Aerial Banners (both from Italy) were awarded for areas C and E.

Before the mission, an on-line training course was held with the participations of all members of the crews (pilot, professional spotters, 2 scientific spotters), in order to provide them with the detailed instructions on the methodology and the way to fill the sighting forms. In addition to the GBYP Coordinator, the course was given by an external expert (Dr. J. Antonio Vázquez Bonales) who has multiple years' experience in GBYP AS.

As well as other years' surveys, the 2022 ones were also conducted in the period from the end of May to the beginning of July, following the standard protocol and using classical visual observations. The surveys were carried out following the design which defined four replicas in each area.

The survey in Area A (Balearic Sea) was carried out with a Cessna 337 plane, from 7 to 27 June 2022. During this period, 15 flights were completed, over 13 working days. On the other days, it was mainly the weather conditions that prevented the team from doing aerial work. The weather conditions sometimes forced the team to divide the flights initially planned, in order to be able to fly over the entire area. In addition, in mid-June a strong heat wave over the Balearic Islands forced the flight to be cut short because it was far too hot on the plane. Nevertheless, all 30 transects divided into 4 replicas were flown over. In total, during the time on effort, 24 observations of bluefin were recorded, which summed to nearly 23,600 individuals with a total mass of 3,755 t. The majority of the observed schools were made up of large individuals (weighting between 150 and 300 kg). The preliminary maps (**Figure 1**) show a distribution of Atlantic bluefin tuna near the islands of Majorca and Minorca but also in the south-west of the prospecting area. The report is available in Annex 1a, document no. 1.

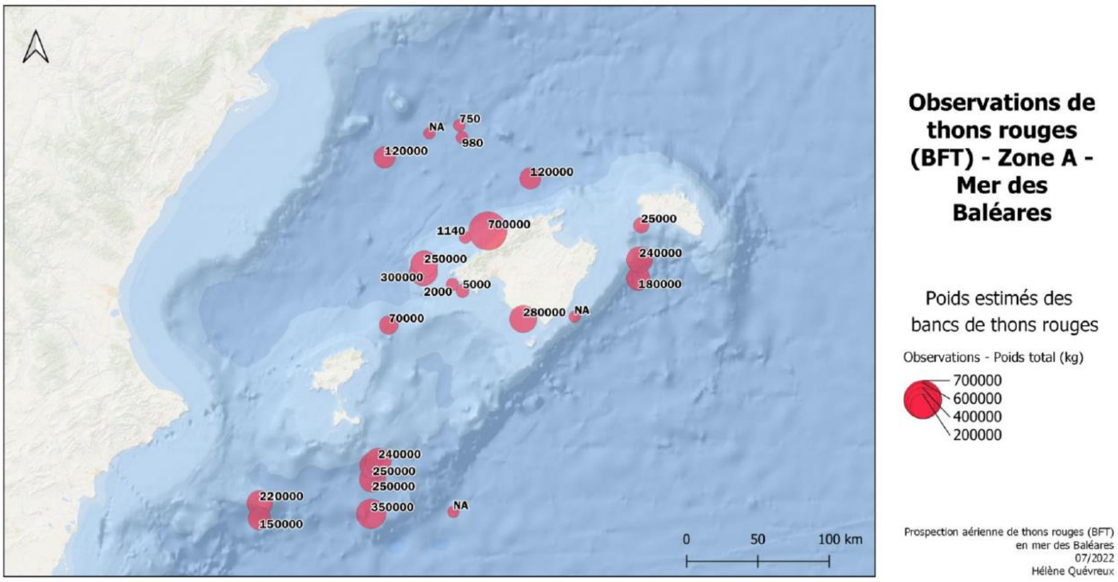

Figure 1. Bluefin tuna observations in the Balearic Sea area

The survey in the Southern-Tyrrhenian Sea (area C) was carried out by a plane Partenavia/Vulcanair P68 B model during the period from 11 to 20 June. It's worth to remark that the surface water temperature, as occurred also in Balearic sea area, was exceptionally high for this season (over 25 °C). It is possible that these conditions could have an effect on the visibility of Bluefin tuna schools, since according to the professional spotters' opinions, part of the BFT adult's schools could swim deeper and hence making more difficult the detection from the airplanes. Although the 2022 survey was performed somewhat later than usual in other years, the bluefin sightings occurred almost over the whole survey period. The distribution of sightings is shown on **Figure 2**. The report is available in Annex 1a, document no. 2.

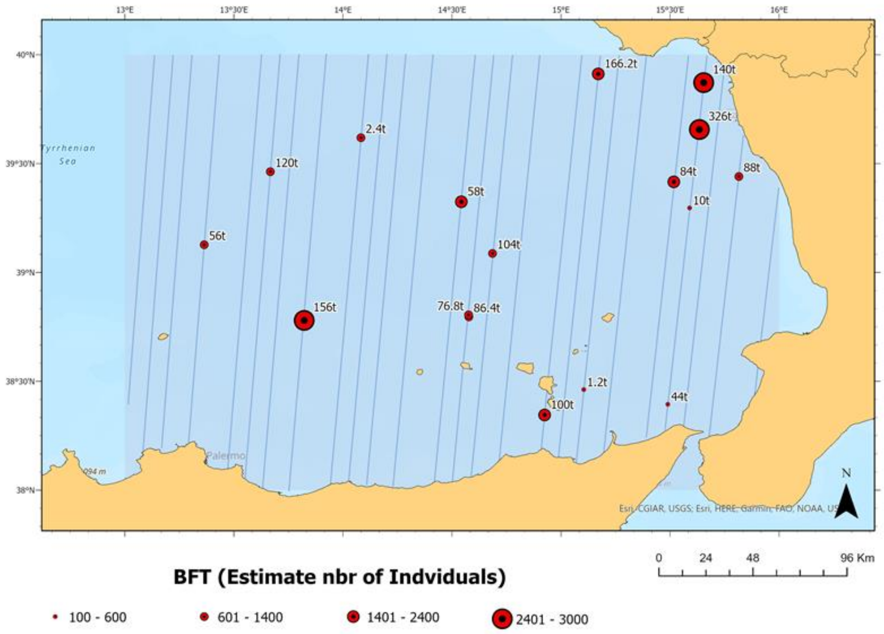

Figure 2. Bluefin tuna observations in the Southern Tyrrhenian area

The survey in Area E: Central-southern Mediterranean Sea (Sicily Channel) was carried out from 21 June to 4 July. The delayed start of the mission was caused by the fact that the initially awarded bidder withdrew its offer just before the start of the campaign, and this obliged the launch a new Call and signing the contracts later than usual. The survey was carried out in parallel by two planes, both of them of model

Partenavia/Vulcanair P68 B, through 16 survey flights. In total, 10 bluefin sights were recorded, which is more or less the same as in previous years. However, 8 out of 10 spotted schools were composed by small individuals, a percentage higher than in previous years, and they were in any case in feeding activity. The other 2 were composed both by small and medium fish. Most of the schools were seen under the surface rather near to the aircraft. This suggest that maybe the adult fish schools were not fully available of aerial observations. So, the impact of the anomalously high SST on the detectability of spawners schools will be explored. The distribution of sightings is shown on **Figure 3**. The report is available in Annex 1a, document no. 3.

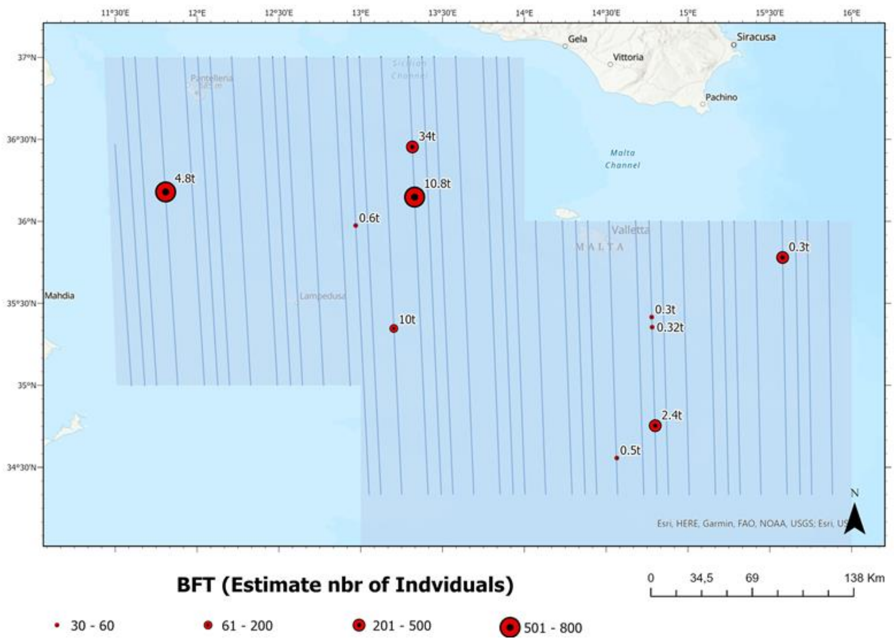

Figure 3. Bluefin tuna observations in the Central-southern Mediterranean Sea area

4.2.2. 2021 aerial survey data analysis

In 2022, the analysis of the data from the pilot aerial survey in 2021 in the Balearic Sea area (Area A) has been done as well. The contract for the data analysis was signed with the Centre for Research into Ecological and Environmental Modelling (CREEM) team at the University of St Andrews. The CREEM has been identified as a leading institution in the design and analysis of distance sampling surveys, being the developers of the DISTANCE software used for the analyses of the GBYP aerial survey. In addition, the CREEM team had already conducted the complete re-analyses of GBYP aerial survey data up to 2019, providing the updated index time series.

So, within Phase 11 they were contracted again to update the GBYP aerial survey time series in this area to estimate density, abundance and biomass of bluefin tuna in the Balearic Sea including the 2021 aerial survey observations and, in addition, to make a comparison between estimates for the core area (A-core) and the area outside the core area (A-outer).

Two approaches to estimating abundance have been used: design-based methods and model-based methods. Design-based methods estimate a constant density within a survey block, whereas model-based methods allow density and abundance to be estimated as a function of location and environment, allowing density to vary spatially throughout a region. The objective was to further assess the feasibility of using model-based methods (a preliminary feasibility study had been already carried out in 2021). There were too few sightings to use data from 2021 only (8 and 12 in A-core and A-outer, respectively) and so data from 2017-2019 were included for both analyses. In these previous years only the A-core area was surveyed.

A range of models including various covariates and detection functions were fitted to the 2017-2021 data, both excluding A-outer and also including A-outer. The final models included company and school size as explanatory variables, as it was for 2017-2019 models. The estimated abundance in A-core in 2021 was 26,300 BFT (CI: 9,620 - 71,920) when only sightings in A-core were included in the model, and 26,110 BFT (CI: 9 590 - 71 130) when A-core and A-outer were included. These are lower estimates than in 2019. The estimated abundance in A-outer was 80,990 BFT (CI: 26,860 - 244,170). The summary of results for period 2017-2021 is shown in **Table 2**.

Table 2. Summary of results for period 2017-2021 for Region A (using sightings from A-core in all years for fitting the detection function): detection probability (p), Search effort (km), number of schools within truncation distance (n), encounter rate (ER, schools/km) and coefficient of variation (ER.CV), individual density (N-D, fish/km^2) and coefficient of variation (N-D.CV), individual abundance (N, in thousands), coefficient of variation (N.CV) and lower (N-LCL) and upper (N-UCL) limits of the 95% confidence interval for N, expected school size (N-ES),CV (N-ES.CV), biomass (B, tonnes), CV of B (B.CV) and lower (B-LCL) and upper (B-UCL) limits of the 95% confidence interval for B, biomass density (B-D, kg of fish/km^2), coefficient of variation (B-D.CV), and expected school biomass (B-ES, kg) and CV of B-ES (B-ES.CV)

Survey	p	Effort	n	ER	ER.CV	N-D	N-D.CV	N	N.CV	N-LCL
A-2017	0.17	4949.538	18	0.0036	0.30	0.82	0.44	50.79	0.44	22.22
A-2018	0.24	6092.870	24	0.0039	0.21	1.34	0.31	83.08	0.31	46.19
A-2019	0.23	5574.084	20	0.0036	0.24	1.23	0.38	76.30	0.38	37.37
A-2021	0.86	6715.943	7	0.0010	0.53	0.43	0.54	26.30	0.54	9.62

Survey	N-UCL	N-ES	N_ES.CV	B	B.CV	B-LCL	B-UCL	B-D	B-D.CV	B-ES	B-ES.CV
A-2017	116.10	118.56	0.56	8072.21	0.45	3467.16	18793.67	130.54	0.45	19.22	0.57
A-2018	149.43	245.48	0.39	13470.74	0.31	7427.84	24429.85	217.84	0.31	39.60	0.41
A-2019	155.77	234.42	0.42	11648.99	0.38	5670.44	23930.97	188.38	0.38	36.01	0.43
A-2021	71.92	1050.99	0.17	4716.59	0.53	1751.02	12704.74	76.27	0.53	210.92	0.16

Two models were fitted in the model-based approach, one to describe the number of groups and the other to describe group size. To illustrate this approach a limited set of potential explanatory variables were used, such as sea surface temperature on the day of the survey, the difference in sea surface temperature between day of the survey and 10 days before and depth, year and location. The selected models explained only small fractions of variation in density of groups and group sizes and there are large uncertainties around the estimated values. These data present considerable challenges for modellers and further analyses may benefit from careful consideration of new environmental covariates. The report is available in Annex 1a, document no. 4.

4.3. Tagging

This line of research has faced two important problems from the beginning of the program, which have prevented or limited the fully achievement of these initial objectives. One is the very low recovery rate of conventional tags, which impede the use of these data to estimate reliable mortality rates. Because of that GBYP SC, decided to cancel the conventional tagging program in Phase 4, initiated in Phase 2 besides the tag awareness and recovery programme, maintaining only complementary conventional tagging activities by providing tags and tagging equipment to different institutions or organizations which ask for this support, as well as maintaining the awareness and rewards campaigns and the data base integrating all the results from recovered tags. The second major problem has been the relatively short time on fish of most of the electronic pop-up tags, which limits the usefulness of the recorded data to achieve the stated objectives. The premature releases are attributable to different factors, as technological problems of the tags, fishing activities, death of the fish after tagging and, in general, probably the use of equipment and tagging methodologies not fully adequate for BFT. These potential problems have been addressed through different ways, as the use a new reinforced model of MiniPAT satellite tag designed to minimize "pin broke" problems, selection of tagging areas with lower fishing pressure and exploring and applying whenever possible improved tagging methodologies. In Phase 9 further methodological improvements were introduced in GBYP tagging operations, as the use of a new type of reinforced tether with titanium darts and the use of a retention loop with a second anchor. In addition, an ad hoc workshop on satellite tags deployment methodologies was held for instructing the taggers, including practical sessions. Consequently, the time on fish of the tags deployed in the last two years has improved a lot, with increasingly higher proportion of tags remaining on fish the whole programmed year, for the first time in GBYP tagging campaigns.

4.3.1. Tagging campaigns in 2021

As recommended by the Steering Committee, the tagging activities carried out under contract on specific agreements in the Phase 11 were limited again to the deployment of electronic tags, keeping the deployment of conventional tags only as a complementary activity.

As in the previous season, the specific objectives of the 2021 campaign were to improve the estimations of the degree of mixing of western and eastern Atlantic bluefin tuna stocks in the different statistical areas over the year cycle, specifically considering the current needs of the MSE modelling process, with the immediate objective to improve the knowledge of the bluefin spatial patterns.

Similarly to Phase 10, the GBYP tagging program in 2021 included with electronic tagging programs developed at national level. This allowed to strengthen collaboration, taking advantage of the synergies between the different tagging programs and increase the efficiency of each, with the final goal of providing better scientific advice. With this aim, a call for expressions of interest was published (ICCAT Circular #G-0471-2021), for deployment of a total of 70 pop-up satellite tags by experienced tagging teams in the Mediterranean and/or North Atlantic Ocean, targeting eastern stock individuals.

As a response to the call, several expressions of interest were received, describing their work-plan for the deployment of the tags. These were carefully evaluated by the GBYP Steering Committee and the Secretariat staff in order to select the most adequate ones to fulfil SCRS research needs. Consequently, memorandums of understanding were signed between ICCAT and the awarded research teams, to formalize the cooperation. GBYP provided electronic tags and covered the costs of PSATs satellite transmission, while national teams provided the human resources, including experienced scientific personnel in deployment of electronic tags in bluefin tuna and infrastructure required to successfully conduct such tagging operations. It was agreed that the tags data would be shared by both parties. The following national teams were awarded:

- Technical University of Denmark (DTU) - 9 PSAT tags for their deployment in North Eastern Atlantic water (Eastern North Sea, Skagerrak, Kattegat and Øresund).
- Instituto Español de Oceanografía (IEO) in collaboration with Large Pelagics Research Center of the University of Massachusetts - 14 PSAT tags for their deployment in Western Mediterranean and off Atlantic USA coasts
- Institute of Marine Research (IMR) of Norway - 5 PSAT tags for their deployment in Norwegian waters
- The Marine Institute in collaboration with Dr. Barbara Block team (Stanford University) - 9 PSAT tags for their deployment in the coastal waters off Ireland
- Swedish University of Agricultural Sciences (SLU) - 9 PSAT tags for their deployment in Skagerrak, Kattegat or the Sound Strait
- Stanford University Hopkins Marine Station in collaboration with DFO (Fisheries and Ocean Canada) and Acadia University - 11 PSAT tags for their deployment in Canadian waters
- Stanford University Hopkins Marine Station in collaboration with “Asociación Catalana de Pesca Responsible” (ACPR), Tag a Giant (TAG) and Barcelona Zoo - 9 PSAT tags and 5 internal archival tags for their deployment off Canary Islands
- University of Genova - 5 PSAT tags for their deployment in Ligurian Sea
- Cefas Laboratory in collaboration with Exeter University - 9 PSAT tags for their deployment in the western English Channel, the Celtic Sea, within waters of Jersey and Guernsey (a UK Crown dependency) and off the west coast of Scotland

Technical University of Denmark (DTU) deployed, within the framework of the Swedish and Danish collaboration “Scandinavian Bluefin Marathon”, a variety of electronic and conventional tags on 133 ABFT (205 to 288 cm curved fork length (CFL)) in Skagerrak, Kattegat and Øresund during 15 tagging days between 21 August and 2 October 2021. All fish were tagged with an acoustic tag and a conventional tag, and a subset was also tagged with PSAT (of which 9 PSAT were provided by ICCAT GBYP) and accelerometer tags. Biological sampling was undertaken at the time of tagging through a fin clip for genetic analysis, a muscle biopsy and blood sample to explore the physiological status of each tagged individual. The report is available in Annex 1a, document no. 17.

The Institute of Marine Research in Norway deployed the tags along the coast of Norway between the 11 August and 6 October 2021. The major aims were to collect genetic samples of BFT and tag these with both pop-up satellite archival tags and conventional tags as far north as possible. Tagging was performed on-board a specially designed tagging vessel with an aluminium ramp to pull the fish on board. In total, nine BFT ranging from 244 cm to 292 cm (CFL) in length were tagged with PSATs and conventional tags, and genetic samples were collected. 5 of these tags were provided by GBYP. All fish were caught using rod-and-line and spreader bars as lures. The report is available in Annex 1a, document no. 18.

The Marine Institute carried the electronic tags deployment activities at the end of August and first two weeks of September 2021, with 14 individuals tagged and released with Wildlife Computers pop-off satellite archival tags (PSAT) (Table 2) and numbered spaghetti tags. However, presence and abundance of bluefin tuna in Irish waters was greatly reduced when compared to the previous tagging years. Scarcity of fish resulted in the Marine Institute tagging team being unable to deploy the 9 satellite tags provided by ICCAT GBYP, despite eight full day attempts to deploy these tags in the North-West and South of Ireland. The report is available in Annex 1a, document no. 19.

Swedish University of Agricultural Sciences (SLU) deployed a variety of electronic and conventional tags on 36 large (> 210 cm curved fork length) Atlantic bluefin tuna captured by volunteer rod-reel anglers in Skagerrak between 21 August and 5 September 2021. In total, they deployed 17 pop-up satellite archival tags, 9 of which were provided by GBYP. Additionally, sampling fin clippings was done for each tagged individual for genetic analysis and muscle biopsy to explore the physiological status. The report is available in Annex 1a, document no. 20.

Stanford University deployed a total of 13 ICCAT GBYP satellite tags in Canada 2021 campaign (12 WC PATs, 1 Lotek PSAT). These tags constituted 8 WC PATs and 1 Lotek PSAT from the 2021 MOU, and 2 WC PATs which were added, substituting 2 of the 3 Lotek tags, after the original agreement was made. The remaining 2 WC PATs that were deployed were initially awarded by GBYP to Stanford University under a MOU to carry out a campaign in Canary Islands in 2020, which was unfulfilled due to COVID-19 travel restrictions. In addition, during the Canada 2021 tagging campaign, 11 experimental Lotek PSATs were received by Stanford for deployment. Of the 11 tags received, 7 were deployed in Canada under the ownership of the Block lab, 1 was deployed under the ownership of ICCAT GBYP according to the 2021 MOU, and the remaining 3, also owned by ICCAT GBYP, were shipped to Ireland to be finally deployed in Celtic Seas under another of the MOUs signed by ICCAT GBYP under GBYP Phase 11 in relation to E-tagging activities, specifically with the Irish Marine Institute. Moreover, the campaign was also carried out in North Carolina, despite the fact that it is was not formally included under the aforementioned MOU signed in relation to Canada 2021 campaign, under which 3 WC PATs deployed from the unfulfilled 2020 Canary Island MOU, and 2 Lotek archival tags deployed were from the current 2021 Canary Island MOU allocation. The report is available in Annex 1a, document no. 21.

Cefas and Exeter University, as part of the Thunnus UK and FISH-INTEL projects, deployed 51 electronic tags on ABT (125 to 243 cm curved fork length, CFL; mean ± 1 S.D. = 191 ± 26 cm) off southwest England (n=44) and the Channel Islands (n=7). Of these, 6 pop-up satellite archival tags (MiniPATs) were provided by GBYP. Two vessels fished for 31 days between 1 August and 15 November 2021 from Falmouth (England) and an additional vessel fished for 7 days from Jersey in the Channel Islands. ABT were caught by experienced anglers by trolling surface lures and brought to the tagging vessel as quickly as possible to avoid harm. Biological sampling was undertaken at the time of tagging in the form of a fin clip for genetic analysis and a muscle biopsy. The report is available in Annex 1a, document no. 16.

In 2021 GBYP had agreed with Mediterranean Fisheries Research, Production and Training Institute (MEDFRI) from Türkiye, for deployment of 20 electronic tags in Levantine Sea, near Antalya, since tagging in Levantine Sea has been identified as one of the priorities by the Steering Committee since 2019. Unfortunately, it was not possible finally to sign the MoU and carry out the campaign due to mobility restrictions derived from the Covid pandemic. Finally, in June 2022 it was possible to carry out the campaign, within the framework of a MoU signed to this end, in close collaboration with local scientists (MEDFRI). Two expert taggers were also hired by GBYP to help with the deployment of tags and GBYP Coordinator supervised the whole operation. The campaign took place in June 2022, and finally 13 tags were successfully deployed. Tagged fish had been caught after the commercial fishing operations by commercial purse seine fishing vessel boat and kept in a towing cage until the tags' deployment took place. The report is available in Annex 1a, document no. 22.

In addition to formal agreements, GBYP also supported tagging activities by the Italian branch of WWF Mediterranean Marine Initiative, which deployed 2 electronic tags in the Western Mediterranean. GBYP covered the cost of their satellite transmission and the corresponding data have been directly integrated into the GBYP database.

Currently available electronic tag tracks from the tags deployed by GBYP are shown on **Figure 4.** In addition to these tags, GBYP also acquired numerous e-tags datasets from other tagging programs through its data recovery activity. Namely, these include tags deployed by Stanford University (Hopkins Marine Station, Block Lab), Large Pelagics Research Center and WWF. The complete tracks currently available in the GBYP repository are shown on **Figure 5**. The electronic tags datasets are being used in MSE for determination of BFT stocks mixing rates.

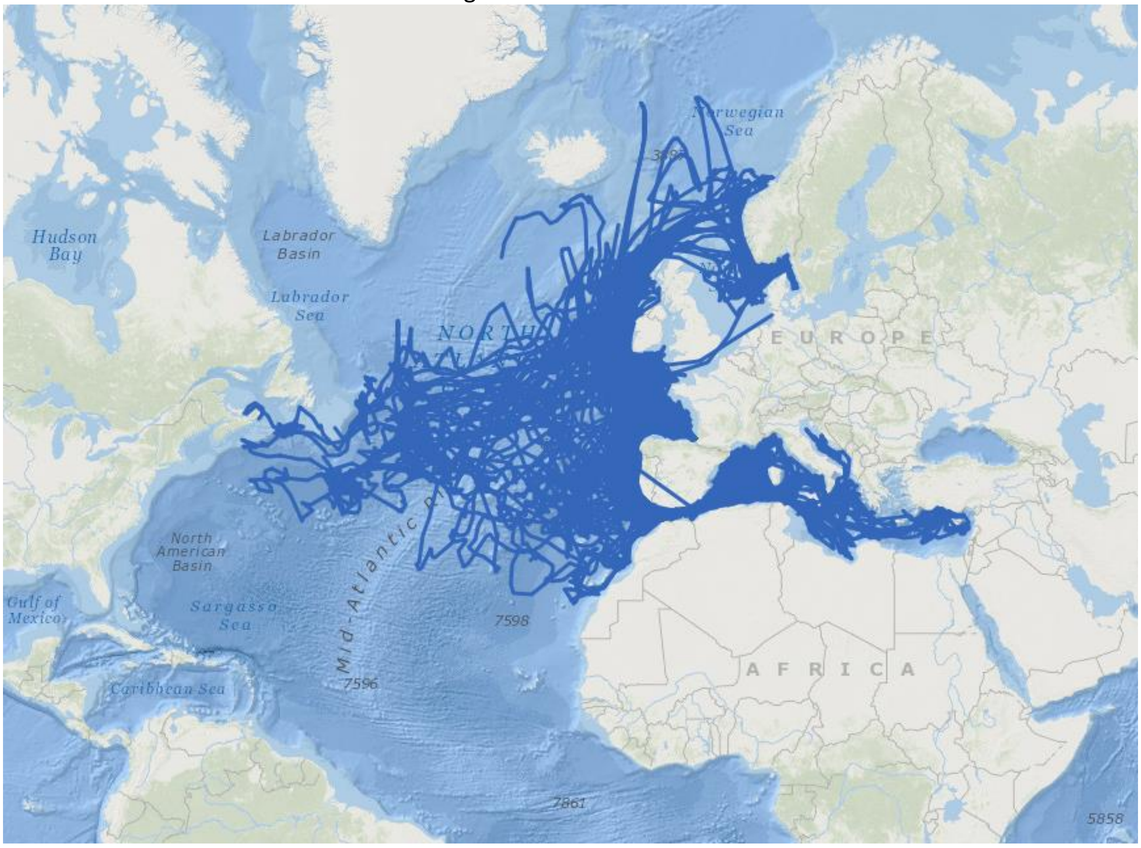

Figure 4. Currently available electronic tag tracks, for tags deployed by GBYP up to 2021

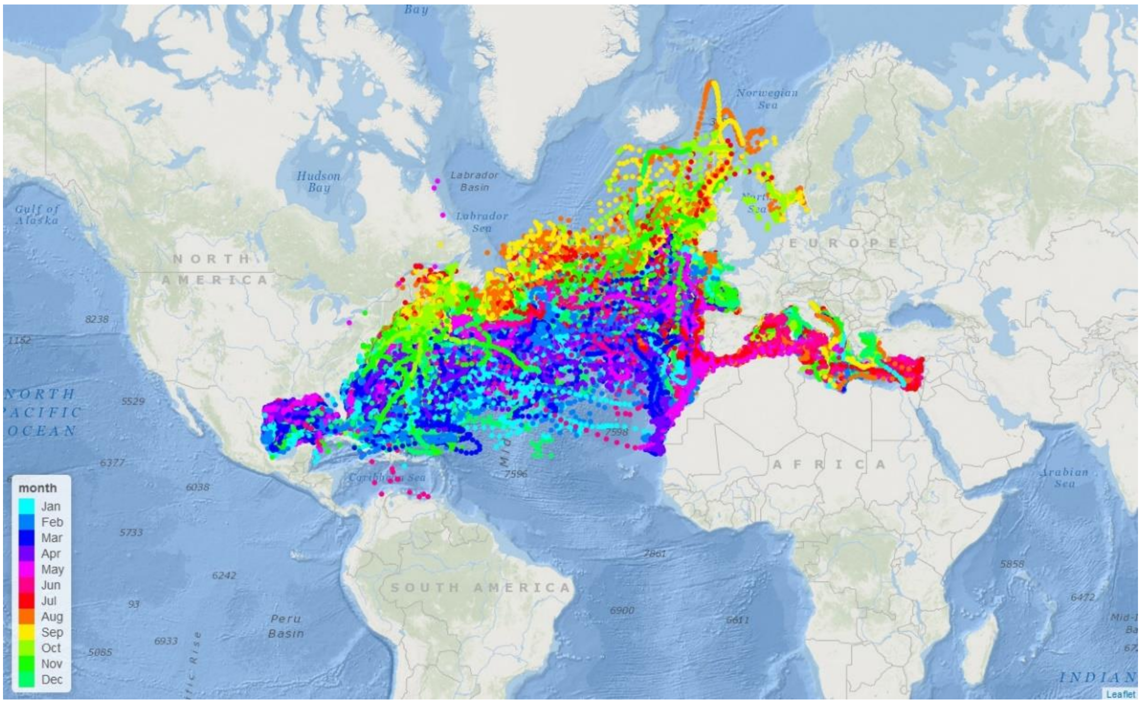

Figure 5. Currently available electronic tags tracks, for tags deployed by GBYP and acquired through data recovery activity from other programs. Daily positions are colored by month.

Besides the activities carried out under formal GBYP contracts or agreements, GBYP has supported e-tagging activities carried out independently by other institutions, by allowing the use of GBYP RMA in case of BFT casualties during tagging operations.

As regards conventional tags, within Phase 11 "spaghetti" tags, along with applicators and the tagging protocols and forms to report tagging operations were delivered to various institutions (**Table 3**). In addition, conventional tags and related equipment was also delivered to the teams in charge of satellite tags deployment, since in this phase they have been asked to carry out a double tagging whenever possible, implanting conventional tags besides the satellite tags.

Table 3. Number of conventional tags sent to different collaborators in Phase 11 (from March 2021 until March 2022)

Country	Institution	Conventional tags (number)
United Kingdom	Centre for Environment Fisheries and Aquaculture Science	1400
Norway	Institute of Marine Research	250
EU-Spain	Instituto Español de Oceonografía	300
EU-Ireland	Marine Institute	1575
EU-Denmark	Technical University of Denmark	200

In Phase 11, a total of 1388 tags were deployed on 1311 bluefin tuna individuals (**Table 4** and **5**). The level of tagging was much lower than in the beginning of the Programme, since the conventional tagging was cancelled by the Steering Committee in Phase 4, keeping it only as a complementary activity. In total, from the beginning of the Programme up to 1 March 2021, more than 24 thousand bluefin tuna individuals were tagged, using more than 32 thousand tags of different types (**Table 6** and **7**).

Table 4. Number of fish tagged during Phase 11 (from March 2021 until March 2022)

	ALL FISH TAGGED	FISH SINGLE TAGGED			FISH DOUBLE TAGGED		
		FT-1-94	FIM-96 or BFIM-96	Mini-PATs	Double Tags - Conventional	Mini-PATS + Conv.	Archivals + Conv.
Canada	13	0	0	0	0	13	0
West Med.	9	9	0	0	0	0	0
Central Med.	101	100	1	0	0	0	0
East Med.	23	10	0	0	0	13	0
North and Celtic Seas	1151	134	971	9	17	20	0
Canary Islands	9	0	0	0	0	9	0
Northwest Atlantic	5	0	0	0	0	3	2
TOTAL	**1311**	**253**	**972**	**9**	**17**	**58**	**2**
		1234			**77**		

Table 5. Number of tags implanted during Phase 11 (from March 2021 until March 2022)

	TOTAL NUMBER OF TAGS	TAGS IMPLANTED			
		FT-1-94	FIM-96 or BFIM-96	Mini-PATs	Archivals
Canada	26	13	0	13	0
West Med.	9	9	0	0	0
Central Med.	101	100	1	0	0
East Med.	36	23	0	13	0
North and Celtic Seas	1188	165	994	29	0
Canary Islands	18	9	0	9	0
Northwest Atlantic	10	5	0	3	2
TOTAL	**1388**	**324**	**995**	**67**	**2**

Table 6. Number of fish tagged since the beginning of GBYP (up to 1 March 2022)

	ALL FISH TAGGED	FISH SINGLE TAGGED					FISH DOUBLE TAGGED						
		FT-1-94	FIM-96 or BFIM-96	Mini-PATs	Archivals	Acoustic	Double Tags - Conventional	Mini-PATS + Conv.	Mini-PATS + 2Conv.	Mini PAT+ Acoustic+ Conv.	Archivals + Conv.	Archivals + 2Conv.	Acoustic + Conv.
Canada	2162	0	2139	0	0	0	0	23	0	0	0	0	0
Bay of Biscay	7718	4173	15	3	0	0	3493	18	0	0	16	0	0
Morocco	365	129	48	45	0	0	121	14	0	7	0	0	1
Portugal	347	53	39	94	0	0	154	7	0	0	0	0	0

Strait of Gibraltar	5561	2254	43	0	0	0	3212	22	5	0	23	2	0
West Med.	1843	1081	377	28	0	0	352	5	0	0	0	0	0
Central Med.	3509	1264	1707	32	0	0	479	15	0	0	12	0	0
East Med.	122	59	0	50	0	0	0	13	0	0	0	0	0
North and Celtic Seas	2445	475	1744	13	0	0	101	71	36	0	5	0	0
Canary Islands	10	0	0	0	0	0	0	9	0	0	1	0	0
Northwest Atlantic	5	0	0	0	0	0	0	3	0	0	2	0	0
TOTAL	**24087**	**9488**	**6112**	**265**	**0**	**0**	**7912**	**200**	**41**	**7**	**59**	**2**	**1**
		15865						**8222**					

Table 7. Number of tags implanted since the beginning of GBYP (up to 1 March 2022)

	TOTAL NUMBER OF TAGS	TAGS IMPLANTED				
		FT-1-94	FIM-96 or BFIM-96	Mini-PATs	Archivals	Acoustic
Canada	2185	13	2149	23	0	0
Bay of Biscay	11245	7700	3508	21	16	0
Morocco	515	258	183	66	0	8
Portugal	508	182	225	101	0	0
Strait of Gibraltar	8618	5491	3075	27	25	0
West Med.	2199	1434	732	33	0	0
Central Med.	3915	1743	2113	47	12	0
East Med.	135	49	0	50	0	0
North and Celtic Seas	2695	646	1924	120	5	0
Canary Islands	20	10	0	9	1	0
Northwest Atlantic	10	5	0	3	2	0
TOTAL	**32045**	**17531**	**13909**	**500**	**61**	**8**

4.3.2. Tag recoveries

a) Tag awareness and reward policy

This activity is considered essential for improving the low tag reporting rate existing so far in the Eastern Atlantic and the Mediterranean Sea. The tag awareness material was produced in 12 languages, considering the major languages in the ICCAT convention area and those of the most important fleets fishing in the area: Arabic, Croatian, English, French, Greek, Italian, Japanese, Mandarin, Portuguese, Russian, Spanish and Turkish. Several thousands of posters of various sizes (A1, A3 and A4) and stickers were produced so far and distributed to all major stakeholders, such as Government Agencies, scientific institutions, tuna scientists, tuna industries, fishers, sport fishery federations and associations in the area. In addition, in 2016 two short propaganda videos on ICCAT GBYP tagging activities were produced, which are available in 8 languages through YouTube.

The ICCAT GBYP tag reward policy has been considerably improved since the beginning of the program, with the purpose of increasing the tag recovery rate. The current strategy includes the following rewards: 50€/ or a T-shirt for each spaghetti tag; 1000 € for each electronic tag; annual ICCAT GBYP lottery (September): 1000 € for the first tag drawn and 500 € each for the 2nd and 3rd tag drawn. According to the recovery data, this policy (along with the strong tag awareness activity) was very useful for improving the tag reporting rate.

For further improving the results, meetings with ICCAT ROPs have been organized periodically, further informing them about the ICCAT GBYP tag recovery activity and asking them to pay the maximum attention to tags when observing harvesting in cages or any fishing activity at sea, which have resulted in an increase of recoveries by ICCAT observers in farms.

b) Tag recovery and reporting

The important tag reporting improvement registered after the beginning of the tagging and tag awareness activities by ICCAT GBYP is impressive. So, the average ICCAT recoveries for the period before 2010 were much lower than during GBYP, as shown in the **Figure 6**. The first significant increase in the rate of the tag recoveries was recorded from 2012. Such a success should probably be attributed, not only to the recent tagging activities, but to the settled tag awareness campaign as well. In the year 2021, a total of 163 tags were recovered. It should be stressed that, in last couple of years, for the first time in ICCAT bluefin tuna tagging activities, the number of tags recovered and reported from the Mediterranean Sea has been higher than any other area. Considering that reported tags from the Mediterranean were almost nil before GBYP, this is the clear evidence that GBYP tag awareness campaign is producing positive effects.

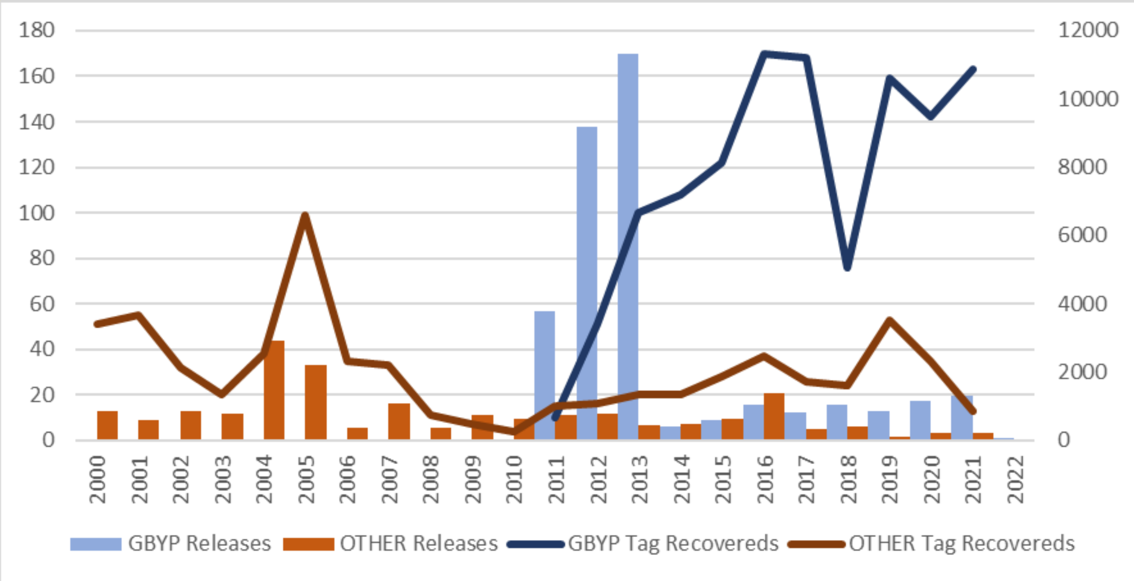

Figure 6. Annual trend of bluefin tuna tag recoveries reported to ICCAT since 2002 (up to 1 March 2022)

As for the study of conventional tags shedding rate, 534 tags were recovered from 357 double tagged fish (up to 1 March 2022). According to the results (**Table 8.**), it seems that both types of tags (single barb and double barb) are more or less equally resistant, with the slight better resilience for the double barb.

Table 8. Tag recoveries from double tagged fish by type (up to 1 March 2022)

Release	Spaghetti tag only	Double Barb Tag only	Both	TOTAL FISH	TOTAL TAGS
2011	8	9	13	30	43
2012	20	35	57	112	169
2013	36	46	86	168	254
2016	1	2	1	4	5
2017	7	14	15	36	51
2018	0	1	2	3	5
2019	0	0	0	0	0
2020	0	1	3	4	7
2021	0	0	0	0	0

2022	0	0	0	0	0
Total N	**72**	**108**	**177**	**357**	**534**
Total percent	**20%**	**30%**	**50%**		

4.4. Biological Studies

One of the core activities of ICCAT GBYP are the so-called Biological Studies, which ICCAT GBYP started in 2011, maintaining a biological sampling programme covering the main bluefin fisheries and funding a series of studies based on the analysis of these samples, as microchemical and genetics analyses to investigate mixing and population structure, with a particular attention to the age structure and the probable sub-populations identification. Bluefin tuna biological samples are stored in the GBYP Tissue Bank, which is maintained by AZTI.

The general objectives of the Biological Studies initially stated for Phase 11 were:
-Maintain an GBYP tissue bank capable of providing the samples required to carry out the studies necessary for improving the understanding of key biological and ecological processes affecting BFT, particularly stock piling samples that can be used for eventual close-kin mark recapture or other population-level genomics studies.
-Update the estimation of key biological parameters and population age structure required for BFT stocks evaluation and management.
-A better understanding of the BFT population genetic structure particularly in light of recent advances in genomic techniques and insights.
-Provide accurate and reliable estimates of mixing rates between Atlantic BFT populations (western and eastern stocks in the different statistical areas throughout along the year cycle.
-Develop and/or refine methodologies based on microchemical analyses allowing to determine the timing of relevant biological traits throughout the whole life cycle, such as migrations to spawning areas.
-Design and implement an Information System allowing a proper management of the samples and data generated by the biological studies, integrating not only metadata on sampling and analytical tasks, but whenever possible, the results from such analyses.

In addition, in order to guarantee the availability of a sufficient number of biological samples of adult bluefin tuna, in Phase 11, a dedicated sampling was performed in farms, for fish captured in the Balearic Sea, in the Southern Tyrrhenian Sea and in the South-Central Mediterranean Sea.

4.4.1. Biological sampling and analyses

As done in previous GBYP phases, a call for tenders was issued for maintenance and management of ICCAT GBYP Tissue Bank, collecting tissue samples and otoliths and performing analyses – both microchemistry analyses of otoliths and genetic analyses of tissue samples. Two offers were received and after their evaluation, the contract was awarded to AZTI, as leader of a Consortium which included 8 more institutions. In addition, a call for tenders was published for sampling of adult bluefin tuna individuals in farms. Four offers were received for this concept, out of which two were awarded a contract. Taxon Estudios Ambientales SL was contracted for sampling 300 individuals fished in the Balearic Sea and AquaBioTech was contracted for sampling 300 individuals from the South Tyrrhenian Sea and other 300 from the Central/Southern Mediterranean Sea.

The activities in Phase 11 were mostly directed to enhance knowledge about Atlantic bluefin tuna population structure and mixing, but also to focus on age dynamics, in order to improve stock assessment and manage advice. Population structure is a key uncertainty for BFT, given the possibility that more than two subpopulations/contingents coexist in the Atlantic, while ICCAT manages so far assuming two separate populations with no mixing. This is in contrast with the fact that the stock structure assumed for stock assessment and management purposes must be in line with real population structure. If not, overfishing of less productive populations and under exploitation of most productive ones can occur.

On population structure, one of the most important uncertainties to resolve is related to the understanding of the implications of the new spawning ground detected in the Slope Sea (Richardson et al 2016). Therefore, the genetic analysis of individuals caught in the Slope Sea was performed, in order to shed light on whether they represent a different population, or a subgroup using a different spawning ground of the already identified populations. Moreover, it must also be considered that few BFT larvae were recently identified in the Bay of Biscay by IEO researchers. Given the potential implications of such findings, there is a need to assess the volume and persistence of BFT larvae in this area, and hence a sampling of fish larvae in the Bay of Biscay was performed, in search of BFT specimens, taking advantage of the yearly AZTI acoustic survey. In addition, the population structure of Atlantic BFT might be more complex than previously thought if contingents with different migratory behaviours exist, as suggested by some results obtained during Phase 8. On top of that, mixing is an issue given the highly migratory behaviour of bluefin tuna, and it is important to know the origin of the individuals that are caught so as to properly assess and manage populations, especially if mixing occurs on some important fishing grounds. During the construction of the Management Strategy Evaluation (MSE) framework for BFT, the importance of the mixing data has been stressed several times. While constructing the Operating Models, it seemed that the observed (while partial) stock composition data can only be explained if the western stock is not as small (compared to the east) as predicted by the stock assessment. On the other side, if the stock sizes simulated in the Operating Models are inconsistent with those of the stock assessment, it might be hard to accept the MSE exercise to decide on a Management Procedure for the future management of bluefin tuna. Thus, it is of outmost importance to focus on the mixing analyses to provide accurate information and clear alternative hypotheses to the MSE process. Finally, an activity of gathering and sorting of biological material (BFT larvae from the Balearics) was performed, that can be used in future genetic analyses.

Thus, the level of biological sampling was comparable to that of Phase 10, focusing mainly on the Atlantic subregions where mixing potentially occur, such as Central Atlantic, Canary Islands and Morocco. The main objective of the proposed sampling scheme was to complete the sampling conducted in previous Phases in order to provide the necessary material (in terms of sample number and quality) for the various types of analyses envisaged in this and future Phases of the GBYP program. Regarding sampling for constructing the age length key, which was one of the priorities identified by the Bluefin Species Group, the focus was collecting of hard parts of under-represented strata from previous years, with emphasis on Atlantic areas and Gibraltar. Sampling of adults in Mediterranean farms was performed as well.

The final reports are available in Annex 1a, documents no. 5-7. The main specific activities carried out in relation to biological sampling and analysis of biological samples and their more relevant results are summarized below:

a) Biological sampling

During Phase 11, following sampling protocols agreed in earlier Phases, the Consortium sampled a total of 452 Atlantic bluefin tuna (129 YOY, 1 juvenile fish, 47 medium sized fish and 275 large fish) from different regions (140 from the Strait of Gibraltar, 41 from Portugal, 34 from the Canary Islands, 180 from Norway, 22 from the Central North Atlantic, 34 from the South of Spain and 1 from the Bay of Biscay). In total, 1067 biological samples (309 otolith samples, 307 fin spines and 451 genetic samples) were collected by the Consortium and incorporated into the tissue bank. The Consortium also received samples from other ICCAT contracts with tagging teams and farm operators. In total, the Consortium handled 3198 biological samples (1046 otolith samples, 995 fin spines and 1157 genetic samples) from 1189 individuals. All these samples have been catalogued and stored together in the biological tissue bank. The total number of bluefin tuna individuals and samples collected in the Phase 11 is shown in **Table 9**.

In addition, tissue bank and related information system has undergone a restructuring process to revise and standardize all the information gathered over the last 10 years of the project , with the ultimate goal of creating a database with an interface that is easily manageable for any user who requires it. To this end, the existing database in Excel has been cleaned and structured. The revision, standardization, and cleaning of all the available information to date is being continuously updated. Steps are being taken to bridge the gap between the biological information of each bluefin tuna and the results obtained in the different analytical tasks. In addition, the sampling protocol and sampling sheet have been updated to meet the current working needs, as the previous one had become a bit outdated. It is expected that it can be distributed soon.

Table 9. Total number of bluefin tuna sampled in Phase 11 by area and size class

		Size-class sampled				
		Age 0	Juvenile	Medium	Large	
		<3 Kg	3-25 Kg	26-100 Kg	>100 Kg	TOTAL
North Sea	Norway	0	1	0	179	180
Central North Atl.	Central North Atl.	0	0	1	21	22
Northeast Atlantic	Bay of Biscay	0	0	1	0	1
	Portugal (Algarve)	0	0	0	41	41
	Canary Islands	0	0	0	34	34
Strait of Gibraltar	Gibraltar	95	0	45	0	140
Western Med.	South Spain	34	0	0	0	34
	Balearic Islands	0	0	4	335	339
	Tyrrhenian Sea	0	0	10	41	51
Central Med.	Malta	0	0	24	323	347
	TOTAL	**129**	**1**	**84**	**975**	**1189**

b) Biological analyses

The most relevant results from each type of analysis are summarized below:

Otolith microchemistry

Within Phase 11, the baseline for Mediterranean vs. Golf of Mexico origin was improved, by combining stable isotope and trace element analyses. Besides, the area of otolith transverse sections best discriminating between two stocks was identified. In all otoliths analyzed, Sr and Ba concentrations were lower during the early life stages in both Mediterranean and Gulf of Mexico bluefin tuna. A cyclicity in Sr and Ba concentrations was visible in most of the otoliths, presumably related to seasonal migrations between water masses. In contrast, Mg and Mn concentrations were highest at early life stages, and an abrupt decrease was observed after the first year. The results are concordant with previous findings showing that incorporation of Mn into fish otoliths is sensitive to growth and Mg concentration reflects metabolic activity of fish. A cyclicity in Mn concentration was observed in some individuals, although Mn banding was attenuated with time. Differences in Mn patterns among individuals could be explained by different ecological strategies adopted by individual tuna. As a result, an effective neural network application was developed to classify otoliths, which successfully predicted the origin of bluefin tuna with a classification accuracy of 98%. As a conclusion, two-dimensional mapping of trace elements allows a refined identification of individual bluefin tuna origin, which can serve to answer ecological questions, such as controversies between genetic and otolith stable isotope data. Moreover, two-dimensional mapping of trace elements reveals spatial heterogeneity across the otolith sections allowing to identify fluctuations in specific tracers, such as Sr, Ba and Mn that would not be evident from single transects. The examination of elemental patterns in a two- dimensional scale contribute to a greater appreciation of otolith composition, which translates into increased understanding about stock dynamics, migration patterns or connectivity between habitats of bluefin tuna.

Regarding otolith microchemistry, the results from previous phases suggested that western origin contributions were negligible in the Mediterranean Sea, Bay of Biscay and Strait of Gibraltar, but mixing rates could be considerable, in some years, in the central North Atlantic, Canary Islands and western coast of Morocco. To further assess the spatial and temporal variability of mixing proportions, new carbon and oxygen stable isotope (δ13C and δ18O) analyses were carried out in 119 otoliths of Atlantic bluefin tuna captured in Central North Atlantic, Norwegian Sea and western Moroccan coast. This task builds on prior research carried out under the GBYP program, and by increasing the sample size, the interannual variations of mixing rates in the North Atlantic Ocean are better understood.

Otolith δ18O and δ13C values corresponded well with those measured in yearling otoliths from the eastern (Mediterranean) and western (Gulf of Mexico) nurseries. Previous otolith chemical analyses indicated that individuals from both production zones readily cross the 45°W management boundary and mixing of the eastern and western population occurs throughout the North Atlantic Ocean. Mixing proportions were found to be important particularly in the western side of the Atlantic Ocean. In 2018, otolith δ13C and δ18O values from this region were comprised almost entirely by the eastern (Mediterranean) population. The data suggest that the presence of western migrant is minor, and therefore, Mediterranean population is the main component of Japanese fisheries operating east of the 45ºW management boundary. Regarding the samples from the Norwegian Sea, the results showed that Mediterranean population may be the only contributor to the Norwegian fisheries. As for the north-west African coast (Moroccan traps), it has been identified as a putative mixing area of eastern and western populations. The contribution of western individuals to the east Atlantic fisheries is of particular interest to resource managers because of the strong asymmetrical production between the two populations. Based on the stable isotope markers, the results indicate that in 2019, bluefin tuna captured by Moroccan traps were entirely of Mediterranean origin. The combination of all the isotope values analyzed under the GBYP program suggest that the Mediterranean population is the main contributor to Moroccan fisheries, and that the contribution of western migrant in this region is a sporadic phenomenon (**Figure 7** and **8**).

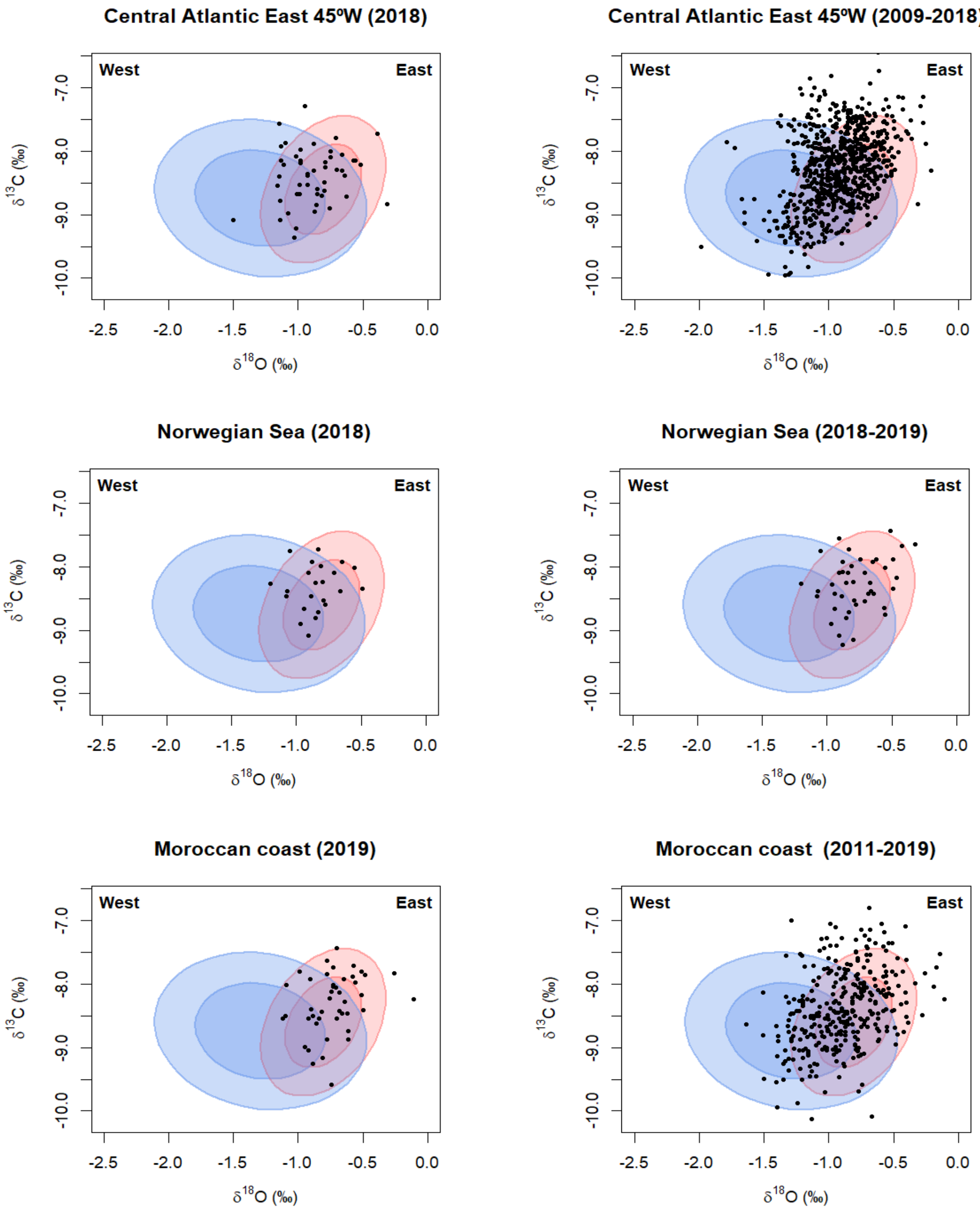

Figure 7. Confidence ellipses (1 and 2 SD or ca. 68% and 95% of sample) for otolith δ13C and δ18O values of yearling bluefin tuna from the east (red) and west (blue) nurseries along with the isotopic values (black) for otolith cores of bluefin tuna of unknown origin collected from three locations during the current GBYP Phase 11 (left) and during previous GBYP Phases (right).

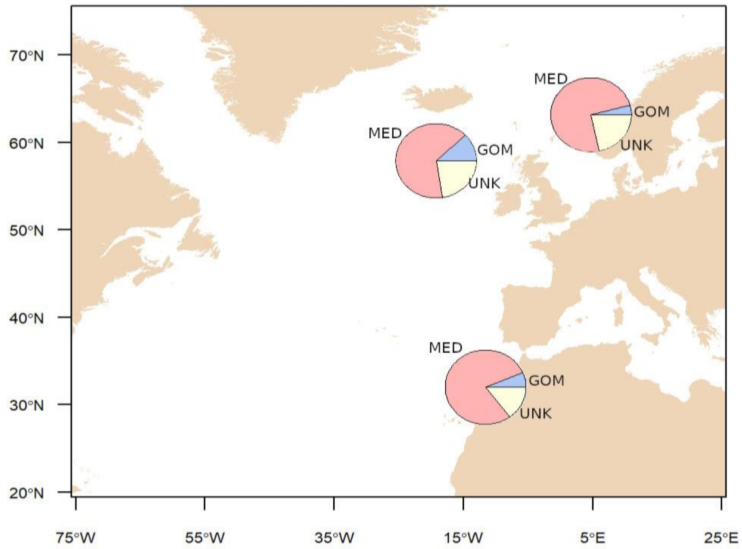

Figure 8. Origin of bluefin tuna (Thunnus thynnus) captured in Norwegian Sea, central North Atlantic and Moroccan coast analyzed during GBYP Phase 11. Individual origin assignments are estimated using Quadratic Discriminant Function Analysis with adult spawners as reference samples

Additionally, otolith δ18O measurements using high-precision secondary ion mass spectrometry (SIMS) and isotope ratio mass spectrometry (IRMS) were cross-calibrated. IRMS measurements of δ18O were linearly related to δ18O from the same otolith portion, obtained using SIMS (IRMS δ18O = 0.36*(SIMS δ18O) +0.25; R2 =0.63). This regression can be used to convert SIMS measurements to their equivalent IRMS measurements, allowing for comparison across studies and integration of information from both techniques.

Finally, good progress has been made during this phase to conduct a tagging experiment on Atlantic bluefin tuna held within a farm. This experiment could provide information about the relationship between otolith δ18O and environmental conditions and the influence of internal physiology on that relationship and could be used to validate the periodicity of annual growth bands in the otolith. Ten archival tags were purchased and planning for future deployment in a tuna farm in Malta commenced. Otolith δ18O profiles from tagged fish for the period of captivity can be related to internal and external temperature profiles from the tags to parameterize the relationship between δ18O and water chemistry, and to examine the influence of internal physiology.

Genetic analyses

Previous research had shown that population structure of Atlantic Bluefin tuna (ABFT) is more complex than the previous assumption of two reproductively isolated populations (Gulf of Mexico and Mediterranean Sea) that mix for feeding in the Atlantic, and that, contrastingly, individuals from the Gulf of Mexico and Mediterranean Sea interbreed. Yet, the frequency in which this interbreeding occurs in still unknown. Understanding the phenomena driving existing genetic differentiation between the Gulf of Mexico and Mediterranean populations despite this interbreeding is paramount for developing appropriate management and conservation measures. To further understand the phenomena driving genetic differentiation despite gene flow, the mixing and interbreeding dynamics of ABFT, and to evaluate the potential epigenetic approaches for ageing in ABFT samples, five main tasks have been carried out:

Task 1 has consisted of new data generation by extracting new DNA samples of > 600 individuals, the improvement of the 96 SNP traceability panel by replacing the least informative markers by 10 newly selected ones (including 3 genetic markers for sex identification), and the genotyping of 564 and 384 individuals using the improved 96 SNP traceability panel and the SNP array respectively. The 96 SNPs traceability panel has successfully been improved by including seven markers more informative for assignment than those that were removed. The increased number of genotyped individuals provided with an enlarged reference dataset, which reflects better the genetic variability of the Atlantic bluefin tuna and allowed to select better SNP markers for genetic origin traceability.

Task 2 has consisted of the analysis of ABFT population structure using three different datasets: a Copy Number Variants (CNVs) dataset obtained from the re-analysis of the available RAD-seq data, the analysis of Whole Genome Sequencing data produced for 25 and 2 ABFT and Thunnus alalunga individuals respectively, and the analysis of > 700 samples genotyped using the SNP array. Regarding the population structure, the results confirm presence of two ancestry genetic profiles. Samples from the eastern side of the Atlantic (including feeding aggregates) are predominantly Mediterranean-like, whereas samples from the Western side are mostly Gulf of Mexico like (those from the Gulf of Mexico) or cover a wide range of profiles (Western and Central Atlantic). Genetic origin of 640 samples genotyped using the SNP array based on neutral markers are shown on **Figure 9**. Additional conclusions on the population structure of will be derived from an integrated view when results from whole genome sequencing are available.

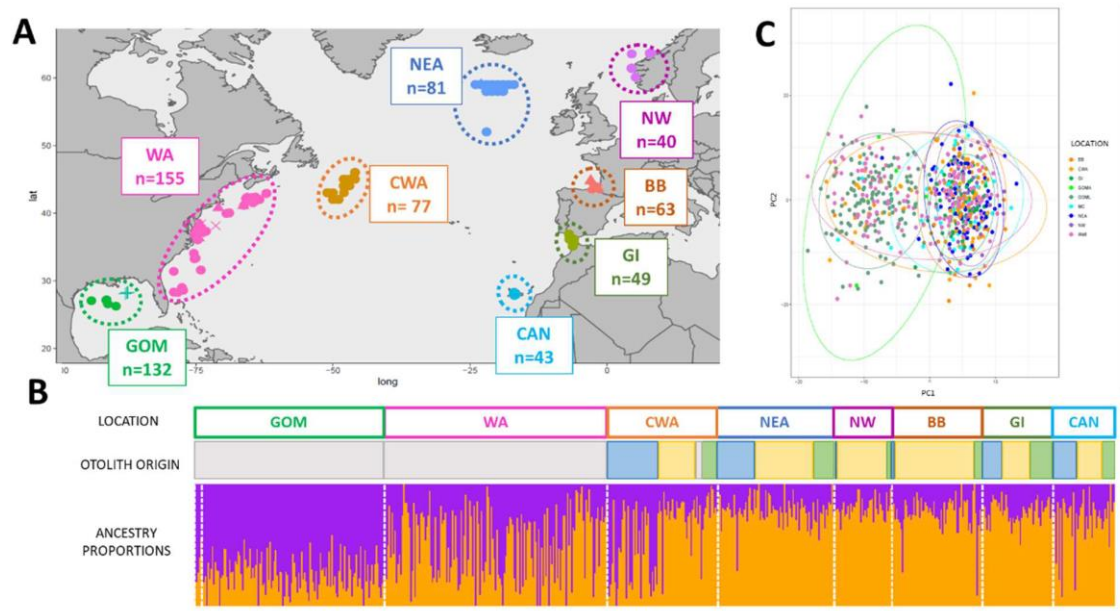

Figure 9. Genetic origin of genotyped samples: **A.** Catch locations of genotyped samples, where each dot represents one individual and the different colors represent different locations (GOM=Gulf of Mexico, WA= West Atlantic, CWA= Central West Atlantic, NEA= North East Atlantic, NW = Norwegian Sea, BB =Bay of Biscay, GI=Strait of Gibraltar, CAN= Canary Islands). Crosses within the GOM represent larvae samples. **B.** Individual proportions from each of the two ancestral populations of Atlantic bluefin tuna. Catch locations are indicated, and origin assigned based on otolith microchemistry (otolith origin) is indicated for each sample in blue is assigned to the Gulf of Mexico), yellow when assigned to the Mediterranean Sea) and green if unassigned. Samples for which otolith origin was not available are represented in grey. **C.** PCA performed using the same dataset shows that genetic diversity of all samples is explained by distribution of samples in two main clusters and several intermediate individuals.

Task 3 has consisted of the analysis of genetic variability at different feeding aggregates by combining genetic information based on different types of markers with otolith microchemistry data. The results showed that some samples were assigned to different origin based on otolith microchemistry and genetic markers, where the most common mismatch is Mediterranean genetic profile and Gulf of Mexico otolith origin. These individuals could correspond to individuals of Mediterranean origin performing early (yearling individuals) departures from the Mediterranean Sea, or to individuals of different origin, such as alternative spawning areas used by eastern individuals, such as the Bay of Biscay. Analysis of individuals genetic profile suggests weaker and stronger stock mixing within the Eastern and Western stocks, respectively, than that concluded from otolith origin data. Final conclusions on the populations mixing behavior in foraging areas will be derived from an integrated view when genotyping results of 470 individuals with the final 96 SNP panel are available.

Task 4 has consisted of the evaluation of the performance of the genetic sex markers included in the SNP array and the 96 SNP traceability panel for sex identification using genetic tools. Genetic markers for sex identification were successfully included in the origin traceability panel and genetic profile array, with a success rate of 80,55% with the SNP array and 89% with the 96 SNP panel. Comparison of the most frequent genotype combination in visually identified female and male individuals obtained with both methods show some differences with the expected outcomes, as shown on **Table 10**. It should be further tested if the percentages of misassigned samples are due to a visual misidentification or to a failure of the genetic method.

Table 10. List of designed genetic markers adapted from (Suda et al. 2019). Expected genotypes for males (M) and females (F) according to the descriptions in Suda et al. (2019) and obtained genotypes considering the majoritarian genotype combinations for samples from each visually identified sex using markers adapted to the SNP array and the 96 SNP panel.

	Expected from Suda *et al.* 2019		SNP array		96 SNP panel	
	M	F	M	F	M	F
SEX_IA	GG	TT	GG	TG	-	-
SEX_IB	CC	TC/TT	CC	TT	CT	TT
SEX_IIA	AA	TT	-	-	AT	TT
SEX_IIB	TT	CC	TC	CC	CC	CC
SEX_III	-/-	TAATGTA/TAATGTA	-/-	TAATGTA /-	TAATGTA/-	TAATGTA / TAATGTA

Task 5 has consisted of an evaluation of the potential of epigenetic approaches for ageing of Atlantic bluefin tuna samples to be applied for the Close-Kin Mark Recapture studies, based on a in depth review of available bibliography. It was concluded that the development of an epigenetic clock in Atlantic bluefin tuna requires a sampling scheme that ensure good representation of the species population in terms of environment, genetic component, sex and age classes. The samples used in the development and testing of the method will be aged using otolith ring count analyses, which could bias the results if this ageing method is not considered accurate. The method for CpG site identification should ensure that the best set of informative markers is found and for that aim the reduced representation or whole genome sequencing are the best approaches. Since the error rates from previous studies are high for the oldest specimens, using a large set of training samples, a good chronological ageing method and a large set of CpG sites would probably reduce this error. It should be further evaluated if the expected error rates (based on previous studies on long lived species) are compatible with the application of the CKMR and if the reduced cost and logistics implied in epigenetic clock ageing compensate the implicit error rates.

Ageing related analysis

The description of the life cycle and effective management requires comprehensive age and growth studies. One of the most widely used methods for estimating the age of ABFT has been based on the examination of calcified structures. Direct age assignment depends not only on the number of annuli found in the calcified structure, but also on the periodicity of annuli formation. In order to transform the band count into ages it is necessary to consider the marginal edge type related to the catch date and the birth date.

In Phase 11 a determination of annual periodicity in annuli formation in Atlantic bluefin tuna otoliths has been carried out. The periodicity of annuli formation is commonly determined by marginal increment analysis in which the distance from the growth annulus to the edge of the otolith is tracked over time. This method requires a good representation of observations throughout the year to detect any seasonality trend in the formation of growth bands.

Controversies remain regarding the periodicity, or seasonality, of otolith growth band formation which directly influences a correct age determination of Atlantic bluefin tuna using otoliths. Thereby, the aim of this work was to apply marginal increment analysis (MIA) and marginal edge analysis to determine the timing of band deposition. The index of completion (MIA) was also analyzed using General Additive Models (GAMs) to evaluate the importance of variables such as month, age/size, reading criteria, light type and reader.

Results indicated that the opaque bands begin to form in July and continue to form up until October. The translucent band starts to form in November and peaks in May and June, with the highest percentage of wide translucent bands (**Figure 10**). GAM model indicated that the opaque band would finish forming in November. From the end of the year and the beginning of the following year there is minimal marginal edge growth, and this is when the translucent band begins to form and reaches its maximum development in June. MIA and marginal edge analyses have evidenced that the annulus in the Atlantic Bluefin tuna otolith start to be formed in November. This would mean to delay the date of the current July 1st adjustment criterion to November 30. The change in the date of the otolith fitting criterion allows for a better outline of the strong 2003-year class (**Figure 11**). Age results based on otolith counts have been updated accordingly in the ICCAT catalogue, which also allowed to obtain a new growth curve (**Figure 12**).

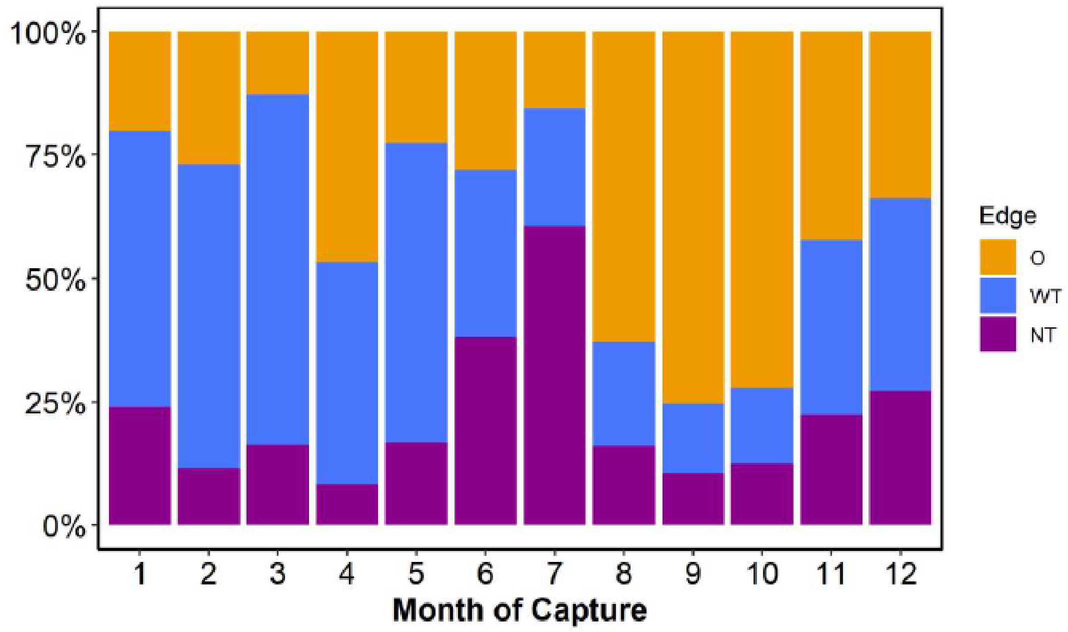

Figure 10. Percent edge type by month. Legend indicates opaque bands (O), narrow translucent bands (NT) or wide translucent bands (WT)

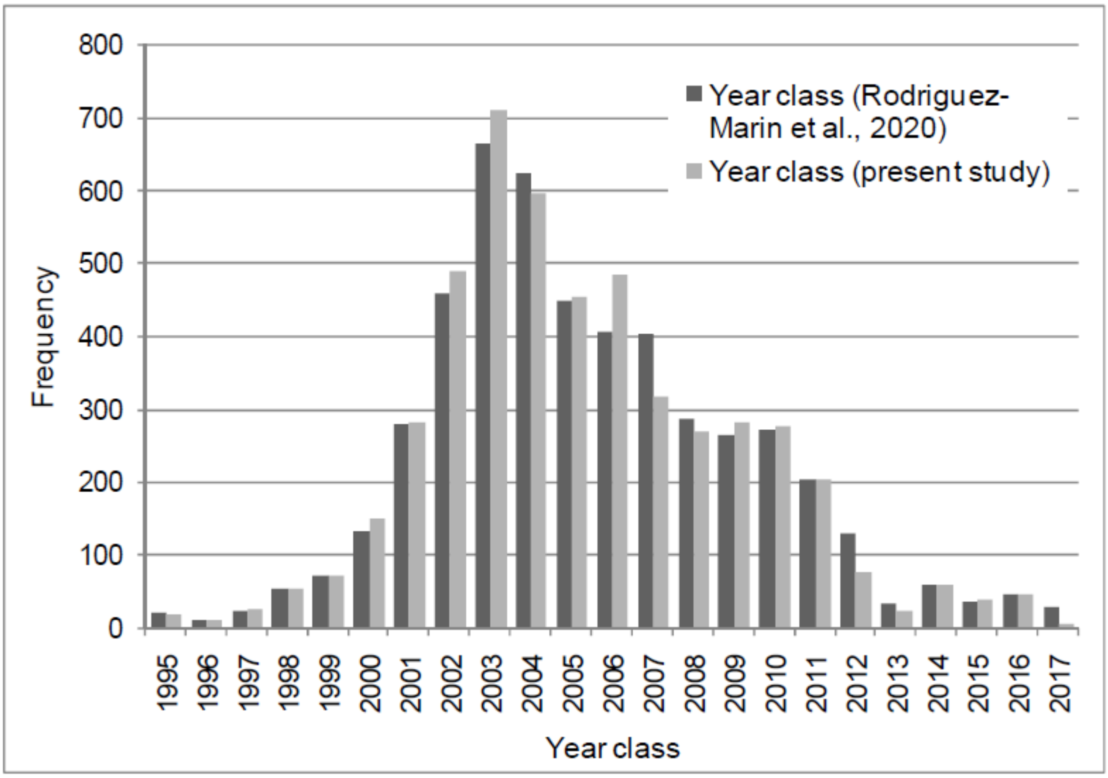

Figure 11. Number of Atlantic bluefin tuna individuals by year class, by applying the current (Rodriguez-Marin et al., 2020) and new age adjustment criteria to otolith band counts.

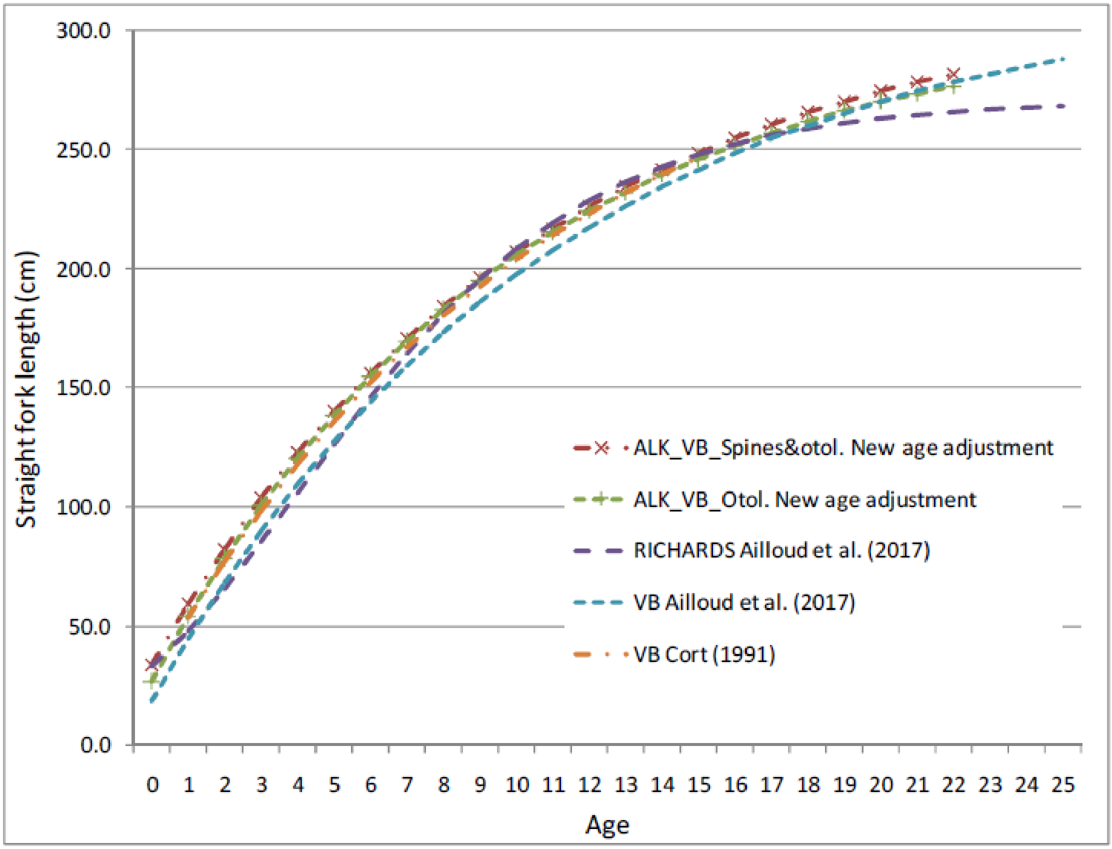

Figure 12. Growth curves obtained from the age-length keys (ALK) of the ICCAT database by applying the new age adjustment criterion (conversion of number of bands into ages). Both ALKs growth functions (one using all the available calcified structures: fin spines and otoliths, and another using only the otoliths) are

represented together with the growth curves currently applied to both stocks of Atlantic bluefin tuna. VB represents the von Bertalanffy fit to the length at age data.

Larvae identification in the Bay of Biscay

Recently, ABFT larvae were found outside the Mediterranean Sea, in the Bay of Biscay, demonstrating that ABFT can spawn in this area. During the previous GBYP phases, samples collected in the Bay of Biscay were analyzed, and one ABFT larvae was found in 2019. In 2021, taking advantage of the ABFT index acoustic survey (**Figure 13**), additional plankton samples were collected and analyzed under the microscope in search of ABFT larvae. Four plankton samples were obtained, but there was no evidence of bluefin larvae. Two main factors may contribute to explain the lack of bluefin tuna larvae in the sampled area. The first one, the absence of adult bluefin tuna in the area during the survey days, where only few juvenile or pre-adult fish were found. The second one is the limited number of plankton hauls carried out (N=4). More plankton samples are needed to draw further conclusions, ideally covering the entire adult distribution area. However, preliminary results suggest that the bluefin spawning in the Bay of Biscay could be sporadic phenomenon.

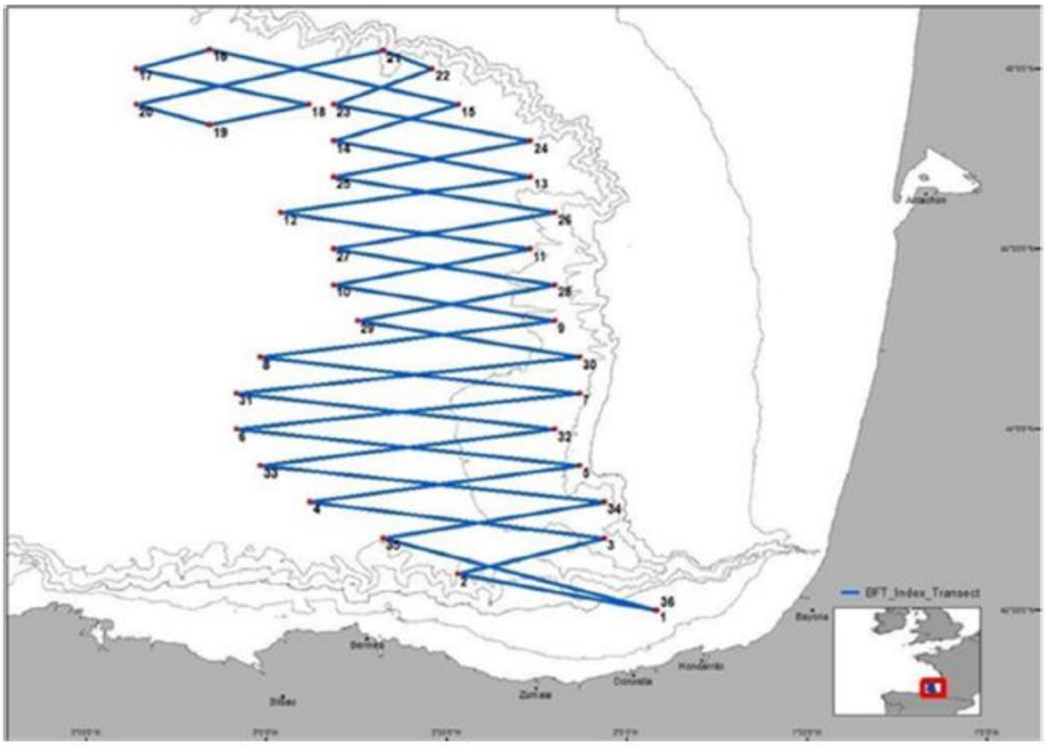

Figure 13. Area of study with acoustic transects (blue lines) for the adult ABFT abundance index survey

Sorting of larvae from the Balearic Sea

The collection of Atlantic bluefin tuna larvae in the main spawning area of the NW Mediterranean Sea provides a novel opportunity to provide samples of the early life stages of this species to the biological sample bank. Having larvae well preserved provide a novel opportunity to genetically mark actively spawning adult fish through DNA analysis in the future, explore genetic connectivity and ensure sampling that can help to solve uncertainties in current knowledge of the species.

Therefore, ABFT larvae from surveys conducted in the Balearic spawning ground were sorted and identified for genetics to be applied in understanding population structure in the Eastern stock and specially for potential close-kin analyses. For this purpose, larvae have to be preserved in ethanol, because preservation in formalin prevents the larvae be used for purposes different than species identification. In total, 2880 individuals from 30 samples collected during 2019 were identified. Bluefin tuna larvae were found in 18 out of the 30 samples analysed. In addition, stages of larval development were identified (i.e., yolk sac, preflexion, flexion, or postflexion). The sorted individuals were preserved in 100% ethanol in different 4 ml jars and kept in the freezer for a perfect conservation.

4.5. Modelling

The modelling programme addresses the GBYP general objective 3, which is to "Improve assessment models and provision of scientific advice on stock status through improved modelling of key biological processes, further developing stock assessment models including mixing between various areas and developing and use of biologically realistic operating models for more rigorous management option testing".

Initially, it was planned that GBYP start with carrying out operational modelling studies only from the year 4, but following the recommendation of Steering Committee and SCRS, the modelling activities already started from the year 2. It became evident that this line of study has greater importance than perceived in the moment when GBYP was conceived and hence the amount of effort for this activity has been much larger than initially considered. In addition, the MSE process being embarked upon by ICCAT has been an important initiative which represents a significant investment of time and resources by the Commission, CPCs and scientists involved.

An initial ICCAT GBYP multi-annual modelling work plan for the MSE was proposed at the Core Modelling Group meeting held in Monterrey, based on the Gloucester meeting. The main objective of MSE is to provide advice that is robust to uncertainty, and this requires a number of steps, namely:

1. Identification of management objectives and mapping these into statistical indicators of performance;
2. Selection of hypotheses for considering in the Operating Models (OMs) that represent the simulated versions of reality;
3. Conditioning of the OMs based on data and knowledge, and weighting of model hypotheses depending on their plausibility;
4. Identifying candidate management strategies and coding these as Management Procedures;
5. Projecting the OM forward in time using the MPs as a feedback control in order to simulate the long-term impact of management (Ramaprasad, 1983); and
6. Identifying the Management Procedure that best robustly meets management objectives.

To successfully conduct an MSE requires the engagement of stakeholders to evaluate alternative management actions and the risks of not meeting management objectives. Conducting an MSE allows the consequences of the improvement of knowledge, collection of data and implementation of alternative management measures to be evaluated.

Under previous contracts an OM (a mathematical simulation model), capable of a number of variations, has been coded and is available in the software repository https://github.com/ICCAT/abft-mse. In addition, a manual has been provided which forms the basis of a Software Development Plan (SDP) for future development. This will allow multiple developers to collaborate in its development and the development of candidate MPs in the future.

The development of the OM required test units to be developed to ensure that the code is fit for use, and in particular to ensure that resource dynamics in the OM are implemented as agreed by the Bluefin WG and the Technical MSE Group (formerly Core Modelling Group (CMG)). This required that the individual source code procedures and modules together with associated control data, usage procedures, and operating procedures, be tested. This will also help to avoid errors when the code is revised, and when collaboration involves multiple developers.

4.5.1. MSE development expert

In Phase 11 the contract for modelling approaches for providing support to bluefin tuna stock assessment was again awarded to Dr. Tom Carruthers (Blue Matter Science, Canada), who initiated the work on MSE and modelling in 2014. Given the extension of Phase 11, the contract for modelling approaches was extended up to June 2022.

The contract saw a major consolidation of the modelling foundations of the MSE including reconditioning of all operating models, integration of OM weighting, the refinement of seven CMPs authored by five independent developer groups and a comprehensive external code review. The most recent bluefin data were provided by the Secretariat and all operating models were reconditioned to 2019 and a full set of before/after comparisons were presented to the group. Following the Delphi approach, the operating model weightings were incorporated in both the code to conduct CMP tuning and the presentation of CMP results. Materials and documentation were prepared to support a comprehensive, independent code review that found no notable coding errors. Presentation of MSE results and documentation was improved by additions to the ABTMSE Shiny app and the production of an MSE splash page, serving as a hub for all relevant ABT MSE documentation and links. Further refining of CMPs to follow Panel 2 guidance on area-based caps, production of tables and figures for characterising CMP performance and selecting CMPs, and addition of robustness OMs are key priorities for 2022. All tasks and deliverables listed in the contract were completed on time with the exception of the conditioning of a single requested robustness test that was not feasible for technical reasons.

Given the extension of Phase 11, the contract with the same expert was extended for 6 months, during which the contractor not only fulfilled the task listed in the contract, but also addressed the requests from the various members of the MSE group. Of the 11 robustness tests (44 OMs in total) all were completed except for 1 (4 OMs) – the non-linear indices OM would not converge and an alternative is being investigated where only future changes in index linearity are simulated.

Principal developments in Phase 11 were the following:

- Reconditioned all reference grid OMs to include data up to 2019 and included these in an updated ABTMSE R package.
- A complete before-after reconditioning comparison documented in an SCRS paper and presented to the group
- Consolidation and presentation of CMP performance
- M3 Code Review completed successfully
- New artificial intelligence (AI) CMP tuned to development targets
- Model-based surplus production (SP) CMP tuned to development targets
- Index-based multi-stock CMP (TC) tuned to development targets
- Almost all robustness set OMs coded and fitted
- Incorporated OM weighting, into CMP tuning tools and presentation of results in the Shiny app.
- Coded new additions to the Shiny app including: downloadable MSE results data, sortable CMP selection and 'results normalized by selection'.
- Hosted an updated ABT MSE Shiny App on an online server: http://142.103.48.20:3838/ABTMSE/
- Developed an ABT MSE splash page providing a location for updated links to the latest documentation, packages and App: https://iccat.github.io/abft-mse/
- Presentation on updated TC, AI and SP CMPs.
- A presentation on MSE contractor progress.
- A draft SCRS paper describing the newly configured SP, AI and TC CMPs and a summary of their performance and trade-offs
- A draft SCRS paper summarizing the performance of all submitted CMPs to date including trade-offs among performance metrics and across stocks
- A presentation accompanying CMP performance paper above
- A presentation of latest developments in robustness OMs
- A presentation including straw-dog examples of CMP comparison tables and figures
- Revised shiny app including latest CMP results
- Updated Trial Specifications document

The final reports are available in Annex 1a, documents no. 12-14 and the additional deliverables are available in Annex 1b.

4.5.2. MSE Code Review

Consistent with the MSE implementation Roadmap adopted by the Commission, in 2021 the SCRS initiated an independent peer review of MSE code. Accordingly, there was a need to hire a MSE Code Technical Expert to work directly with the bluefin tuna MSE developers, the Bluefin Tuna Species Group and its Rapporteur, the SCRS Chair and Vice-Chair, and in consultation with the Secretariat to review the code and algorithms used and verify whether it performs as expected. The expert was also asked to suggest improvements to the code used to perform the simulations.

For several years the bluefin tuna working group has recorded MSE technical specifications in a Trial Specifications document (TSD). This covered a wide range of issues including data processing, fleet structure, operating model structure, likelihood functions for model conditioning and statistical properties of data for projections. Where applicable, the TS doc included mathematical equations that could be directly compared to ADMB and R code. The primary purpose of the code review was to check that the description of the operating model detailed in the TSD was correctly implemented in the code of the M3 model and the ABTMSE R package. However, the review was not focused on the suitability of the specifications described in the TSD.

For this purpose, a call for tenders was issued for M3 and ABTMSE R package code review and the contract was awarded to Dr. Emil Aalto (The Ocean Foundation), who was the only expert presenting the proposal. Dr. Aalto reviewed the code and checked it for mathematical correctness (i.e., all formulae matched the equations specified in the TSD) and programming correctness (i.e., no coding errors). He also analyzed the ABTMSE package for improvements in computational efficiency, with particular focus on speeding up the MSE process which will be used by third parties to develop and test candidate management proposals (CMPs).

In addition, the reviewer found that the M3 model and ABTMSE code base were correctly implemented at every level, with generally accurate (if occasionally insufficient) description in the TSD. A few minor errors were found and described, including typos in the TSD. Many minor improvements to the code were suggested, mainly for readability and maintainability. Although major gains in speed would require reimplementation of core code in a faster language such as C, widespread replacement of the apply function with a faster alternative promises to substantially improve runtime. Nothing was found in the review to suggest any reservations for the use of this package in ICCAT management. The final report is available in Annex 1a, document no. 15

4.5.3. Stock assessment review

In addition to MSE development, the SCRS in 2022 was conducting a full stock assessment for the Eastern Atlantic and Mediterranean bluefin tuna. In order to provide the most robust scientific advice, it was decided to contract an independent external expert who would assist to SCRS in the process and provide constructive advice. For that purpose, a direct contract was issued to the expert Dr. James Ianelli.

The reviewer was part of the full process, from data preparation to the projections. He participated actively in the discussions, providing advice and expert opinion where he considered that to be warranted in time to support the process. As such, he attended several online meetings and gave a brief report or presentation during each meeting.

The final report is available in Annex 1a, document no. 24

4.5.4. BFT MSE Technical Group

In order to support the important and complex MSE development by an effective coordinating body with the required technical expertise and appreciation of needs of the SCRS and Commission, in 2014 the GBYP Core Modelling and MSE Group was created. The Steering Committee provided its terms of reference and recommended the membership of the Group. The Group was intended to provide technical oversight and advice on the MSE process and review technical contributions and outputs of the work program. From December 2014 to 2017 the Group held 6 meetings. During the MSE intersessional meeting on 16-20 April 2018, it was decided to formalize the creation of the BFT MSE Technical Group, which, unlike Core Modelling Group, would be open to all interested ICCAT scientist, without restriction to participation. Therefore, GBYP Core Modelling Group was dissolved and it was substituted by the BFT MSE Technical Group. Nevertheless, although this Group was not formally constituted within the framework of Programme GBYP, it has continued providing its support, by covering the travel expenses, whenever needed, for participating in MSE related meetings of the members of the previous MSE Core Modelling

Group. Between February 2020 and July 2022 the Group did not hold in-person meetings due to the Covid pandemic.

The reports from the meetings of MSE Technical group in Phase 11 are available in Annex 1a, documents no. 36-37.

Annex 1. List of reports and scientific papers in Phase 11

a) List of deliverables and reports produced within the framework of GBYP contracts and activities

1. Aerial survey – July 2022. Short term contract for the monitoring of bluefin tuna spawning aggregations in the Mediterranean Sea – Area A (ICCAT GBYP 07/2022) – Final report. Air Perigord: 1-40.
2. Aerial survey – 13 July 2022. Short term contract for the monitoring of bluefin tuna spawning aggregations in the Mediterranean Sea – Area C (ICCAT GBYP 05/2022) – Final report. Unimar and Aerial Banners: 1-20.
3. Aerial survey – 13 July 2022. Short term contract for the monitoring of bluefin tuna spawning aggregations in the Mediterranean Sea – Area E (ICCAT GBYP 06/2022) – Final report. Unimar and Aerial Banners: 1-21.
4. Aerial survey – June 2022. Short term contract for the 2021 Aerial survey data analysis (ICCAT GBYP 04/2022). Final report. CREEM, University of St Andrews: 1-40.
5. Biological studies – 31 May 2022. Short term contract for biological studies (ICCAT GBYP 05/2021). Final report. Consortium led by AZTI: 1-92.
6. Biological studies –4 February 2022. Short term contract for biological studies –sampling of adults (ICCAT GBYP 06/2021-B). Final report. AquaBioTech: 1-11.
7. Biological studies – March 2022. Short term contract for biological studies –sampling of adults (ICCAT GBYP 06/2021-A). Final report. Taxon Estudios Ambientales: 1-19.
8. Coordination – 19 October 2021: ICCAT GBYP Steering Committee Meeting, Report, Anon: 1-6.
9. Coordination – 4 November 2021: ICCAT GBYP Steering Committee Meeting, Report, Anon: 1-7.
10. Coordination – 9 December 2021: ICCAT GBYP Steering Committee Meeting, Report, Anon: 1-11.
11. Data Recovery – 25 August 2022. Short term contract for the support of the development of the ICCAT electronic tags management system ETAGS (ICCAT GBYP 2/2022). Chi Hin Lam for Big Fish Intelligence Company: 1-5.
12. Modelling - 15 December 2021. Short term contract for the modelling approaches: support to bluefin tuna stock assessment (ICCAT GBYP 02/2021). Modelling and MSE –Final report. Evaluating management strategies. Dr Tom Carruthers for Blue Matter Science: 1-12.
13. Modelling – 21 July 2022. Short term contract for the modelling approaches: support to bluefin tuna stock assessment (ICCAT GBYP 01/2022). Modelling and MSE –Final report. Evaluating management strategies. Dr Tom Carruthers for Blue Matter Science: 1-4.
14. Modelling – 9 September 2021. Specifications for MSE trials for Atlantic bluefin tuna. Version 21-03. Anon: 1-41.
15. Modelling. Short term contract for modelling and MSE - M3 and ABTMSE R package code review (ICCAT GBYP 03/2021). Dr. Emilius Aalto for The Ocean Foundation: 1-26.
16. Tagging – April 2022. Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2021. Final report. Thunnus UK: 1-8.
17. Tagging – March 2022. Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2021. Final report. Consortium led by DTU Technical University of Denmark: 1-12.
18. Tagging – 11 November 2021. Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2021. Final report. IMR Institute of Marine Research: 1-8.
19. Tagging – January 2022. Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2021. Final report. Consortium led by Marine Institute: 1-22.

20. Tagging – 10 January 2022. Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2021. Final report. SLU Swedish University of Agricultural Sciences: 1-9.

21. Tagging – 20 January 2022. Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2021. Final report. The Ocean Foundation: 1-6.

22. Tagging - August 2022. Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2022. Final report. MEDFRI Mediterranean Fisheries Research, Production and Training Institute: 1-17.

23. Data Recovery – Short term contract for the data recovery programme – electronic tag data recovery (ICCAT GBYP 09/2022). Dr. Molly Lutcavage for Tuna2Oceans: 1-2.

24. Modelling – Short term contract for eastern bluefin tuna stock assessment external review (GBYP 03/2022). Report in broad terms on the adequacy and reliability of the advice framework. Dr. James Ianelli: 1-9.

25. Meetings – Report of the Standing Committee on Research and Statistics (SCRS). 27 September – 2 October 2021. Anon: 1-287.

26. Meetings – Report of the first 2021 intersessional meeting of the BFT species group (including W-BFT data preparatory) (5-13 April 2021). Anon: 1-86.

27. Meetings – Report of the second 2021 intersessional meeting of the BFT species group (2-9 September 2021). Anon: 1-72.

28. Meetings – Report of the 2021 Western Atlantic BFT stock assessment meeting (30 August-1 September 2021). Anon: 1-45.

29. Meetings – Report of the 2022 Eastern Atlantic and Mediterranean BFT data preparatory meeting (18-26 April 2022). Anon: 1-74.

30. Meetings – Report of the 2022 ICCAT Eastern Atlantic and Mediterranean BFT stock assessment meeting (4-9 July 2022). Anon: 1-75.

31. Meetings – Report of the intersessional meeting of Panel 2 (2-5 March 2021). Anon: 1-269.

32. Meetings – Report of the second intersessional meeting of Panel 2 (13-15 September 2021). Anon: 1-90.

33. Meetings – Chair's summary of the Panel 2 meeting on BFT MSE (12 November 2021). Anon: 1-17.

34. Meetings – Report of the intersessional meeting of Panel 2 (1-3 March 2022). Anon: 1-202.

35. Meetings – Report of the second intersessional meeting of Panel 2 on MSE (9-10 May 2022). Anon: 1-17.

36. Meetings – Report of the 2021 intersessional meeting of BFT MSE technical group (5-10 July 2021). Anon: 1-25.

37. Meetings – Report of the 2022 intersessional meeting of BFT MSE technical sub-group (3-6 May 2022). Anon: 1-52.

b) List of scientific documents produced within the framework of GBYP activities or based on GBYP data

1. Anonymous, 2021, Report of the ICCAT Atlantic-Wide Research Programme for Bluefin Tuna (ICCAT GBYP), Activity report for the last part of Phase 10 and the first part of Phase 11 (2020-2021), SCI-100/2021.

2. Ortiz M., Karakulak S., Mayor C., and Paga A. 2021. Review of the size distribution of caged eastern bluefin tuna (Thunnus thynnus) in Turkish farms 2014-2020 (SCRS/2021/019) Collect. Vol. Sci. Pap. ICCAT, 78(3): 159-169.

3. Deguara S., Alemany F., Ortiz M., and Rodriguez-Marin E. 2021. Briefing on the progress of the research activities concerning the growth in farms of bluefin tuna (SCRS/2021/043) Collect. Vol. Sci.

Pap. ICCAT, 78(3): 506-511.

4. Butterworth D.S., and Carruthers T.R. (2021) Atlantic bluefin tuna MSE topics for consideration and decision (SCRS/2021/047). Not published.

5. Carruthers T. R. (2021) Overview of Atlantic bluefin tuna Operating Model reconditioning data and results (SCRS/2021/124). Not published.

6. Carruthers T. R. (2021) Overview of Robustness OM specification and conditioning (SCRS/2021/125). Not published.

7. Carruthers T. R. (2021) A 'Model-based' multistock CMP for Atlantic bluefin tuna based on an efficient state-space surplus production assessment model (SCRS/2021/126). Not published.

8. Carruthers T. R. (2021) A reconfigured a multi-stock spatial management procedure for Atlantic bluefin tuna following Operating Model reconditioning (SCRS/2021/127). Not published.

9. Carruthers T. R. (2021) A retrained A.I. CMP for Atlantic bluefin tuna following Operating Model reconditioning (SCRS/2021/128). Not published.

10. Carruthers T. R. (2021) Ad-hoc weighting for Operating Model #35: 'does it matter' analysis (SCRS/2021/129). Not published.

11. Carruthers T. R. (2021) A summary of preliminary candidate management procedure performance for the reconditioned reference grid Operating Models (SCRS/2021/130). Not published.

12. Rodriguez-Marin E., Busawon D., Addis P., Allman R., Bellodi A., Castillo I., Garibaldi F., Karakulak S., Luque P.L.,Parejo A., and Quelle P. 2021. Calibration of Atlantic bluefin tuna otolith reading conducted by an independent fish ageing laboratory contracted by the ICCAT research programme GBYP (SCRS/2021/137) Collect. Vol. Sci. Pap. ICCAT, 78(3): 938-952.

13. Alemany F., Tensek S., and Pagá García A. 2021. ICCAT Atlantic-Wide Research Programme for Bluefin tuna (GBYP) Activity report for Phase 10 and the first part of Phase 11 (2020-2021) (SCRS/2021/138) Collect. Vol. Sci. Pap. ICCAT, 78(3): 953-1005.

14. Alemany F., Pagá A., Deguara S., and Tensek S. 2021. Modal Progression Analyses (MPA) to determine BFT seasonal growth rates in farms (SCRS/2021/145) Collect. Vol. Sci. Pap. ICCAT, 78(3): 1006-1023.

15. Ortiz M., Mayor C., and Paga A. 2021. Preliminary results analyses of weight gain of bluefin tuna (Thunnus thynnus) in farms from the farm harvest database 2015 -2020. (SCRS/2021/147) Collect. Vol. Sci. Pap. ICCAT, 78(3): 1006-1023.

16. Anonymous, 2021. The BFT technical sub-group on growth in farms status of analysis (SCSR/2021/150) Collect. Vol. Sci. Pap. ICCAT, 78(3): 1052-1058

17. Muñoz-Benavent P., Puig-Pons V., Morillo-Faro A., Andreu-García G., Espinosa V., and Pérez-Arjona I. (2021) Automated BFT growth monitoring in cages from a ventral perspective (SCRS/2021/157). Not published.

18. Aarestrup K., Alemany F., Arregui I., Arrizabalaga H., Cabanellas-Reboredo M., Carruthers T., Hanke A., Lauretta M., Paga A., Rouyer T., Tensek S., Walter J., and Rodriguez-Marin E. 2022. Update of electronic tagging data and methodologies for Atlantic bluefin tuna in order to plan future tagging activities (SCRS/2022/069). Collect. Vol. Sci. Pap. ICCAT, 79(3): 196-210.

19. Alemany F, Tensek S, Paga A. (2022) GBYP Aerial survey: overview and latest results (Presentation SCRS/P/2022/018)

20. Alemany F, Tensek S, Paga A. (2022) Updating on GBYP matters (Presentation SCRS/P/2022/019)

Annex 2. GBYP Contracts and MOUs issued in Phase 11

COORDINATION

ACTIVITY	RETAINED PROPOSAL	working schedule		COST
		initial date	final date	
07/2021	Steering Committee External Expert – Ana Parma	01/02/2022	30/06/2022	15.000,00 €

DATA MINING AND MANAGEMENT

ACTIVITY	RETAINED PROPOSAL	working schedule		COST
		initial date	final date	
02/2022	Big Fish Intelligence Company Limited- Dr. Tim Lam (Hong Kong)	28/12/2021	30/06/2022	30.000,00 €
09/2022	Tuna2Oceans – Dr. Molly Lutcavage (USA)	17/08/2022	31/08/2022	25.000,00 €

AERIAL SURVEY

ACTIVITY	RETAINED PROPOSAL	working schedule		COST
		initial date	final date	
4/2022	AS 2021 Data analysis - University St Andrews – Creem (United Kingdom)	08/04/2022	15/07/2022	£ 26.116,89
7/2022	AS in Zone A - Air Perigord (France)	03/06/2022	31/07/2022	124.510,00 €
05/2022	AS in Zone C - Unimar and Aerial Banners (Italy)	09/06/2022	31/07/2022	73.486,00 €
06/2022	AS in Zone E - Unimar and Aerial Banners (Italy)	09/06/2022	31/07/2022	138.304,00 €

TAGGING PROGRAMME

ACTIVITY	RETAINED PROPOSAL	working schedule		COST
		initial date	final date	
MoU	Tagging in North Eastern Atlantic waters - DTU Technical University of Denmark	30/08/2021	31/08/2022	-
MoU	Tagging in in Western Mediterranean and off Atlantic USA coasts - IEO Instituto Español de Oceanografia and LPRC (USA)	04/04/2022	31/08/2022	-
MoU	Tagging off Norway - IMR Institute of Marine Research (Norway)	31/08/2021	31/08/2022	-
MoU	Tagging in Celtic Sea - MI Marine Institute (Ireland) and Stanford University (USA)	14/10/2021	31/08/2022	-
MoU	Tagging in North Eastern Atlantic waters - SLU Swedish University of Agricultural Sciences	02/11/2021	31/08/2022	-
MoU	Tagging in Canada - Ocean Foundation (USA), DFO and Acadia University (Canada)	01/10/2021	31/08/2022	-
MoU	Tagging off Canary Islands - Ocean Foundation (USA), ACPR and Zoo Barcelona (Spain)	03/05/2022	31/08/2022	-
MoU	Tagging in Mediterranean Sea - University of Genova (Italy)	15/12/2021	31/08/2022	-

MoU	Tagging off UK - CefaS Centre for Environmental, Fisheries and Aquaculture Science and Exeter (UK)	15/12/2021	31/08/2022	-
MoU	Tagging off Türkiye - MEDFRI	27/05/2022	31/08/2022	-

BIOLOGICAL SAMPLING AND ANALYSES

ACTIVITY	RETAINED PROPOSAL	working schedule		COST
		initial date	final date	
5/2021	Biological studies sampling and analyses – Consortium led by AZTI (Spain)	19/07/2021	31/05/2022	300.011,00 €
06/2021-B	Sampling adult BFT in farms – AquaBioTech (Malta)	27/08/2021	31/12/2021	25.500,00 €
06/2021-A	Sampling adult BFT in farms – Taxon (Spain)	08/09/2021	28/02/2022	43.006,87 €

MODELLING APPROACHES

ACTIVITY	RETAINED PROPOSAL	working schedule		COST
		initial date	final date	
2/2021	MSE Expert – Blue Matter Science (Canada)	09/04/2021	31/12/2021	100.000,00 €
3/2021	MSE code review (Dr. Emil Aalto)- The Ocean Foundation (USA)	13/07/2021	31/12/2021	$ 29.040,00 €
1/2022	MSE Expert (second contract) – Blue Matter Science (Canada)	07/02/2022	30/06/2022	50.000,00 €
03/2022	E-BFT stock assessment review – Dr. James Ianelli (USA)	22/06/2022	30/06/2022	12.000,00 €