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ICCAT ATLANTIC-WIDE RESEARCH PROGRAMME FOR BLUEFIN TUNA (GBYP) ACTIVITY REPORT FOR PHASE 10 AND THE FIRST PART OF PHASE 11 (2020-2021)

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SUMMARY

The ICCAT GBYP Phase 10 has been implemented between 1 January 2020 and 31 July 2021. Phase 11 was initiated on 1 January 2021, with planned duration of one year, therefore temporarily overlapping with Phase 10. As in previous years, GBYP programme has promoted and funded several activities in the following lines: (a) data recovery and management, (b) biological studies, (c) stock indices: aerial survey on spawning aggregations, (d) tagging, including awareness and rewarding campaign and (e) further steps of the modelling approaches. The present report summarizes the final results of the activities carried out in Phase 10 and describes the activities initiated in Phase 11, and their preliminary results, if available.

RÉSUMÉ

La phase 10 du GBYP de l'ICCAT a été mise en œuvre du 1er janvier 2020 au 31 juillet 2021. La phase 11 a été initiée le 1er janvier 2021, avec une durée prévue d'un an, chevauchant donc temporairement la phase 10. À l'instar des années précédentes, le Programme GBYP a encouragé et financé plusieurs activités dans les domaines suivants : (a) récupération et gestion des données, (b) études biologiques, (c) indices des stocks : prospection aérienne des concentrations de reproducteurs, (d) marquage, y compris campagne de sensibilisation et de récompense et (e) nouvelles étapes des approches de modélisation. Le présent rapport résume les résultats finaux des activités menées dans le cadre de la phase 10 et décrit les activités entreprises au cours de la phase 11, ainsi que leurs résultats préliminaires, si disponibles.

RESUMEN

La fase 10 del GBYP de ICCAT se implementó entre el 1 de enero de 2020 y el 31 de julio de 2021. La fase 11 se inició el 1 de enero de 2021, y tiene una duración a prevista de un año, por lo tanto, se solapa temporalmente con la fase 10. Como en años anteriores, el GBYP ha fomentado y financiado diversas actividades, en la siguiente línea: (a) recuperación y gestión de datos, (b) estudios biológicos, (c) índices del stock: prospección aérea de concentraciones de reproductores, (d) marcado, lo que incluye una campaña de concienciación y recompensas y (e) más avances en los enfoques de modelación. El presente informe resume los resultados finales de las actividades llevadas a cabo en la fase 10 y describe las actividades iniciadas en la fase 11 y sus resultados preliminares, si los hay.

KEYWORDS

Bluefin tuna, ICCAT, historical data, biological analyses, tagging, genetics, maturity, microchemistry, aerial survey, modelling, Mediterranean Sea, Atlantic Ocean.

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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 programme 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 mining, 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 have 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 meeting on November 2014, 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. From 2015 GBYP has been 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 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 were set considering the aforementioned priorities stated initially by SCRS (data collection, understanding of key biological and ecological processes and assessment improvement). These objectives have been maintained throughout the programme, but they have been adapted to the evolution to the "state of the art" as regards scientific knowledge on bluefin tuna, in order to better match SRCS research needs and Commission recommendations. Therefore, within the Phase 10, these objectives were:

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

b) Improving understanding of key biological and ecological processes, mainly through electronic tagging experiments, coordinated with national programmes, to determine BFT spatial pattern 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.

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. It should be pointed out that the changes in the SC members, derived from those in the institutional components, sometimes resulted in different views for some GBYP activities, which affected the continuity of some lines of research.

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 programme, including the elaboration of the calls for different types of contracts, the reports on the different GBYP meetings 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.

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).

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 has 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, 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

The tenth Phase of the ICCAT GBYP officially started on 1 January 2020 following the signature of the Grant agreement for the co-financing of the ICCAT GBYP Phase 10 (SI2.819120) by the European Commission. Initial duration of the Phase was one year, but it was extended for seven months, thus officially ending on 31 July 2021.

Phase 10 has been amended twice. First amendment included extending the agreement duration till July 2021. 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 9 December 2020. The second amendment was requested in order to adjust the budget to the actual costs, as well as to incorporate the changes derived from the pandemic or other *force majeure* reasons into the work-plan. It must be pointed out that such modifications and time extension did not imply any change in the total budget for GBYP Phase 10, which remained fixed at 2,000,000 €, with an EU contribution of 1,600,000 €.

The eleventh phase of the GBYP officially started, following an EU request, on 1 January 2021, after the signature of the Grant Agreement for co-financing of Phase 11 (SI2.839201) by the European Commission with the planned duration of one year.

It is worth to mention that the GBYP Phase 10 overlapped with Phase 9 for four months (January-April 2020, and with Phase 11 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 Phase 10, the budget had the following funders when the proposal was presented (in order of contribution already received or committed):

European Union	1,600,000.00 €
Algeria	105,479.22 €
Japan	68,344.70 €
Morocco	64,962.81 €
United States of America	64,326.00 €
Libya	20,775.11 €
Canada	19,252.55 €
Egypt	13,007.74 €
Norway	11,438.30 €
Albania	7,718.45 €
China	4,401.12 €
Korea	4,054.67 €
Iceland	3,239.33 €
Chinese Taipei	3,000.00 €
TOTAL BUDGET	**2,000,000.00 €**

In Phase 11, the budget had the following funders:

European Union	1,280,000.00 €
Morocco	61,981.13 €
Japan	53,204.87 €
Tunisia	50,109.59 €
Libya	43,583.77 €
Turkey	43,503.81 €
Norway	19,000.00 €
Canada	18,834.89 €
ICCAT Secretariat	10,000.00 €
United States of America	8,420.00 €
Egypt	6,228.31 €
Albania	3,208.52 €
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 10 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

The Steering Committee in the Phase 10 and 11 was composed by the SCRS chair (Dr. Gary Melvin), the Western BFT rapporteur (Dr. John Walter), the Eastern BFT rapporteur (in 2020 Dr. Ana Gordoa; from 2021 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 Center for the Study of Marine Systems - CONICET in Argentina.

During Phase 10, four SC meetings have been held, in April, November and December 2020 and in January 2021. Other decisions have been taken via email, following the regular correspondence held between the GBYP Coordinator and GBYP SC members for all relevant issues.

In the Phase 10 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.

During Phase 10, a total of 3 calls for tenders and 12 official invitations have been released, which have resulted in a total of 16 contracts awarded to various entities (Annex 2). In addition, one call of expression of interest was published, which resulted in 5 memorandums of understanding. A total of 30 reports were produced in the framework of ICCAT GBYP in Phase 10 (Annex 1a). A total of 15 scientific papers have been produced in Phase 10 (list in Annex 1b), while others will be published in the following months. So far, the GBYP has produced in total, over the first 10 Phases, 399 activity reports and 307scientific papers.

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

Regarding RMA, during 2020 the Research Mortality Allowance was used for covering the incidental death of 117 specimens of bluefin tuna, which equals to a total of 7260 kg, reported through 35 RMA forms. Most of these are associated to the growth in farms study.

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 and in the SCRS second workshop on collaborative work to assess sea turtle bycatch in pelagic longline fleets (South Atlantic ocean and Mediterranean sea, held in Malaga, Spain, between 27 and 31 January, 2020) and in the EU Regional Coordination Group on Large pelagics, held on line between 28 and 30 June 2021.

Moreover, GBYP coordination team has organized two important workshops within this phase: Electronic tagging workshop (15-16 March 2021) and Close-kin workshop (8-9 February 2021). Both workshops were held online and were attended by more than 60 scientists from different ICCAT CPCs. GBYP has also been involved in organizing the meeting on larval survey standardization, held online on 12 May 2021 between Spanish, Italian and Turkish scientists directly involved in this field.

The GBYP coordinator could not participate directly in the training course for ROP observers in 2020, due to Covid derived scenario, but contributed to these courses revising and proposing new contents to the "Observer's Manual" and the presentations dealing with tagging.

4. Activities

In general, although several tasks have been affected by Covid-19 pandemic derived problems, most of the activities planned within both phases have been or are being implemented successfully. The activities in both phases have continued to be structured considering the same main lines of research established since the beginning of the programme, i.e. data recovery, biological studies, tagging, stock indices (aerial surveys) and modelling, but this does not mean that the workplans of these last two phases mimic those of the previous ones, given that the specific activities have been adapted to the current SCRS research needs and Commission requests. All activities carried out throughout the GBYP Phase 10 and those launched during the first part of Phase 11, as well their final or preliminary results and the related coordination activities, are described and summarised in this report.

Since March 2020, the implementation of GBYP Phase 10 has been hampered by significant challenges that have arisen due to the contention measures imposed by governments to mitigate the effects of the COVID-19 pandemic. These have affected the functioning of all 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 10 was requested.

As mentioned above, while most GBYP phase 10 scheduled activities have been developed successfully and on schedule, or with minor delays, some have been cancelled or postponed due to mobility restrictions. These include aerial surveys, some tagging activities and planned in-person meetings/workshops. 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, as well the workshops on electronic tagging, close-kin methodology and larval surveys.

4.1. Data recovery and management

This activity involves the storage, review and compilation and of all relevant scientific information, original and processed, produced 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.

The original plan of activities in Phase 10 included a specific budget related to the data recovery, just in case some relevant datasets regarding presence, catches, length distribution and spatial patterns not previously available to SCRS would be detected. Nevertheless, since no new relevant datasets were available, this activity was cancelled, which was reflected in the Amendment to the Grant agreement.

In addition, the work-plan under the information and data management activity, continuing the new strategic approach already initiated in Phase 9, included also in-house work to be carried out within ICCAT Secretariat in close collaboration between the ICCAT Department of Research and Statistics department, SCRS scientists and the GBYP coordination team, focused on the development of relational databases allowing the proper storage and analysis of all raw data from GBYP funded research activities or other data relevant for BFT management not included yet in current ICCAT databases.

Specifically, the actions carried out or in development under GBYP Phase 10 have been:

- Contribution to the creation of a database integrating the data related to BFT farming, including those from stereo camera measurements and harvesting operations, relating to and complementing them with data from eBCD and VMS systems. Specifically, after a deep review of more than 600 files submitted by CPCs in different formats, followed by several coordination meetings to discuss on problems encountered and agree on the best way to standardize and validate the info, more than 200.000 individual BFT measurements from official Stereo-cameras recordings have been incorporated to ICCAT DB and are available for analyses. Thanks to this review and data consolidation tasks, the Secretariat is planning to modify the current official forms to include new data fields, necessary for the proper management of this new Database on BFT farming.
- The design and creation of a database incorporating the information obtained from the different studies contracted by GBYP studies on growth in farms 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 data on daily feeding and environmental conditions are 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 stablished in coordination with ICCAT Science and Statistics Department staff, through several internal coordination meetings. As a first step, after some coordination meetings between the GBYP coordination team, the Secretariat and the main biological study contractor, a detailed template to get relevant info about the biological sampling activities and storage procedures of biological samples was designed and submitted to the institution in charge of storing and maintain the GBYP Tissue bank. 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 is being processed for including it in the new ICCAT biological data and information system, to be used as a reference to improve the coordination between CPC and ICCAT special scientific programmes sampling activities.
- Updating and improvement of the quality of the information from tagging activities, including the elaboration of the development plan for the design and building up of a common electronic tagging database.
- Contribution to the design and build up a data repository to store the information from the aerial survey activity.

4.2. Stock indices (Aerial Surveys)

ICCAT GBYP Aerial survey on bluefin spawning aggregations 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. Summing up, aerial surveys on selected spawning areas were carried out in Phase 1 and 2, and then the activity was suspended in Phase 3. An extended aerial survey, covering 90% of the Mediterranean Sea surface was realized in 2013, at the beginning of Phase 4, but due to budget constrains the aerial survey was suspended again in 2014. An extended survey, similar to that carried out in 2013, was developed in 2015. In addition, in 2015 a reanalysis of all data up to that point was carried out, taking into reference only four overlapped areas (the Balearic Sea, the Tyrrhenian Sea, the Southern-Eastern Mediterranean and the Levantine Sea) and making some further corrections, thus producing standardized 4 years series of fisheries independent index. In 2016 the survey was suspended, basing the decision of the Steering Committee on the assumption that the financial resources were not sufficient for carrying out an adequate survey. The aerial survey activity was resumed in 2017, 2018, and 2019 on the same four overlapped areas only, using the same methodology and sampling strategy already established in 2015, producing three more years of standardized index. In addition, 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 had not been detected before and also introducing 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 from 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.

4.2.1. Calibration and validation of aerial survey

As a consequence of the aforementioned high interannual variability and striking differences among successive estimations of the aerial survey indices, in 2020 it was decided to carry out an in-depth review of the whole GBYP aerial survey programme, in order to evaluate the survey and take decisions regarding the nature of its continuation. The contract was awarded to the Centre for Independent Experts from USA for an independent desk review of the survey design, statistical treatments and analytical procedures, and of its general capacity to achieve its objectives. The review was carried out by two external experts: Dr S.T. Buckland, an expert in line-transect methods for estimating animal abundance, and Dr. J.H. Vølstad, an expert in the application of statistics in fisheries stock assessment.

The review focused on the aforementioned re-analysis of the surveys carried out in 2019, which showed large differences in estimates of BFT spawning biomass from previous estimates and high interannual variation both within and between regions, possibly because spawning locations and spawning times vary across years.

The reviewers found that there is strong evidence that a long-term monitoring programme would require a survey design that covers much of the Mediterranean, including areas outside of the four subareas currently surveyed. Given cost limitations, one option to accomplish this is to continue annual spatial and temporal sampling coverage in the four main spawning areas at current levels, and to cover the remaining spawning area with less effort. Model-based methods could be used to combine data from the two survey components and complement the design-based methods used to date. Given the difficulties that observers face in recording reliable data for the line transect method, the use of high-resolution imagery should be considered as an alternative to observers, possibly in conjunction with long-distance drones. Video or still images taken from higher altitude provide a permanent record, allowing verifiability. In addition, the reviewers found several inconsistencies in the re-analysis results, which suggested errors in the computer code that needed to be corrected.

4.2.2. Recalculation of AS indices

With reference to the results of the external aerial survey review, several inconsistencies were found which indicated possible errors in the computer code used for calculating the aerial survey index. Therefore, the GBYP Steering Committee recommended to review the code used for aerial survey data analysis and re-calculate the index. For that purpose, the contract was awarded to the CREEM Team at the University of St. Andrews (United Kingdom), which were the original developers the original developers of the DISTANCE methodology applied for the aerial surveys data analysis.

The CREEM team conducted both a re-analysis of the whole available time series applying the same design-based approach followed in previous Phases, to eventually correct the previous results, and developed a model-based approach to model density and abundance of bluefin observed during aerial survey campaigns based on part of the data set (Balearic Sea Area for 2017-2019 period to evaluate the feasibility and potential improvements derived from this alternative methodological approach. The re-analyses using the design-based approach showed that the new (corrected) abundance estimates are comparable to previous results for regions A, C and G, while for region E the new estimates are lower than previous, although the previous results are within confidence intervals of the new ones. In terms of biomass, the two estimates are comparable for all regions, except for much higher previous estimates for year 2015 in area E, which may be due to different grouping of the data. The largest discrepancy between the previous and new results are in expected mean fish weight. The CREEM team suggested to perform more analysis and research to explain the differences in average fish weight across years, especially to check whether these differences are results of a biological process or changes in search protocol. These differences between years resulted in estimates of density of biomass (kg of fish/km^2) to be even 20 times higher in later years than at the beginning of the survey. Comparable results are presented in previous analysis.

With respect to the model-based methods, they allow density and abundance to be estimated as a function of location and environment, allowing density to vary spatially throughout a region. Such an approach was applied, as mentioned above, to the aerial survey data collected in block A for the years 2017 to 2019, with the objective to assess the feasibility of using model-based methods to estimate tuna abundance/biomass for the other survey blocks, or indeed for the region of the Mediterranean covered by aerial surveys. The results show that the number of groups and group sizes from model-based approach are slightly higher than for the design-based approach, but are within the 95% confidence interval. Nevertheless, only a limited set of potential explanatory variables were used to illustrate these methods such as sea surface temperature on the day of the survey, sea surface temperature 10 days before, and depth. Year, and location were, however, most important predictors in the models. The selected model explained only small fractions of variation in density and there are large uncertainties around the estimated values. Also, these data present challenges for modelers for various reasons and therefore further analyses, including more environmental covariates, are needed.

MSE consideration

Although the aerial survey index was previously agreed for use in the MSE process, given that it required re-evaluation and the associated results were not available in the first half of 2021, it was not used in the 2021 OM-reconditioning exercise. It was agreed that the BFT Species Group review the index at some point in late 2021 or 2022 and further decide if the MPs finally adopted in late 2022 may include it.

4.2.3. Pilot aerial survey in the Balearic Sea in 2021

Some of the recommendations of the AS programme reviewers were to start moving to digital observing and counting systems to substitute human observers-based system and to extend, if possible, the surveyed areas. These issues were further discussed by BFT Species Group on its meeting held in April 2021 and, taking account its inputs, the GBYP Steering Committee recommended to carry out a pilot survey in the Balearic Sea area. The AS index from this area has been the only one considered for MSE up to now. Also, this area was the most suitable, from the logistic and financial point of view, for carrying out this trial, 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.

Consequently, the call for tenders was launched for the pilot aerial survey for the monitoring of bluefin tuna spawning aggregations in the Balearic Sea, to be carried out by combining classic visual observations made by professional and scientific spotters on board and automatic and continuous recording of high-quality digital images. Two offers were received for this task and the contract was awarded to Action Air Environnement from France, a company which has repeatedly participated in GBYP aerial surveys.

The objective of the aerial survey in 2021 was to continue index series in the Balearic Sea, the only one used up to now for stock management within the framework of MSE implementation, using the same methodology as in the previous years and, at the same time, to evaluate feasibility of using the automatic digital system. Therefore, the same GBYP Aerial survey Protocol and Design were followed as in previous years. Before the mission, the training course for all members of the crew was held, in order to provide them with the detailed instructions on the methodology and the details for filling the usual sighting forms. In addition to the standard crew comprised by a pilot, professional spotter and two scientific spotters, this year’s mission was also supported by an external expert (Dr. J. Antonio Vázquez Bonales), who supervised the team and provided advice on methodological issues.

The survey was held from 2 June to 8 July in the extended area around the Balearic Sea, comprising of a high density transects inner zone and a lower density transect buffer zone (**Figure 1**). A total of 22 flights were realized in the area. During the entire mission, 23 bluefin tuna schools were observed, quite fewer than in 2019 when 31 schools were observed in the same area. Most sightings occurred in the northern part of the area and around the island of Mallorca. As in previous years, the majority of detected tuna were large, weighting between 150 and 300 kg. It was estimated that the 23 observed schools were comprised by a total 17,530 individual bluefin tuna, with a total weight of 3,372 tons. School size varied from 80 to 1925 individuals, having the average size of 762 individuals. The average school weight was 150 tons. Final analyses for Index estimation will be held after September 2021, considering the conclusions from the studies described in point 4.2.2.

The analysis of the data from the new digital system is still ongoing, and up to now 20000 high quality images have been processed, among which more than 400 contain detections of marine megafauna. From the preliminary results it can be concluded that several BFT schools on the track of the plane not observed by human staff have been detected by the digital system, which, if confirmed, could have important implications for the design of such surveys in the future.

4.3. Tagging

This line of research has faced two important problems 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 programme 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 several tags remaining on fish the whole programmed year, for the first time in GBYP tagging campaigns.

4.3.1. Tagging campaigns in 2020

As recommended by the Steering Committee, the tagging activities carried out under contract on specific agreements in the Phase 10 were limited again to the deployment of electronic tags, keeping the deployment of conventional tags only as a complementary activity.

For the 2020 GBYP campaign pop up and internal archival tags were purchased. As usual, PSAT tags were acquired from Wildlife Computers (model MiniPAT), but this year, for the first time, they were also purchased from Lotek (new model PSATFLEX), in order to perform an experimental test on their performance. In addition to satellite tags, GBYP this year also purchased the Lotek archival tags (model LAT2310).

With reference to the Wildlife Computer MiniPATs, there were several technical issues with these tags over the course of the last years, resulting in their lower performance. The most recent was a battery issue, affecting the tags produced in the second half of 2018 and 2019, which caused shorter transmission time to satellite and consequently poor or even zero data received. Therefore, the results of GBYP tagging campaigns in 2019 were greatly compromised. In 2020 Wildlife Computers claimed to have solved the battery issue and integrated a fully functional battery in the newest MiniPAT model. After a series of negotiations between ICCAT and Wildlife Computers, the manufacturer offered a warranty replacement for each tag identified to have a battery failure in 2018-2019 and a number of goodwill tags in order to compensate the deployment costs of the malfunctioning tags. They also provided a few test tags in kind, to demonstrate their good performance. These tags were deployed in 2020 campaigns. In the first half of 2021, once the satisfactory performance of the new model had been proved, GBYP purchased a number of these tags, to be deployed in the following season.

There were several electronic tagging campaigns planned for 2020 in different areas of the Mediterranean Sea and North Atlantic region. However, these were cancelled due to the Covid-19 outbreak. Consequently, the GBYP Coordination team proposed to GBYP Steering Committee an alternative plan for 2020 GBYP e-tagging programme, consisting in the deployment of at least 25 archival tags and 36 pop-up satellite tags in the North Atlantic taking advantage of synergies with ongoing CPCs national e-tagging programmes developed in this area. To implement this plan ICCAT GBYP sought for experienced national research teams willing to collaborate with this GBYP tagging programme through a Circular (0510/2020) submitted by the ICCAT Executive Secretary to all the CPCs Head Delegates and Head Scientists. Expressions of interest were received from several teams and were evaluated by a committee to select the most adequate ones to fulfil the SCRS needs in the tagging field. As in the previous season, the specific objectives of the 2020 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. The added value of the cooperation with national teams aimed to reach the following outcomes and results:

- Development of unique expertise and knowledge
- Minimizing operational costs of the respective research activities
- Generation of data directly applicable to the modelling of BFT stocks dynamics
- Production of sound scientific publications, including high ranked scientific papers

Consequently, memorandums of understanding were signed between ICCAT and several 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 will be shared by both parties. The following national teams were awarded:

- AZTI (Spain) - 10 archival tags of the model LOTEK LAT2310, to be deployed in the Bay of Biscay
- Fisheries and Oceans Canada (DFO) - 5 PSAT tags for their deployment off Newfoundland
- Technical University of Denmark (DTU), jointly with Swedish University of Agricultural Sciences (SLU) and Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and University of Exeter - 9 PSAT and 5 archival tags for their deployment in the North Sea (Skagerrak/English Channel and Celtic Sea)
- Institute of Marine Research (IMR) of Norway - 5 PSAT tags for their deployment off Norway
- Marine Institute (Ireland), in collaboration with Dr. Barbara Block team (Stanford University) - 10 archival and 17 PSAT tags (Lotek PSATFLEX) for their deployment in the coastal waters off Ireland

In Phase 10 AZTI (Spain) deployed 7 internal archival electronic tags of model Lotek LAT2310. The campaigns took place in the Bay of Biscay during July 2020 when first 3 tags were deployed and July 2021 when other 4 tags were deployed. The majority of the BFT were juveniles (78-89 cm CFL) and one individual was an adult BFT (237cm CFL). AZTI is going to implant the remaining 3 archival during the campaign in September 2021.

Fisheries and Oceans Canada (DFO) deployed 5 tags Wildlife Computers MiniPATs in October 2020. The tags were to be deployed targeting as young as possible bluefin individuals present in the area out of St. John’s Newfoundland. Unfortunately, all fishing activities in Newfoundland waters were unsuccessful and therefore, in agreement with GBYP, the tags were deployed off Port Hood, Nova Scotia. The tags were deployed in collaboration with other scientific teams already carrying out other tagging operations in the area – the teams led by Drs. Barbara Block (Stanford University) and Michael Stokesbury (Acadia University). All fish were caught using rod and reel and were tagged on board and were released in a good condition. The average measured curved fork length of the fish was 227 +/- 24 cm and the average estimated round weight was 461.8 +/- 148 lbs.

Technical University of Denmark (DTU), jointly with Swedish University of Agricultural Sciences (SLU) and Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and University of Exeter deployed GBYP tags withing the framework of national programmes i.e. the Scandinavian Bluefin Marathon and Thunnus UK. In addition to 9 WC MiniPATs provided by GBYP, the team also deployed 3 more test tags provided by the tag manufacturer. Moreover, they deployed 5 Lotek LAT2310 archival tags using a new specific methodology, consisting in deploying them externally making use of an adapted floating package, including an archival tag and a satellite tag (mrPAT). The tags were deployed during August and September 2020 in waters of the Skagerrak, Kattegat and western English Channel. All fish were caught using rod and reel and were brough on board for tagging. The size of the fish was 222 to 274 cm CFL in Skagerrak and 185 to 242cm CFL in the English Channel.

Institute of Marine Research in Norway deployed 5 MiniPATs along the cost of Norway during August and September 2020. Tagging was performed on-board a specially designed tagging vessel with an aluminium ramp to pull the fish on board. All but one individuals were caught from the tagging vessel using rod-and-line and spreader bars as lures. One individual was captured by a collaborating recreational fishing boat and was transferred to the tagging vessel. The size of the fish was from 244 cm to 266 cm.

Marine Institute (Ireland), in collaboration with Dr. Barbara Block team (Stanford University) deployed 17 PSAT tags (Lotek PSATFLEX) between August and November 2020. The tags were deployed in the Celtic Seas area, i.e. off the Donegal coast and off the coast of South-West Cork. All fish were captured using angling methods and squid spreader bar lure and were tagged on board. All fish caught were larger than 170 cm with the largest being 238cm. The average curved fork length for the 27 fish caught was 213 cm.

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 are shown on **Figure 2**, including only the tags deployed by GBYP. In addition to these tags, GBYP also acquired numerous e-tags datasets from other tagging programmes 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 3**. The electronic tags datasets are being used in MSE for determination of BFT stocks mixing rates.

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 10 “spaghetti” tags, along with applicators and the tagging protocols and forms to report tagging operations were delivered to various institutions (**Table 2**). 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.

In Phase 10, a total of 1150 tags were deployed on 1069 bluefin tuna individuals (**Table 3** and **4**). 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 22 thousand bluefin tuna individuals were tagged, using more than 30 thousand tags of different types (**Table 5** and **6**).

4.3.2. Workshop on bluefin tuna tagging

Recent compilation of all available electronic tags for Atlantic bluefin as part of the MSE process has greatly informed knowledge of BFT movement and life history, yet numerous gaps remain and the field of bluefin science stands to gain from finding ways to work together to jointly analyse these compiled datasets.

To address this need, the GBYP organized in March 2020 an open workshop on Atlantic bluefin tuna tagging, aiming to reach a broad consensus on the strategic future planning and best use of the already available information. Unfortunately, this workshop had to be cancelled at the very last moment because of the spread of the COVID-19 pandemic. This broad presential workshop will be organized and convened again when the situation allows it.

Meanwhile, the GBYP Steering Committee has considered it useful to hold an online workshop on this topic, aiming to provide recommendations to improve and optimize the BFT tagging campaigns that will be developed in the near future. The Workshop was held online from 15 to 16 March 2021, with the following specific objectives:

- to identify the main knowledge gaps on Atlantic Bluefin Tuna spatial patterns
- to update the status of ongoing BFT electronic tagging programmes, aiming to find potential synergies among national and ICCAT programmes

- to elaborate a list, defining priorities, of research needs related to BFT spatial patterns aiming to improve stock assessment and MSE related modelling
- to agree on the best electronic tagging methodologies (type of tags, tag deployment methods, tagging time and areas, target population fraction…) to fulfil the objectives derived from SCRS research needs.

The Workshop was announced by a Circular letter sent by the Executive Secretary to all CPCs. There was a great interest for this Workshop among the scientist from different CPCs and finally it was attended by more than 60 participants. During the Workshop, different scientific teams briefly presented their tagging programmes, focusing on the latest results and the plans for future campaigns. Special attention was given to the use of electronic tagging data within the framework of BFT MSE modelling. The participants also held detailed open discussions, in order to clearly identify which are the SCRS needs in the field and find possible solutions to the main problems affecting the electronic tagging. Finally, the participants formulated a series of specific recommendations on electric tags deployment strategies and methodologies.

The next workshop, that will be probably held along the first semester 2022 will focus on other topics related to tagging, such as data sharing policy and standards of quality of tracks used for modelling purposes.

The outputs from this workshop were presented and discussed within the Intersessional Meeting of the SCRS BFT Species Group in April 2021 and are available in document SCRS/2021/024.

4.3.3. Tagging campaigns in 2021

Given the successful strategic approach for the implementation of the GBYP e-tagging programme, based on strengthening collaboration with CPCs' e-tagging national programmes initiated in Phase 10, the Steering Committee decided to continue taking advantage of the synergies between the tagging programmes developed at national level and the GBYP one. Therefore, a new Call for Expression of Interest to collaborate with the GBYP e-tagging programme was launched in June 2021. Within the framework of this Call, a total of 70 pop-up satellite tags were awarded to different CPC national teams, deployed in the Mediterranean and/or North Atlantic Ocean, targeting eastern stock individuals, as follows:

- Technical University of Denmark (DTU) – 9 pop-uptags for their deployment in Northeastern Atlantic water (Eastern North Sea, Skagerrak, Kattegat and Øresund)

- Instituto Español de Oceanografía - 14 pop-up tags for their deployment in Western Mediterranean and off Atlantic USA coasts, in collaboration with Large Pelagics Research Center of the University of Massachusetts.

- Institute of Marine Research (IMR) of Norway - 5 pop-up tags for their deployment in Norwegian waters.

- The Marine Institute of Ireland - 9 pop-up tags for their deployment in the coastal waters off Ireland, in collaboration with Dr. Barbara Block team (Stanford University)

- Swedish University of Agricultural Sciences (SLU) - 9 pop up tags for their deployment in Skagerrak, Kattegat or the Sound Straight.

- Stanford University, Hopkins Marine Station (USA) - 11 pop-up tags for their deployment in Canadian waters, in collaboration with DFO (Fisheries and Ocean Canada) and Acadia University

- Stanford University, Hopkins Marine Station (USA) - 9 pop-up tags and 5 internal archival tags for their deployment off Canary Islands, in collaboration with "Asociación Catalana de Pesca Responsable" (ACPR), Tag a Giant (TAG) and Barcelona Zoo.

- University of Genova (Italy) - 5 pop-up tags for their deployment in Ligurian Sea

- Cefas (UK) - 9 pop-up 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, in collaboration with Exeter University.

4.3.4. 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 programme, 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. The average ICCAT recoveries for the period before 2010 were much lower than during GBYP, which is visible from the **Figure 4**. 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 2020, a total of 134 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.

As for the study of conventional tags shedding rate, 491 tags were recovered from 322 double tagged fish (up to 1 March 2021). According to the results (**Table 7.**), 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.

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 information on available samples can be obtained through an interactive web application, especially designed for that purpose on https://aztigps.shinyapps.io/bluefin/.

The general objectives of the Biological Studies initially stated for Phase 10 were keeping an ICCAT GBYP tissue bank able to provide the samples required to carry out the studies necessary for improving the understanding of key biological and ecological processes affecting BFT, providing updated, representative and reliable ALKs useful for BFT stocks assessment and providing accurate and reliable estimations of mixing rates between BFT Western and Eastern stocks. In addition, GBYP continued with the broad study to determine BFT growth in farms.

There were also two workshops related to biological studies held within Phase 10, one on close-kin methods and the other one on larval index surveys. Both workshops had already been planned for 2019, but were cancelled/postponed due to the covid-19 outbreak. The objective of the larval index surveys coordination workshop was to facilitate coordination between different CPCs national studies, while the objective of the close kin workshop was to provide insight in new achievements of the method and evaluate its potential use on Eastern BFT stock, with special focus on the assessment.

4.4.1. Biological sampling and analyses in Phase 10

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 10 more institutions. In addition, a call for tenders was published for sampling of adult bluefin tuna individuals in farms. Three 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 the Ministry for Agriculture, Fisheries and Animal Rights – Department of Fisheries and Aquaculture (DFA-MAFA) was contracted for sampling 300 individuals from the South Tyrrhenian Sea and other 300 from the Central/Southern Mediterranean Sea.

The activities in Phase 10 were mostly directed to resolving the Atlantic bluefin tuna population structure and mixing. Population structure is a key uncertainty for Atlantic bluefin tuna, given the possibility that more than two populations or contingents coexists in the Atlantic Ocean, while ICCAT has managed historically the species assuming two separate populations with no mixing. This is in contrast with the fact that the stock structure assumed for the 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. Therefore, the activities in Phase 10 were focused in the understanding of the implications of the new spawning grounds detected in the Atlantic Ocean (de Sea, Bay of Biscay) and to mixing analyses to provide accurate information and clear alternative hypotheses about population structure and missing for the MSE process.

Thus, the level of biological sampling was comparable to that of Phase 9, focusing mainly on the Atlantic subregions where mixing potentially occur, such as Central Atlantic, Canarias 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 programme. Regarding sampling for constructing the age length key, which was one of the priorities identified by the Bluefin Species Group, the focus was put on collecting of hard parts of under-represented strata from previous years. Therefore, large fish were sampled in the Atlantic and in the Mediterranean farms. It should be mentioned that this task in the future might be achieved through national sampling programmes, such as those developed in relation to EU Data Collection Framework.

On population structure, one of the most important uncertainties to resolve is related to the understanding of the implications of the new spawning ground 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 be also 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.

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 10, following sampling protocols agreed in earlier Phases, the Consortium sampled a total of 713 bluefin tuna (32 YOY, 96 medium sized fish and 585 large fish) from different regions (113 from the Strait of Gibraltar, 7 from Morocco, 25 from the Canary Islands, 400 from Norway, 121 from the Central North Atlantic (sampled in 2019), 31 from the Western Mediterranean and 16 from the Bay of Biscay). In total, 1452 biological samples (348 otolith samples, 391 fin spines and 713 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 3947 biological samples (1243 otolith samples, 700 fin spines, 310 gonads and 1694 genetic samples from 1699 individuals). The total number of bluefin tuna individuals and samples collected in the Phase 10 is shown in **Table 8**.

b) Biological analyses
The most relevant results from each type of analysis are summarized below:

Otolith microchemistry

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 202 otoliths of Atlantic bluefin tuna captured in the Canary Island, Central North Atlantic (east and west of the 45ºW boundary) and the Norwegian Sea, to determine their nursery area.

Stable δ13C and δ18O isotopes values measured in otolith cores indicated that samples from the Northeast Atlantic, Norwegian Sea and Canary Island were dominated by eastern origin individuals, whereas a considerable mixing of the two populations was detected in the western North Atlantic (**Figure 5**). These results are consistent with previous findings and suggests that Mediterranean bluefin tuna may be the principal contributor to the fisheries operating in the eastern North Atlantic. Fisheries operating west of the 45ºW meridian are supported by both Mediterranean and Gulf of Mexico populations, and the proportions of each stock contributing to the catches may vary from year to year.

Around the Canary Islands analyses indicated that in 2018 and 2019 catches were almost exclusively composed by the Mediterranean population (97% and 100% respectively). Mixing rate estimates around the Canary Islands using this methodology varied in preceding years. So, catches in 2013 and 2019 were found to be exclusively composed of the Mediterranean population, but in 2013, 2015 and 2016 a substantial contribution of western migrants was found in this area (**Figure 6**), suggesting that the fishery around Canary Islands may be sustained partly by the western migrants. After all, catches have been largely dominated by the Mediterranean population, so it is expected that Mediterranean bluefin tuna may be the principal contributors to the Spanish fishery operating in the Canary Islands.

Additionally, the existing baseline was aimed to be refined in order to increase its discrimination capacity. For that purpose, otoliths from the Gulf of Mexico and Mediterranean spawners were selected and evaluated using the otolith portion corresponding to the early life period (approx. 3 months). Reducing the portion of the otolith targeted for analyses ensures that the isotopic signature represents the signature of the nursery area by minimizing the incorporation of material accreted while living in the open Atlantic Ocean. The results showed that the discriminatory power of this new baseline was similar to that based on 1-year otolith portion. Therefore, the oxygen stable isotopes are an important tracer to differentiate bluefin tuna from the Gulf of Mexico and Mediterranean population, but by itself are insufficient for sub-stock structure investigations within the Mediterranean Sea (**Figure 7**).

In addition to the stable isotope analyses, 2-dimensional maps of trace elements (Sr, Ba and Mg) concentration were built with a selection of otoliths from the Gulf of Mexico and Mediterranean Sea. The preliminary results suggest that the combination of stable isotopes and trace elements may considerably improve the ability to identify the origin of tuna from the mixing zones.

In relation to life history analyses, secondary ion mass spectrometry (SIMS) was used to measure δ18O along otolith growth profiles at a high temporal-resolution. The oxygen isotope ratio (δ18O value) of fish otoliths is dependent on the temperature and the δ18O value of the ambient water and can thus reflect the environmental history of a fish. Secondary ion mass spectrometry (SIMS) can be used to measure δ18O along otolith growth profiles at a much higher temporal-resolution compared to isotope ratio mass spectrometry (IRMS). When δ18O values are overlaid on visible otolith growth zones they may provide a chronological record of fish's thermal experience over its life history. Given the differences in temperature and 18O composition of the seawater between the Mediterranean Sea and the Atlantic Ocean, otolith δ18O values along otolith growth profiles are likely to vary, depending on whether the tuna inhabited the Mediterranean Sea or the open Atlantic Ocean. The SIMS approach is particularly powerful because it allows for the detection of habitat shifts with high temporal resolution (< 1 month).

During Phase 9, SIMS was used to provide, for the first time, high-resolution estimates of δ18O along otolith growth transects from Atlantic bluefin tuna from the Mediterranean and North Atlantic. The method proved effective at detecting variation in environmental histories, with results showing evidence of individual variability in early life history and possible trans-Atlantic migration of adult fish. However, δ18O signatures in individuals from the same environment (Mediterranean farms) showed considerable variability, probably due to individual physiological effects or differences in behaviour (e.g. depth preferences), which reduce the accuracy of life history reconstructions. The results also showed that due to methodological differences, δ18O values obtained using SIMS are markedly lower than values recorded by IRMS, making comparison with previous studies difficult. Progress made in phase 9 was built on in phase 10 by using the relationship between temperature and δ18O in the otoliths of farmed fish to develop a fractionation equation to allow for the more accurate reconstruction of temperature histories. Patterns of δ18O during early life was examined in Mediterranean spawners. By aligning δ18O profiles with the position of annual growth marks in the otolith it was possible to infer the timing of movement away from the main spawning areas. The fractionation equation was used to estimate the range of otolith δ18O values that could be expected to occur in the otoliths of bluefin residing in different areas of the Atlantic Ocean and Mediterranean Sea and to infer possible migrations patterns in adult bluefin from observed otolith δ18O profiles.

Although movements between the Mediterranean and Atlantic cannot yet be accurately reconstructed using stable isotope profiles, comparison of relative changes across individuals allowed for the detection of groups of fish with characteristic migratory patterns. The results provide some support for the hypothesis that there is a migratory and a Mediterranean resident contingent within the Eastern stock of Atlantic bluefin tuna. Therefore, the method proved effective at detecting variation in environmental histories, with results showing evidence of individual variability in early life history and possible trans-Atlantic migration of adult fish. If a given fish shifts between migratory and resident contingents within the first 8-10 years of life, otolith δ18O profiles could be used to detect the timing of the behaviour change. However, changes in behaviour will be difficult to detect after that age due to the limitations on the resolution of the current available methods.

Genetic analyses

Despite recent efforts in understanding the population structure and connectivity of Atlantic bluefin tuna, numerous questions remain. Perhaps the most important question is how much and since when the two presumed populations, Gulf of Mexico and Mediterranean, interbreed, and what is the role of the Slope Sea in this interbreeding. Interbreeding has been mostly identified to happen in the Slope Sea. Probably this region facilitates interbreeding, but it is not known since when it does, and if it is an old interbreeding region it is not clear why the East-West differentiation still exists. Another hypothesis would be that western spawners migrated to the Slope Sea in more recent years. In recent endeavours the Consortium have used RAD-seq data to tackle these questions. These data have provided unprecedented information about the population structure of Atlantic bluefin tuna, revealing connectivity mediated through the Slope Sea, signals of adaptation and nuclear introgression from albacore. The discovery of the genome markers leading to know these results allow the development of more cost-effective approaches for genotyping, which will allow to upscale Atlantic bluefin tuna population studies by enabling the analyses of much more samples. Additional analyses using alternative approaches are also needed to confirm previous findings on connectivity and potential adaptation, not only because they rely on different genotyping technologies, but also because they allow inclusion of more samples. In parallel to study population connectivity of Atlantic bluefin tuna, it is important to continue monitoring feeding aggregates through small scale assays such as the 96 SNP traceability panel developed in previous phases. The baseline for this panel was based on a few Gulf of Mexico larvae, which was a limitation. Thus, there is scope to improve it by including more larvae from the Gulf of Mexico as they become available.

Therefore, in this Phase, genetic analyses were focused on further confirming previous results on the population structure of Atlantic bluefin tuna by using a new developed assay and on testing assignment of feeding aggregates with an improved origin traceability panel through the use of an enlarged baseline.

The Consortium developed a new cost-effective tool, a genotyping array that includes more than 7000 genetic markers suitable for Atlantic bluefin tuna population genetics. This array includes neutral and outlier SNP markers for population structure analyses as well as markers for traceability (derived from the 96 SNP panel), markers for mitochondrial introgression and markers for sex determination. The results obtained with the array are consistent with those obtained with the RAD-seq data, confirming the suitability of this tool as a cost-effective approach for bluefin tuna population studies. Compared to RAD-sequencing, the array does not require reprocessing the whole dataset when adding new samples, involves easier bioinformatic data analyses and costs about three times less per sample. Additionally, this array has been proven useful to detect kins, making it suitable for applications such as Close-kin Mark Recapture.

The array-based analyses confirm that the Mediterranean individuals have all Mediterranean genetic background, that the Gulf of Mexico individuals include mostly Gulf of Mexico genetic background individuals but also Mediterranean and mixed background individuals, and that the Western Atlantic individuals corresponding to potential Slope Sea spawners have mixed background. The array-based analyses also detect a potential chromosomal inversion that separates samples in three groups, two being homozygous for the inversion and one heterozygous. Altogether these results confirm previous findings on the population structure of Atlantic bluefin tuna, suggesting that the observed “unexpected” findings were not due to artifacts of the used methodology.

Concerning origin assignment, the results showed that improving the baseline by adding more Gulf of Mexico larvae and/or removing Mediterranean origin Gulf of Mexico adult do not result in significant changes in origin assignment rate (**Figure 8**). This suggests that the number of “incorrectly” assigned or unassigned individuals is most likely due to these individuals having a different genetic and catch origin or to having a mixed genetic background (due to a non-complete genetic isolation between spawning components).

In summary, the previous hypothesis on Atlantic bluefin tuna connectivity was confirmed and the presence of signals of adaptation require further studies.

Ageing related analysis

In Phase 10 it was performed a calibration exercise on the 2000 age estimates provided in Phase 9 by Fish Ageing Services (FAS) under a GBYP contract. Such a calibration exercise was performed with the objective of ensuring that there was no systemic bias in age readings performed by SCRS experts compared to FAS age estimates. This is the second calibration performed with FAS readings, since another one was already done with the readings carried out by FAS in ICCAT GBYP Phase 7. In the first calibration, a one-year bias in the count of bands in older specimens was found, with a lower count by FAS compared to the rest of the laboratories starting from 10-13 years of age. To address this issue, the second calibration exercise has been carried out to ensure that all parties were following the ICCAT reviewed reading protocol. The results of the second calibration exercise will serve as quality control monitoring for ageing consistency. In addition, the samples used in the calibration will enlarge the new reference collection.

The findings of the second otolith age calibration exercise confirmed that there are differences in band counts between ICCAT expert readers and FAS readings. These differences start from specimens with more than 10 bands and are more pronounced for older specimens. The results of the present calibration (GBYP Phase 10) are very similar to those of the previous one (GBYP Phase 9). These differences in readings appear to be due to the fact that FAS uses the entire section of the otolith to count annual bands, whereas ICCAT readers focus on the inner part of the ventral arm. Therefore, there is a different band count at the end of the ventral arm, with a higher band count in the inner part of the ventral arm compared to the outer part (**Figure 9**). Analyses conducted to establish which reading is more appropriate, based on growth function estimation and cohort follow-up analysis, seem to indicate that ICCAT readers are more accurate than FAS readers.

In addition, determination of the otolith edge type deposition along year cycle, a widely used semi-direct validation method consisting in observing the evolution of the marginal areas of calcified structures over time, was carried out. The study of the type of marginal edge and its growth throughout the year is also essential to make the appropriate age adjustment, converting the number of annual bands found in the structure into ages. To do this, it is necessary to identify properly the type of edge and, in relation on the date of birth and collection, obtain the adjusted age of the specimen. The study of the edge type deposition requires observations throughout the year and the observation of a large number of samples.

In the case of Atlantic bluefin tuna, it is difficult to assess the nature of the otolith edge: opaque vs. translucent. The difficulty is related to the visualization of a band partial increase affected by refraction and by the reflection of light at the marginal edge and on the curved surface of the otolith. In order to reduce this source of inconsistency the group engaged in this calibration used otolith samples with consensus on edge type and number of annual band and samples with high readability pattern and edge type confidence. In addition, they measured the marginal growth of sagittal otoliths of Atlantic bluefin tuna and verified the formation of marginal edge type throughout the year.

The preliminary results of edge type and marginal increment analysis (MIA) in otolith of ABFT clearly indicate that opaque bands are fully formed in August to November. However, poor data in the early part of the year prevent to reach any conclusive results. Therefore, further sampling effort during winter months are recommended to fully cover the year and examine the relationship between month and index of completion.

Larvae identification in the Bay of Biscay

In 2019, ABFT larvae were found in the Bay of Biscay suggesting that ABFT could have been spawning in this area. For that reason, the search for ABFT larvae in samples collected in the 2020 acoustic survey in the Bay of Biscay was proposed for this study (**Figure 10**). The species identification was performed on plankton samples preserved in ethanol, collected along the track of the acoustic survey, outside the continental shelf, where the probability to find ABFT was considered to be higher. All larvae were extracted and identified through microscopic identification and genetic sequencing would have been used of necessary for confirmation. Among the 6 plankton hauls done during the 2020 survey, 99 larvae were found, of which none was an ABFT larvae, the only scombrid larvae encountered being *Auxis sp*. larvae.

Two main factors may contribute to explain the lack of bluefin tuna larvae in the area prospected. The first one, the absence of adult bluefin tuna in the prospected area during the survey days; There were found juvenile or pre-adult fish mostly, whereas adult aggregations were locally observed in onshore areas nearby the Cape Breton canyon, outside of the survey area. The second one is the low number of plankton samples that were performed during the survey. Other factors may be the big amount of salp in the survey area and the overall number of fish larvae that was low in the area for this time of the year.

The plankton collection took place again in 2021. Big salp aggregations were not observed this year in the study area but in the rest of the Bay of Biscay at least in May. Adult ABFT were spotted at least at one of the plankton sampling locations, which may increase the likelihood of finding bluefin tuna larvae in the samples collected.

Sorting of larvae from the Balearic Sea

Finally, 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.

The collection of Atlantic bluefin tuna larvae in the main spawning area of the NW Mediterranean provides a novel opportunity to genetically mark actively spawning adult fish through DNA analysis and to assess the genetic diversity and population structure in the spawning ground. Besides, the collection of Atlantic bluefin tuna larvae provides a novel opportunity to genetically mark actively spawning adult fish through DNA analysis. The ability to acquire larvae quickly means that larval collections can be useful for further work on EBFT population structure, considering also the early life stage besides the information inferred from the larvae and related to the adults. Sample sorting, initial ID and curation are critical to the success of obtaining high quality DNA. National programmes ensure collecting tuna larvae every summer in the main spawning ground for Bluefin tuna using Bongo nets. One collector is formalin preserved and these samples that are routinely used to identify bluefin tuna larvae since formalin is the best preservation method for the maintenance of pigments used for taxonomic identification and it is further used for the estimation of the larval index used in the assessments. The other Bongo collector is preserved in alcohol since 2019. To ensure the quality of the DNA in the larvae is high, it is important to separate the larvae and storage them separately in ethanol.

A total of 2258 bluefin tuna larvae were identified in 49 samples, and it was confirmed that all of these were suitable for close-kin analyses.

In conclusion, the Consortium achieved to ensure high quality bluefin tuna larvae preserved in ethanol. Different developmental stages within the first month of life of this species were identified and separately preserved. Including early life stages, such as larvae, in the biological sampling programme for Atlantic and Mediterranean bluefin tuna is a main task to ensure a holistic view of the life cycle of the species. Survival upon reproduction is the ultimate goal of the species. On one hand, explanations of the timing, selection of spawning sites and many other biological and ecological aspects of bluefin tuna can be understood from the perspective of the fate and needs of the offspring and therefore recruitment. On the other hand, 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.

4.4.2. Study on BFT growth in farms

Pursuant to special request by the Commission towards the SCRS to provide an update on the potential growth rates of Bluefin tuna in farming/fattening facilities, with the aim of improving the coherence within the growth rates derived from eBCD (request 18-02, paragraph 28 (amended by Rec. 19-04)), GBYP launched several lines of research on this topic, involving ad hoc experiments in selected farms along the eastern Atlantic and Mediterranean. In order to integrate the results from GBYP and other lines of research in a single and coherent answer to the Commission, SCRS BFT Subgroup on growth in farms was constituted in 2020.

Following the successful preparatory work in Phase 8, the studies in Phase 9 were initiated in 5 representative areas: Tunipex in Portugal, Balfegó in Spain, AquaBioTech in Malta, Pelagos Net Farma in Croatia and Akua Group in Turkey. The studies consisted in intensive monitoring of selected cages and, in case of Croatian and Portuguese farms, carrying out also tagging experiments to determine growth of individual fish. The activities in Phase 10 consisted in continuation of experiments initiated in 2019 in farms where it was necessary, as well as the development of new pilot study using acoustic and IAS techniques.

Therefore, in 2020 further contracts were again signed with farms in Portugal, Spain, Malta and Croatia, to allow to continue the monitoring initiated in 2019 or, in the cases of Spain and Portugal, to carry out a second trial of such experiments, since due to several reasons (high mortality rates of tagged fish in the case of tagging study in Portugal and impossibility of getting the length distribution at harvesting in the Balfegó farm since a storm destroyed the monitoring cage before harvesting) the objectives could not be fully achieved in the first trial. . These studies focused on the analysis of seasonal growth of modal groups, based on sequential (bimonthly) stereo camera measurements along farming period and length and weight data at harvesting (Western Med, Adriatic and Central Med) or in individual tagging (Atlantic-adult fish and Adriatic-juvenile fish). The duration of the studies has been variable, from around 6 to 16 months in adult fish and 19 in juveniles. They will allow to estimate seasonal growth rates in length and the total weight gain along the whole fattening period of each of the modal groups (annual cohorts) present in the cages in most of the areas where BFT is farmed and relate these growth rates with environmental parameters and food supply, and in the case of tagging studies, direct estimations of individual growth rates in length and weight.

The study in the Adriatic have targeted 2-3 years old fish (>8 kg) at capture, which have been maintained under usual farming conditions along more than one year and a half. A total of 206 fish distributed in two cages were tagged with PIT tags, most of which have been successfully detected at harvesting, which has allowed to get 157 individual growth rates. PIT tagged fish were mostly equally distributed over all size classes in experimental cages (**Figure 11**). During 19 months of farming bluefin tuna juveniles reached the overall harvested weight between 58 and 64 kg. A mean value of body weight increase of 500% over tested period did not differ among two experimental cages. Body weight increase of maturing fish is greatly retarded during the spawning season compared to immature bluefin tuna. The fish having initial weight from 8-10 kg (estimated age 2+ years) increased body weight 525%, while for the fish of 14-20 kg (estimated age 3+) body weight increase was 334%. Mean increase in length was around 60%. Registered mortality of tagged fish over the entire farming period was neglectable (1%). Unrecovered portion (22%) could be addressed to combination of other factors such as detector failure, and failure of readers being forced with harvesting routine procedures. The retention of external clips attached to the anal fin combined with cutting part of second dorsal fin was s very low (1 against 12 tagged fish). Encapsulated tag appears to be biologically inert with no sign of inflammation of wound area tissue. There was no effect on the length/weight relationship of the tagged fish. Underwater video recordings can be easily used on a routine basis to obtain reliable data on size frequency distribution of BFT reared in grow out cage. Using the appropriate L-W equation, obtained length information from footages can be easily converted into quite precise fish biomass as to adjust feeding regime with other zootechnician measures (i.e. stocking density), and thus improve farm management as whole.

In Portugal, tagging trials have been carried out along two consecutive years, involving adult fish captured in traps when leaving the Mediterranean after spawning, tagging 89 and 107 fish respectively. In 2020, BFT were tagged between 3-17 August, and they were individually weighted, measured, double tagged and returned to the cage for fattening. All fish were harvested as a batch at the end of the season. However, this particular season there were delays associated with the Covid pandemic, and as such harvesting only occurred in December 2020. The premature mortality of tagged fish has been high, around 38%, and almost 13% of fish lost the external tags before harvesting (**Figure 12**). Although the mortality was high, it was lower than in 2019 study. A total of 95 individual growth rates have been obtained, showing a high variability after four/ four and a half months of fattening. The overall weight increase for the harvested fish had a mean of 40.3% (varying between 12% and 74%), for fish that were fattened between 116 and 132 days between tagging and harvesting. The individual growth trajectories will allow to get a precise idea about the potential variability in growth rates and validate the results obtained from the rest of studies.

In 2020 new pilot studies were carried out as well, which consisted in continuous monitoring of growth in length and weight of modal groups by means of a combination of acoustic and image analysis systems. The pilot study was carried out up by Polytechnic University of Valencia 2021 in a fattening cage of Grup Balfegó farm (West Mediterranean) containing 724 BFT. It was planned to carry out a second study in Morocco, but should be cancelled due to Covid outbreak. This system allows to get a massive amount of data by day on length, width and height of probably 100% of fish in the monitored cage, which allows to identify and characterize all the modal groups present in the cage. Given that not only lengths, but also widths and heights are recorded with the stereoscopic cameras and the sonar placed in the bottom of the cage it is possible to estimate, through ad hoc morphometric models, the increase in the weight of the caged population with less than 2% error. Summing up, this system allows to get precise estimations of growth in length and weigh of each modal group at any selected time scale, even daily or weekly if required, along all the farming period. The outputs from this study are useful to get info about seasonal growth in weight and evaluate the accuracy of the studies described in the previous point.

The pilot acoustic study results show that the evolution of the median and percentiles along time cannot be used to estimate growth of a fish population containing fish from different ages and lengths. Instead, a modal analysis able to identify the different cohorts should be done prior to analyze the evolution of length, width and height. Therefore, the Bhattacharya’s method has been applied to the length measurements to identify the cohorts. The average SFL of each period and their evolution over time can be observed in **Figure 13**. The results suggest that growth in length from September to May is approximately between 8 and 18 cm (between 3% and 10%), depending on the fish length. The separation between cohorts decreases as the modal SFL increases, which is expected since the annual growth rates progressively decrease with age. It is also expected that after one year the growth of each cohort is similar to that represented by the distance between consecutive cohorts of the same size range in the initial length distribution. In this case, it is expected that the annual growth, because of the special conditions in cage, is even higher than in the wild, as has been already demonstrated in juvenile BFT. These results show that the modal lengths in May 2021 reach already the size of the next cohorts in September 2020. That implies that, after one year, each modal SFL could at least reach the next cohort’s SFL or a few centimetres more if there is an accelerated growth in cages, as hypothesized. The acoustic system is also used to estimate the height of the fish to provide a more accurate biomass estimation. The results confirm that, for tuna fattened in cages, the availability of more than one dimension to estimate weight improves the predictive power of the model and reduces error in the estimate.

In parallel with field activities, in-house work, already initiated in previous Phases, continued at ICCAT Secretariat in close collaboration between Department of Research and Statistics and GBYP Coordination team. It was oriented to the consolidation of data reported from stereo-cameras to ICCAT (2014-2018), since due to differences in the format of the report between CPCs and/or years, the data needed to be compiled and standardized before making any further analysis. This first step will allow to develop an operative relational data base, linking data on estimated initial lengths and weights from stereo-cameras at caging with measures of real final weighs and lengths at harvesting from e-BCD system, as well VMS data, allowing broad studies on the growth of caged fish in all the areas were BFT farming takes place along Phase 10, at the same time that provides crucial information for stock assessment (length distributions of the captures of purse-seine fisheries).

The data provided by all these GBYP funded studies have been presented and discussed within a series of on-line meetings of the SCRS Growth in farms subgroup organized by GBYP staff and the Subgroup coordinator, Dr. Simeon Deguara, to contribute to the elaboration of the SCRS answer to the Commission. In addition to the final reports on field activities, available at GBYP webpage, detailed results from the different studies will be presented as SCRS papers to the September 2021 BFT Species Group meeting. The scientific teams that provided direct scientific support to the individual growth studies based on tagging techniques, IZOR and IPMA teams in Croatia and Portugal, respectively, will take care of elaborating the scientific papers on this topic, and UPV, the contractor in charge of the pilot study combining acoustic and IAS techniques in the Balfegó farm (Western Mediterranean, will present also a scientific paper to the September 2021 BFT Species Group. The Modal Progression Analysis (MPA) to determine the seasonal growth rates of all the cohorts present in the selected cages within the framework of the studies carried out in Levantine Sea (Turkey), Central Med (Malta), Western Mediterranean (Balfegó farm, in parallel to the aforementioned pilot study) and Adriatic Sea (in parallel with tagging study), have been carried out by GBYP coordination team. The first phase of these analyses, focused on the identification of the cohorts present in the length frequency distributions obtained from the initial official stereo-camera measurements and the bimonthly stereocamera footages carried out in the monitoring cages (minimum 20% of fish in the cage measured and the final length distributions at harvesting (100% of fish measured), by using the FAO software FiSAT II to apply the Battacharia's method to discriminate modal groups. The results from these analyses will also be summarized and presented to SCRS also as a scientific paper within the September 2021 SCRS BFT Species group meeting.

The main preliminary conclusions from these analyses have been:

- MPA can provide seasonal growth rates at least of the main annual cohorts in farming cages
- Growth rates in farms change along the year (higher in warmer months) probably as a result of seasonal variations in T
- Growth rates in length along farming period, and not only in weight, are higher than in the wild, almost double, both in juveniles and adults
- SC footages measuring 20% of fish are not fully representative of all the cohorts inside the cages, since smaller and larger individuals are detected at harvesting, making difficult MPA analyses
- Changes in the equipment and methodologies used for recording the images, as well environmental conditions, which can vary the range of distances at which the fish are measured, can induce changes in the length distributions
- Sizes taken directly at harvesting are systematically lower that those obtained from Stereocams just prior to harvesting

The analyses to relate seasonal growth rates and environmental factors, as T or food supply, will be performed within GBYP Phase 11.

4.4.3. Workshop on close-kin mark recapture

Genetic Close Kin Mark Recapture (CKMR) uses the frequency of closely related individuals (e.g. parent-offspring, siblings) to estimate absolute number or exploitation rate, either of which can be directly used in stock assessments or harvest control rules. In 2016, ICCAT GBYP contracted the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, which is the institution that developed the CKMR application for Southern Bluefin tuna. for an initial feasibility study for its application to the Eastern Atlantic Bluefin tuna (EBFT). The report stated that CKMR was potentially feasible for EBFT, assuming it was possible to: (i) increase annual sample sizes of tissue, otolith and length samples; (ii) distinguish between individuals of eastern and western origin; and (iii) implement high quality sample processing and data management to minimise genotyping errors. The study also recommended holding a workshop focusing on genetic techniques before following up with the next phase of the feasibility study.

However, due to the need to further review the technique and its application to EBFT and concerns regarding feasibility of sampling, the genetic workshop and the second part of the feasibility study were postponed. Recent developments now warrant revisiting CKMR for EBFT, based on the initial success of a pilot study applied to Western Atlantic Bluefin, advances in genetic techniques to distinguish stock of origin and improvements in biological sampling. Hence GBYP Steering Committee (SC) decided to convene a workshop to further evaluate the feasibility of implementing a CKMR study for EBFT. A presential workshop was planned to be held in 2020, but unfortunately it had to be cancelled because of the COVID-19 pandemic.

As an alternative, an online workshop was held on 8-9 February 2021, with the specific objective to evaluate the financial, logistic and scientific feasibility of implementing a CKMR study for EBFT. It was attended by more than 60 scientists from different CPCs. During the workshop, the requirements for a proper development of CKMR study were reviewed and examples of application of CKMR methodology in other tuna stocks were provided. Genetic analyses and sampling issues derived from the necessity of getting well-mixed samples were discussed as well. Finally, a list of recommendations for further steps towards the implementation of CMKR for EBFT was drafted, in the event that the SCRS and Commission decide to go further with this approach.

The outputs from this workshop were presented and discussed within the Intersessional Meeting of the SCRS BFT Species Group in April 2021 and are available in document SCRS/2021/023. The Group endorsed the recommendations provided by the Workshop, giving priority to development of the sampling design and protocol, conducting pilot study for sampling and analysis of larvae from Balearic Sea and elsewhere (if possible), and performing an epigenetic ageing pilot study. In order to develop the sampling design, a technical group meeting should be held. The pilot studies will be funded through GBYP, possibly within the Phase 11 (2021), after redistributing a part of budget initially dedicated to other activities which had to be cancelled due to the pandemic.

4.4.4. Biological sampling and analyses in Phase 11

In Phase 11, the biological studies followed the same general objectives as in previous Phase, and had following specific priorities:

- 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, this year two specific activities were introduced, which were developing a feasibility study on the potential implementation of epigenetic ageing for BFT and determining, through Marginal Increment Analyses, the timing of formation of the opaque and hyaline annual bands in BFT otoliths, aiming at improving the accuracy of BFT ageing studies based on otoliths interpretation. For that purpose, a call for tenders was issued and two offers were received, one of which was awarded. The contract was signed with the AZTI, as a leader of Consortium which included 8 more institutions.

In addition, a call for tenders was published for sampling of adult bluefin tuna individuals in the Mediterranean farms. Four offers were received, two of which were awarded. The contract was signed with Taxon (Spain), for sampling 300 BFT individuals in the Balearic Sea and with AquaBioTech (Malta) for sampling 300 individuals from South Tyrrhenian Sea and 300 from South Central Mediterranean.

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 Monterey. 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 10 and 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.

The main objectives in 2020 were:

- To ensure the OM scenarios agreed by the CMG in 2016 and revised in 2017, 2018 and 2019 by the Technical MSE Group (formerly CMG) and the MSE BFT Group, can be run;
- That third parties can use the OM to evaluate candidate MPs (CMPs) of their own specifications; and
- To provide a set of agreed summary statistics that can be used by decision makers to identify the MP, including data and knowledge requirements, that robustly meets the management objectives.

This contract saw the most substantial step forward yet in the development of a comprehensive and defensible MSE framework from which to provide management advice.

Firstly, an interim reference operating model grid was identified that passed the majority of the 'red-face' tests identified by the group spanning axes of uncertainty relating to recruitment regime, stock productivity (somatic growth and natural mortality rate), western stock mixing, scale and weighting of the length composition data. Secondly, six independent developer groups initiated the development and then tuning of more than 25 CMPs. Thirdly, the online Shiny App for presenting MSE results was fully updated and then revised adding features requested by the group. Lastly, functions were created that allow CMP developers to run MSEs locally and then load these to the Shiny App to view results.

In 2020 a series of tasks were completed, as follows:

- Updated M3 model to version 6 with added stock-specific scale as an OM prior.
- Now comprehensive trial specifications document (Appendix A)
- A new grid of reference set OMs coded and fitted.
- New robustness set OMs coded and fitted.
- Produced extensive index fit diagnostic reports to support index selection and OM plausibility rating (Appendix B)
- Provided functions for visualizing MSE projections of biomass, recruitment and simulated indices.
- Developed an MP that accounts for stock mixing and provides amongst the most promising performance of the current preliminary set of operating models (Appendix C).
- Updated MSE ABTMSE R package to (1) include the revised Shiny App so that it can be run locally, (2) perfect OM matching of the estimation model and (3) include MSE results compilation functions for uploading to the online Shiny App.
- Hosted the ABT MSE Shiny App on an online server: http://142.103.48.20:3838/ABTMSE/
- An extensive 'does it matter' analysis where potentially problematic model behaviour was corrected and MSE projections undertaken to detect whether these scenarios were influential in CMP behaviour.
- Comprehensively address issues raised in a partial and unofficial code review by Dr Fernandez.
- Update OM report to include model estimates of relative abundance in the South Atlantic area, fraction of spawning biomass in the natal area, and other pertinent red-face tests.
- Developed code to assist developers in tuning their CMPs.
- Developed an exceptional circumstances protocol using only existing indices, with considerable power to detect scenarios where western biomass is depleted to low levels.
- Five SCRS papers and six presentations covering OM reconditioning, a multi-stock CMP, the 'does it matter' analysis and relative performance of CMPs (Appendices C-E).

In addition to the contracted tasks, more than 100 models, CMP, shiny App and data changes following requests from the Bluefin Tuna Working Group and MSE Technical Group were realized.

Although the credibility, objectivity and behaviour of the conditioned operating model (M3) and the data inputs are now sufficiently improved to be used in CMP selection, the progress map is essentially unchanged from that reported at the end of 2019. The MSE framework is complete but all components downstream of the Management Procedures and the Management Objectives are currently not finalized (**Figure 14**).

The tasks entrusted to Dr. Carruthers in Phase 11 have been the following:

- provide reconditioning (including reporting of individual OMs, comparisons among OMs and index fits)
- provide comparative analysis on of reconditioned OMs with previous OMs,
- reconstruct R package with new OM grid and OMs,
- revise package documentation including CMP developers guide,
- assist in CMP development and code review,
- remake the ABTMSE Shiny App with the new design of reference OM grid, consolidate CMP results and upload to ABTMSE Shiny App
- specify and fit robustness OMs.

4.5.2. MSE review

In 2021 the SCRS has asked for an independent peer review of the BFT MSE code. Accordingly, a MSE Code Technical Expert was hired 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 this purpose, the contract was issued to Dr. Emilius Aalto (through the Ocean Foundation - USA), for reviewing the code and algorithms used in BFT MSE and verifying if they perform as expected, including checking code to ensure correct recreation of Trial Specification Document (TSD) equations, identifying code that is used in modelling that is not documented in the TSD and identifying areas where code may be made more computationally efficient. The final report is expected before December 2021.

4.5.3. 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 programme. 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 succeeded 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. Last presential meeting of this Group was held in February 2020.

5. Overall GBYP use of data and results

One of the principal objectives of the GBYP is to improve the basic data for their use in the various assessment and modelling approaches. Several types of data obtained by GBYP have been specially formatted and subsequently incorporated in the databases maintained by the ICCAT Secretariat. Other data, that could not be incorporated due to inexistence of a specific database, have been maintained and analysed separately and the final results have been provided directly to SCRS. The data provided by GBYP have been used for the bluefin tuna stock assessment in both 2014 and 2017 and are currently used for the purpose of MSE.

Here below are listed some of the greatest achievements and contribution of the Programme, by line of investigation:

Data mining

- Size data
- LL CPUE
- Historical trap data
- BB data
- Non-GBYP electronic tag data recovered by GBYP
- Historical maturity data
- Historical genetic data

Aerial survey on BFT spawning aggregation

- A 7 years long series of fisheries independent index for adult BFT in 4 spawning areas in the Mediterranean (under revision)

Tagging

- Conventional and electronic tag data
- Growth data from conventional tags
- Mixing determination (MSE areas movement matrices)
- BFT temperature and depth preferences revealed by electronic tags
- Recoveries of tags deployed by other teams on BFT
- Development of improved tagging protocols

Biological studies

- Length/weight correlation
- Reproductive parameters
- Age length key
- Population structure

- Genetic and microchemical studies for stock assignment
- Mixing determination (MSE areas)
- Development of stock of origin assignment methods
- BFT tissue bank with on-line accessible inventory
- Workshop on BFT reproductive biology
- Workshop on BFT larval studies
- Workshop on BFT electronic tagging
- Workshop on close kin mark recapture for Eastern BFT
- Development of sampling protocols
- Development of otolith reading protocols
- Development of otolith cutting protocols

Modelling and MSE

- Development of ABT-MSE analysis software
- Development of ABT MSE Shiny App
- OM development
- SAM application
- VPA training course
- Financial support for organization of BFT MSE technical group meetings, including participations of modelling coordinator and several experts

It is also worth mentioning that so far GBYP has awarded 183 contracts to 66 entities, localized in 26 different countries, involving therefore a work of many hundreds of researchers and technicians. This large and open participation to ICCAT GBYP activities is also considered an important achievement of this research programme.

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
Coordination	210,000	453,000	225,000	600,245	342,000	383,000	415,745	312,500	227,000
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
Biological Studies		505,000	430,000	364,000	363,000	556,000	580,000	583,000	710,000
Tagging	40,000	890,000	1,175,000	1,229,979	669,500	844,000	262,000	159,000	177,500
Modelling		40,000	65,000	122,100	211,000	177,000	121,240	143,000	99,725
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**

Table 2. Number of conventional tags sent to different collaborators in Phase 10 (from March 2020 until March 2021).

Country	Institution	Conventional tags (number)
EU-IRELAND	Marine Institute	2675
EU-SWEDEN	Havsfiskelaboratoriet	250
EU-MALTA	OCEANIS srl	300
EU-SPAIN	Ministerio de Educación y Ciencia	50

Table 3. Number of fish tagged during Phase 10 (from March 2020 until March 2021).

	ALL FISH TAGGED	FISH SINGLE TAGGED		FISH DOUBLE TAGGED			
		FT-1-94	FIM-96 or BFIM-96	Double Tags - Conventional	Mini-PATS + Conv.	MiniPATS+ 2Conv.	Archivals + Conv.
Canada	5				5		
Bay of Biscay	3						3
Central Med.	224	13	211				
North and Celtic Seas	836	56	725	16	17	17	5
Canary Islands	1						1
TOTAL	**1069**	**69**	**936**	**16**	**22**	**17**	**9**
		1005		**64**			

Table 4. Number of tags implanted during Phase 10 (from March 2020 until March 2021).

	TOTAL NUMBER OF TAGS	TAGS IMPLANTED			
		FT-1-94	FIM-96 or BFIM-96	Mini-PATs	Archivals
Canada	10		5	5	
Bay of Biscay	6	3			3
Central Med.	224	13	211		
North and Celtic Seas	908	100	764	34	5
Canary Islands	2	1			1
TOTAL	**1150**	**117**	**985**	**39**	**9**

Table 5. Number of fish tagged since the beginning of GBYP (up to 1 March 2021).

	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.	Mini-PATS + 2Conv.	MiniPAT+ Acoustic + Conv.	Archivals + Conv.	Archivals + 2Conv.	Acoustic + Conv.
Canada	2139	0	2129	0	0	10	0	0	0	0	0
Bay of Biscay	7718	4173	15	3	3493	18	0	0	16	0	0
Morocco	365	129	48	45	121	14	0	7	0	0	1
Portugal	347	53	39	94	154	7	0	0	0	0	0
Strait of Gibraltar	5561	2254	43	0	3212	22	5	0	23	2	0
West Med.	1822	1060	377	28	352	5	0	0	0	0	0
Central Med.	3394	1150	1706	32	479	15	0	0	12	0	0
East Med.	99	49	0	50	0	0	0	0	0	0	0
North and Celtic Seas	1286	333	773	4	84	51	36	0	5	0	0
Canary Islands	1	0	0	0	0	0	0	0	1	0	0
GRAND TOTAL		**9201**	**5130**	**256**	**7895**	**142**	**41**	**7**	**57**	**2**	**1**
	22732	**SUBTOTAL = 14587**		**SUBTOTAL = 8145**							

Table 6. Number of tags implanted since the beginning of GBYP (up to 1 March 2021).

	TOTAL NUMBER OF TAGS	TAGS IMPLANTED				
		FT-1-94	FIM-96 or BFIM-96	Mini-PATs	Archivals	Acoustic
Canada	2149	0	2139	10	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.	2178	1413	732	33	0	0
Central Med.	3800	1629	2112	47	12	0
East Med.	99	49	0	50	0	0
North and Celtic Seas	1499	473	930	91	5	0
Canary Islands	2	1	0	0	1	0
TOTAL	**30613**	**17196**	**12904**	**446**	**59**	**8**

Table 7. Tag recoveries from double tagged fish by type (up to 1 March 2021).

Release	Spaghetti tag only	Double Barb Tag only	Both	TOTAL FISH	TOTAL TAGS
2011	5	9	12	26	38
2012	19	32	55	106	161
2013	35	30	84	149	233
2016	1	2	1	4	5
2017	7	13	15	35	50
2018			2	2	4
Total N	67	86	169	322	491
Total percent	**21%**	**27%**	**52%**		

Table 8. Total number of bluefin tuna sampled in Phase 10 by area and size class.

		Size-class sampled					
		Larvae	**Age 0**	**Juvenile**	**Medium**	**Large**	
			<3 Kg	**3-25 Kg**	**26-100 Kg**	**>100 Kg**	**TOTAL**
Central Mediterranean	Malta					752	752
Western Mediterranean	South Spain		31				31
	Balearic Sea	2258				310	310 (+*2258*)
Strait of Gibraltar	Gibraltar		1		109	16	126
Northeast Atlantic	Bay of Biscay					15	15
	Portugal						0
East Atlantic	Canary Islands					25	25
Norwegian Sea/North Sea	Norway					400	400
Central and North Atlantic	Central and North Atlantic					180	180
	TOTAL	**2258**	**32**	**0**	**109**	**1698**	1839 (+*2258*)

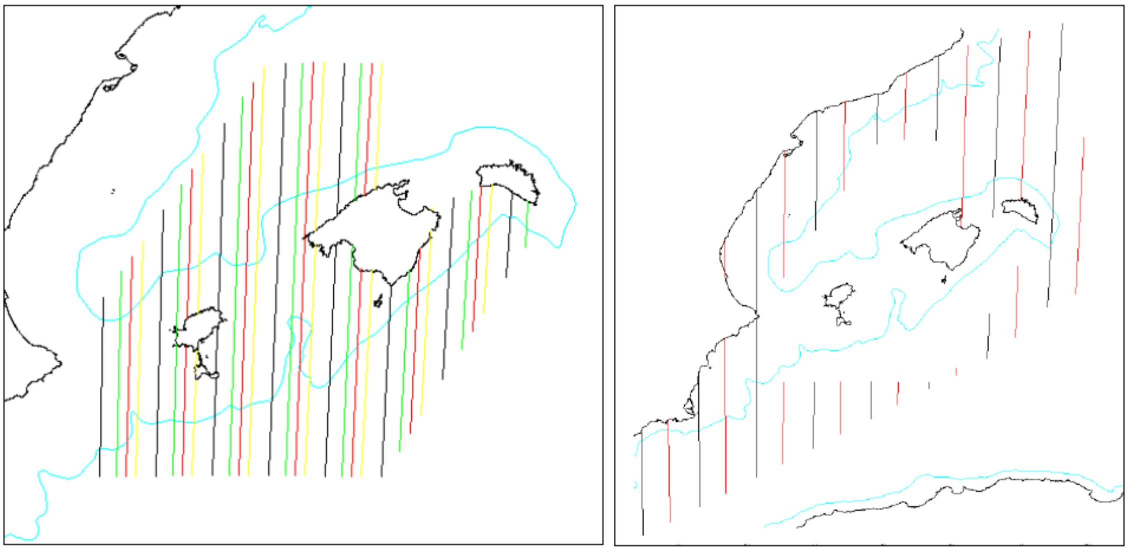

Figure 1. Aerial survey in the Balearic Sea in 2021 - Transects in area IN (left) and area OUT (right).

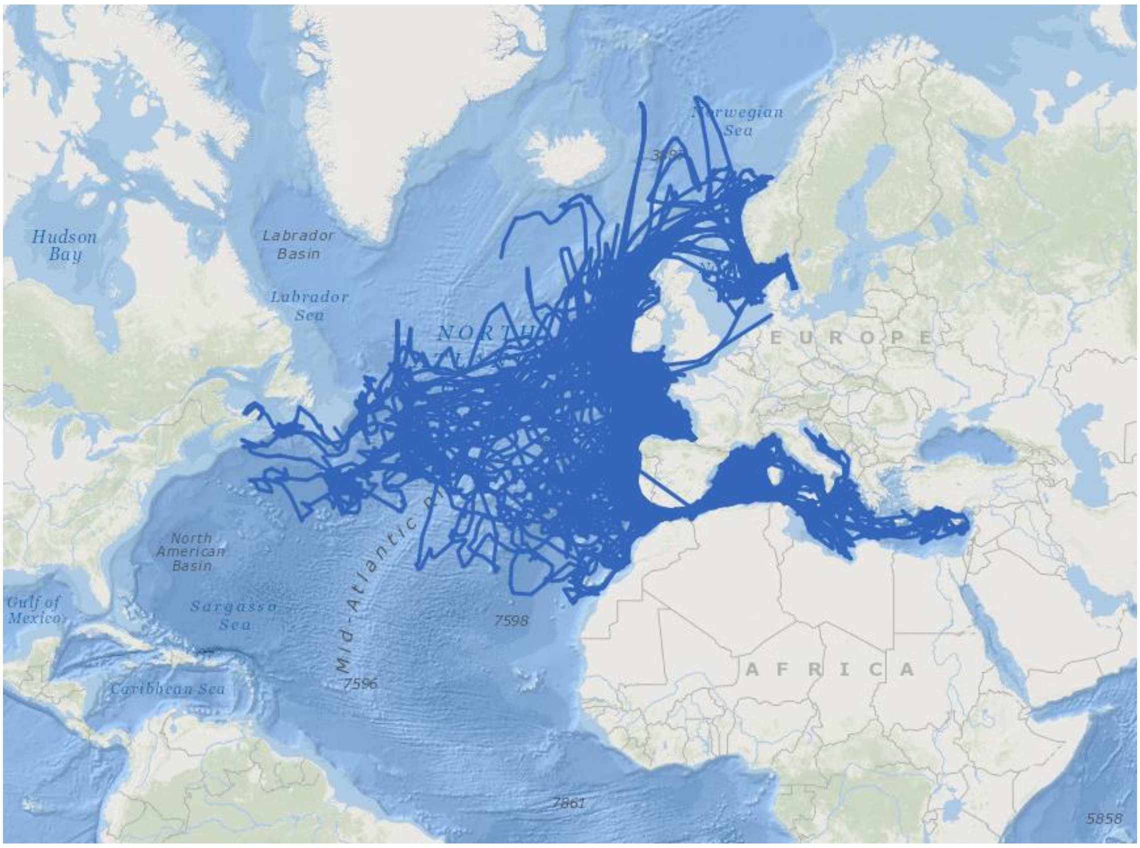

Figure 2. Currently available electronic tag tracks, for tags deployed by GBYP up to 2021.

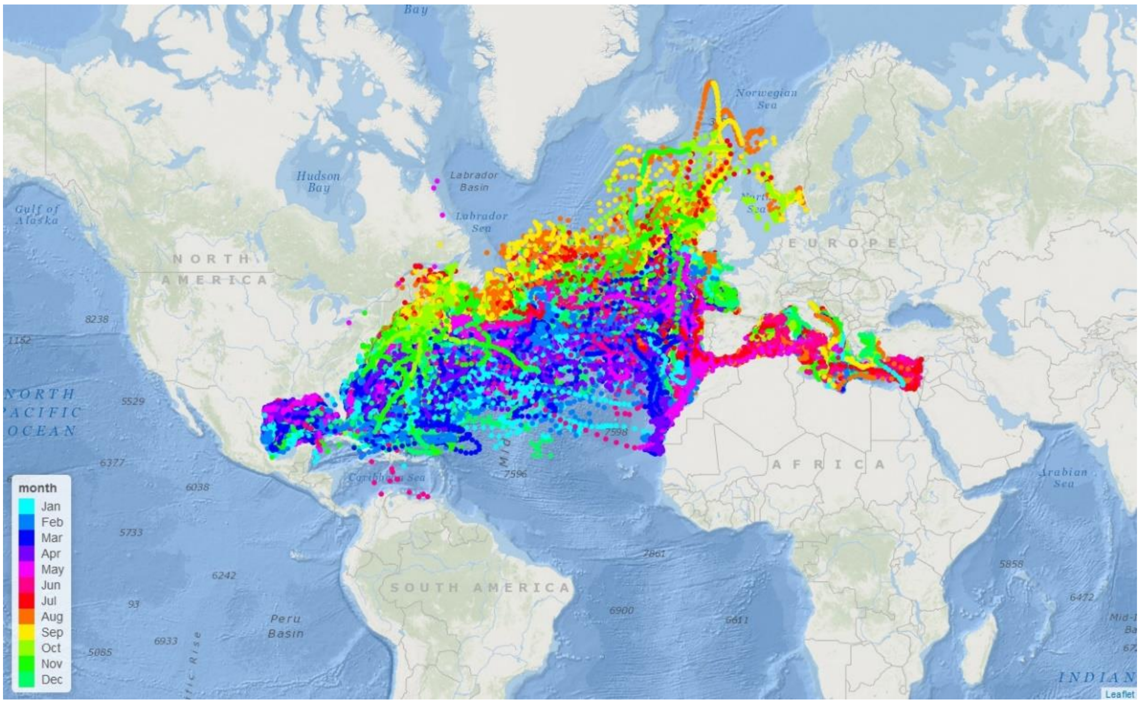

Figure 3. Currently available electronic tags tracks, for tags deployed by GBYP and acquired through data recovery activity from other programs. Daily positions are colored by month.

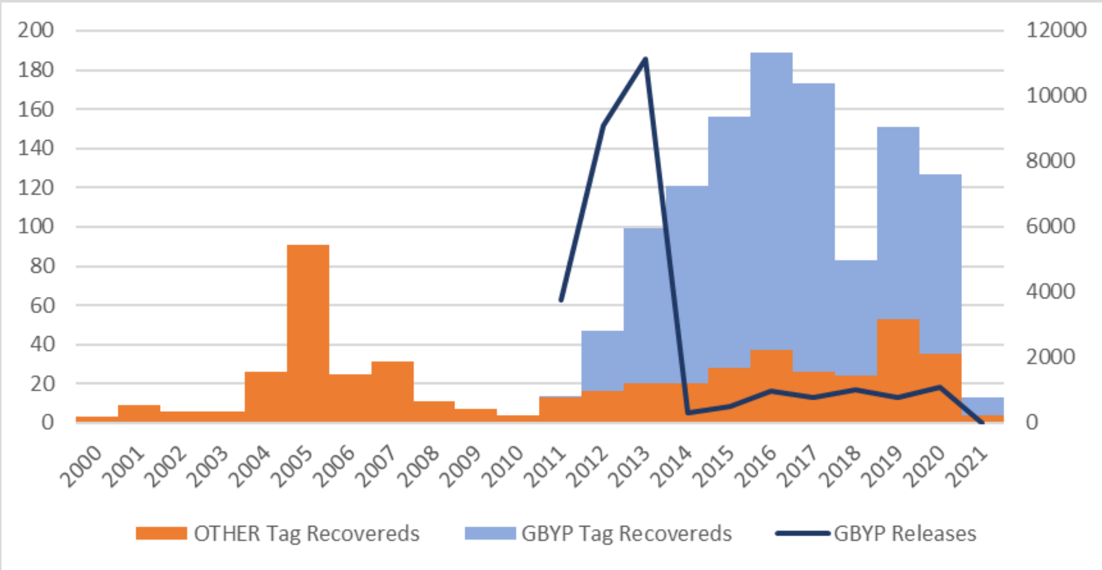

Figure 4. Annual trend of bluefin tuna tag recoveries reported to ICCAT since 2002 (up to 1 March 2021).

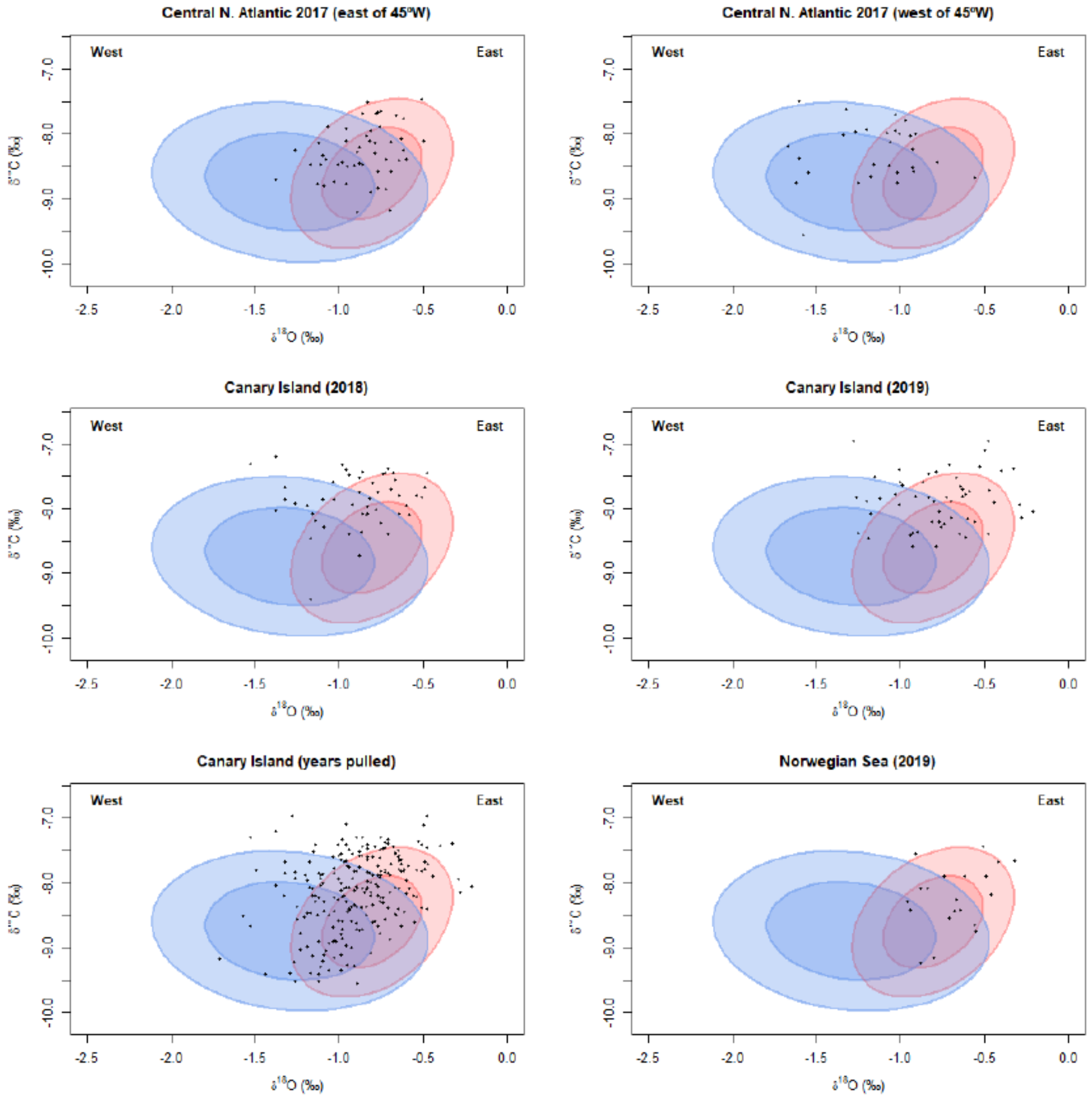

Figure 5. Confidence ellipses (1 and 2 SD or ca. 68% and 95% of sample) for otolith δ13C and δ18O values of yearling bluefin tuna from the east (red) and west (blue) nurseries along with the isotopic values (black) for otolith cores of bluefin tuna captured by Japanese longliners operating in the central North Atlantic in 2017 (east and west of the 45ºW boundary; N=79), Spanish baitboat fishery around the Canary Islands in 2018 (N=49) and 2019 (N=54), and by Norwegian purse-seiners in 2019 east (N=20).

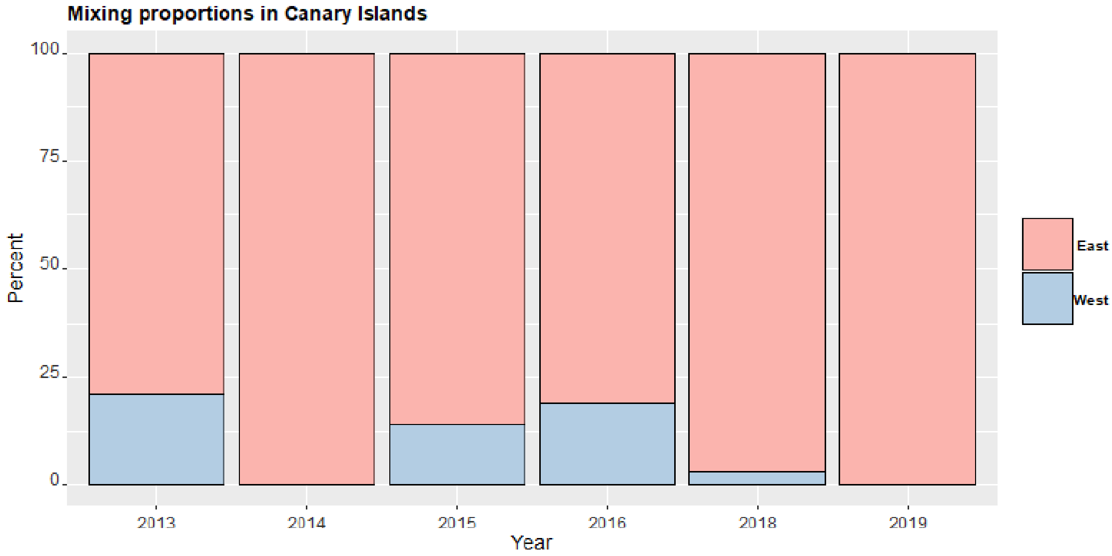

Figure 6: Interannual variation of the mixing proportions in the Canary Islands estimated by Maximum Likelihood Estimator (HISEA program). Data from 2018 and 2019 were analyzed during the current phase.

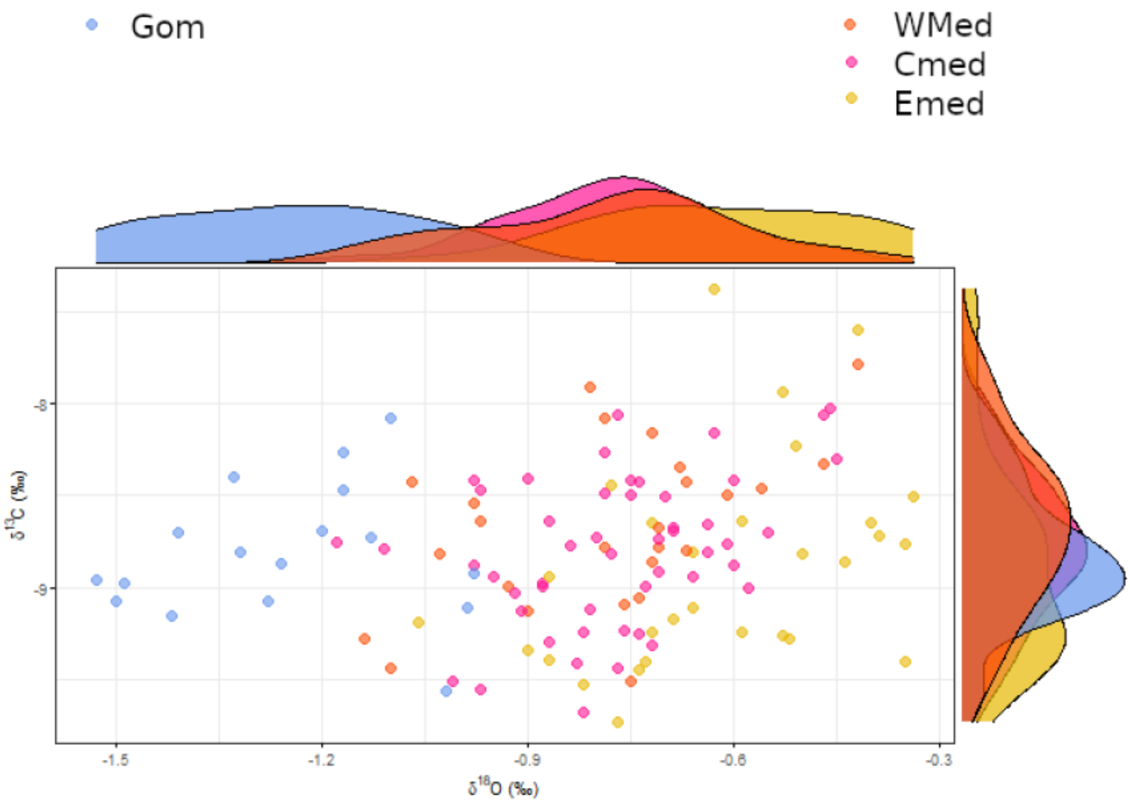

Figure 7: Scatter and density plots of δ13C and δ18O values in otoliths of adult bluefin tuna spawning in the Gulf of Mexico (Gom) and western, central and eastern Mediterranean Sea (WMed, CMed and EMed respectively).

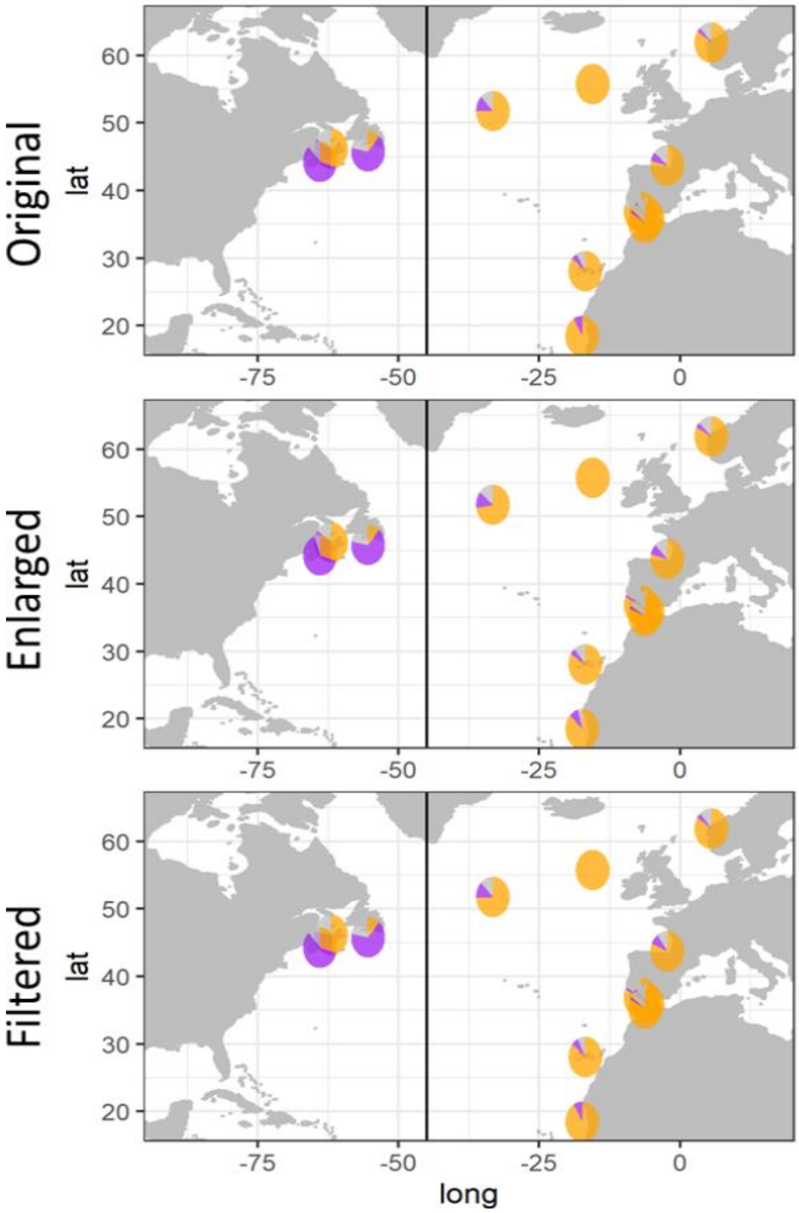

Figure 8. Proportion of samples assigned to Mediterranean (orange) or Gulf of Mexico (purple origin and unassigned (grey) from different locations using the three different baselines analyzed.

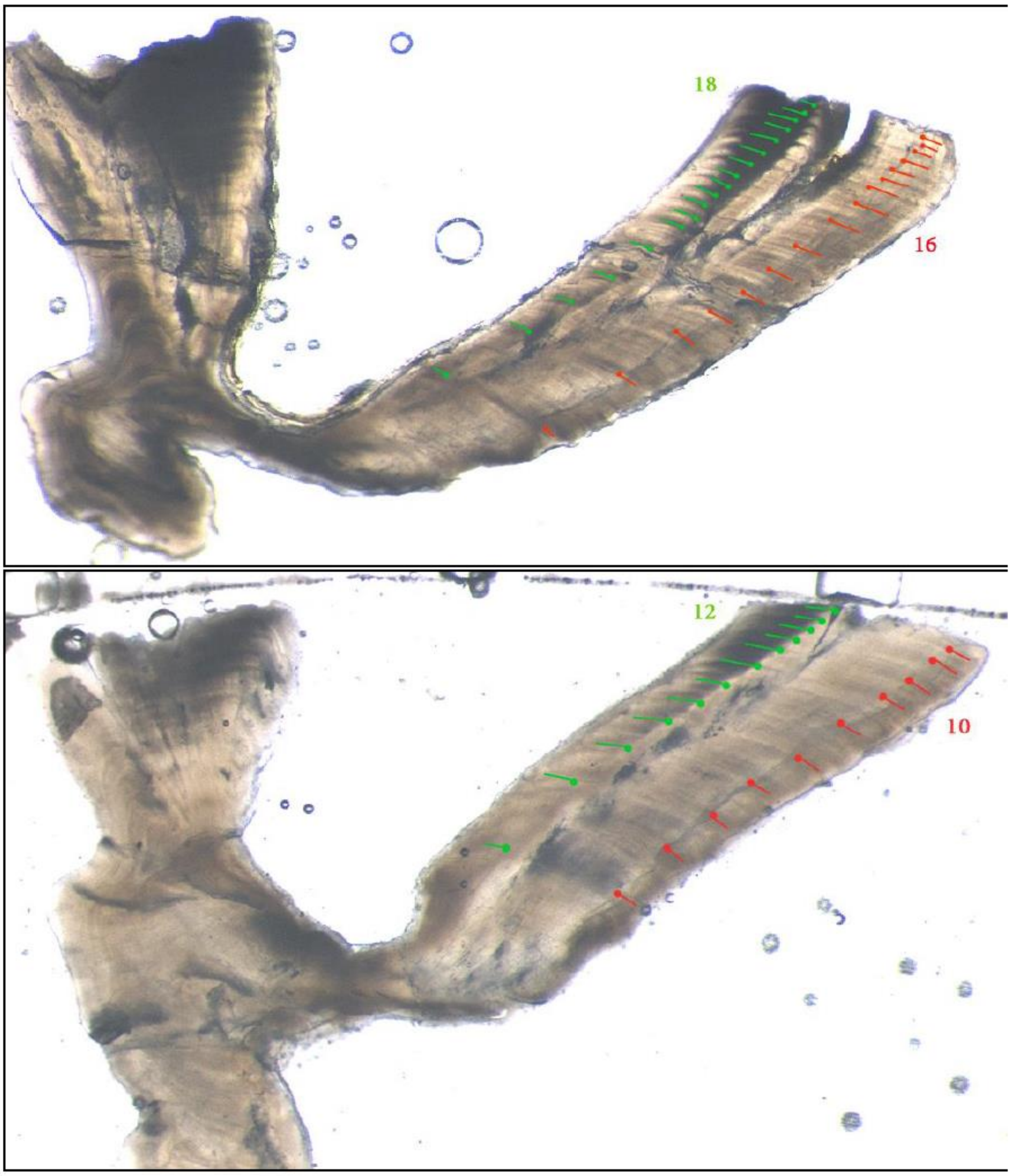

Figure 9. Images of bluefin tuna otolith sections with different band counts on the inner and outer part of the ventral arm.

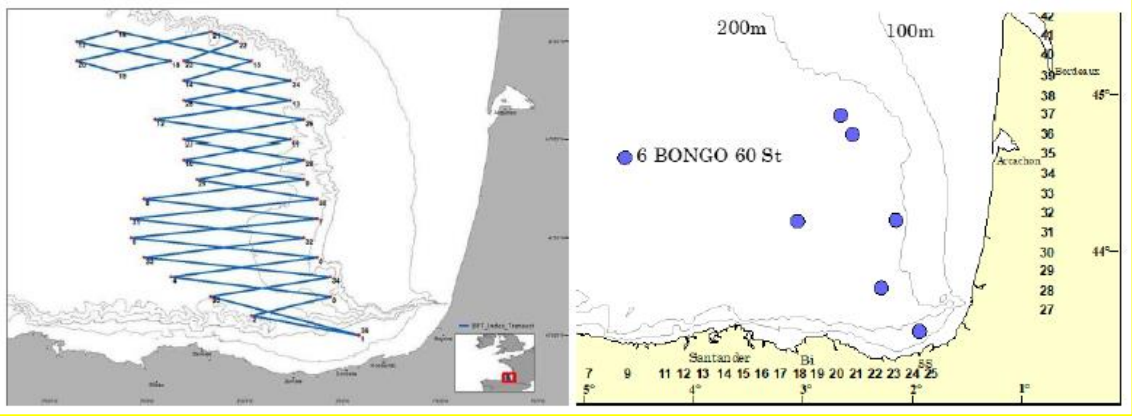

Figure 10. Area of study with acoustic transects (blue lines) (left) and Bongo 60 plankton stations (right).

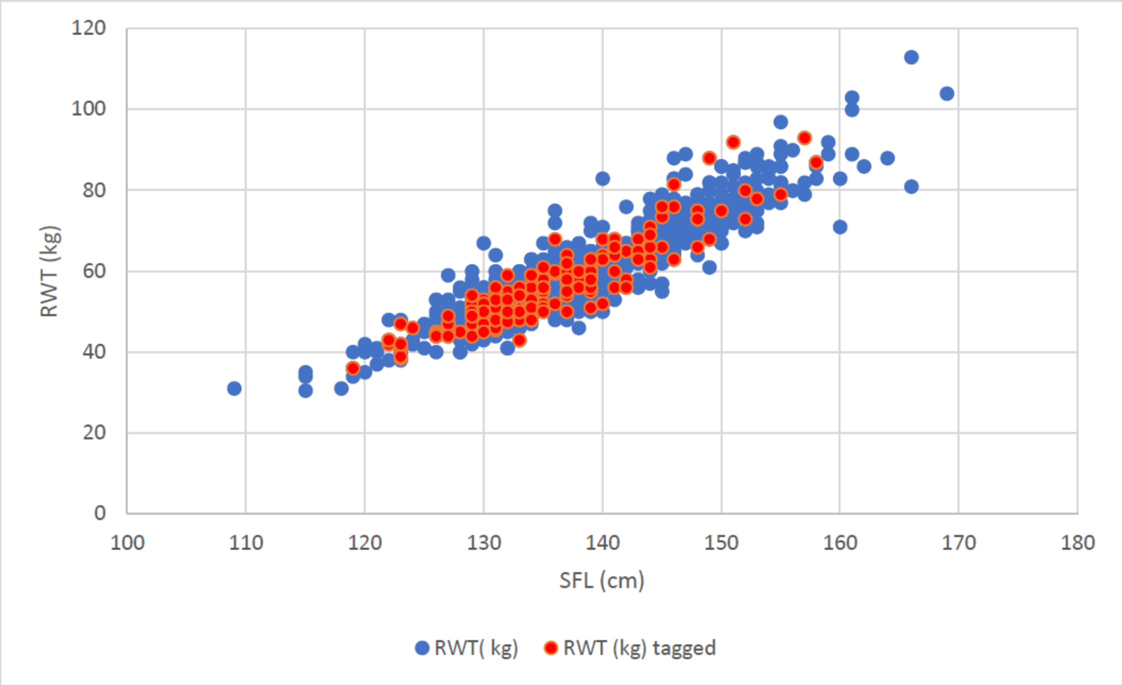

Figure 11. L-W distribution of tagged (n=156) and non-tagged (n=938) bluefin tuna from experimental cages #1 and #5 in Pelagos Net Farma (Croatia).

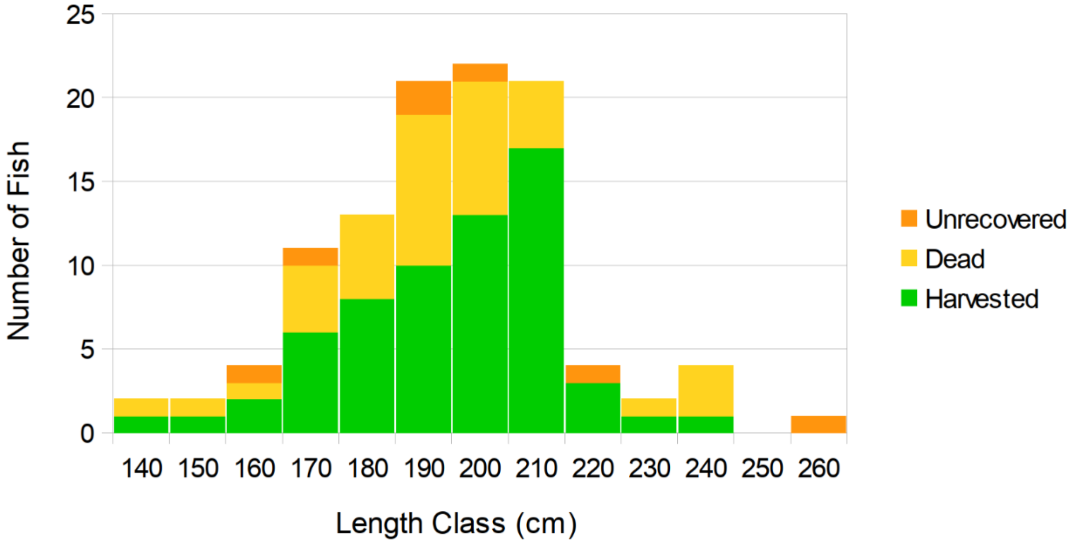

Figure 12. Number of fish tagged per 10cm size class with Number of Fish Harvested (Green), Dead (Yellow) and Unrecovered (Orange) in Taxon farm (Portugal).

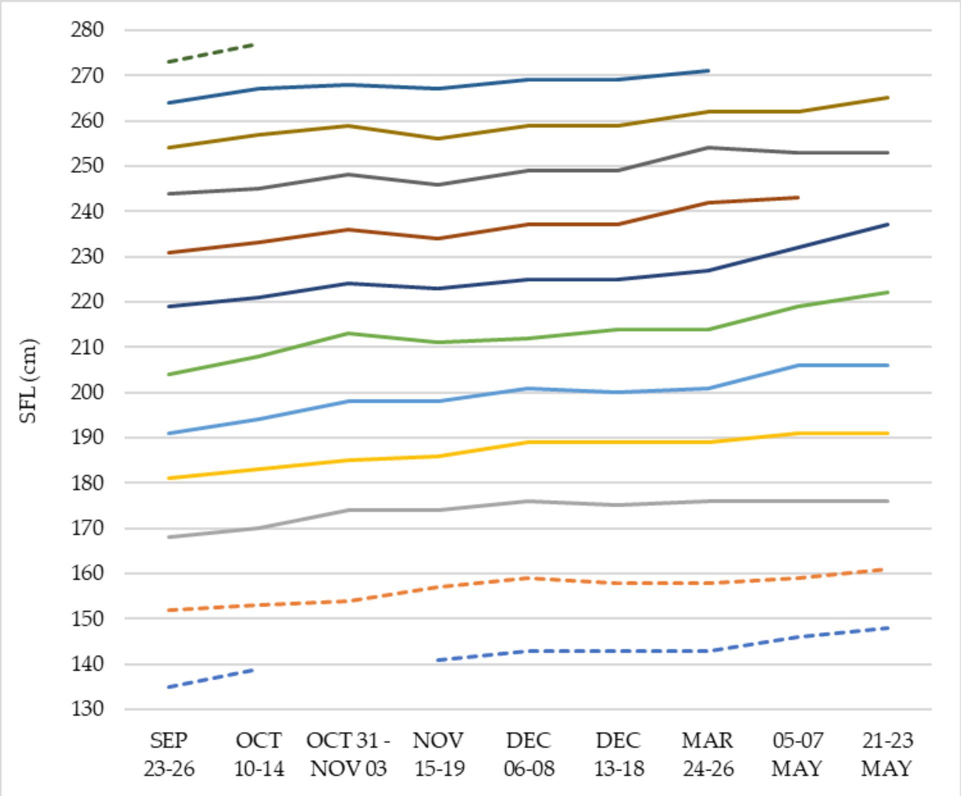

Figure 13. UPV-Pilot study. Identification of cohorts and evolution of average SFL resulting from Bhattacharya's method. Cohorts with few specimens represented in dashed-lines.

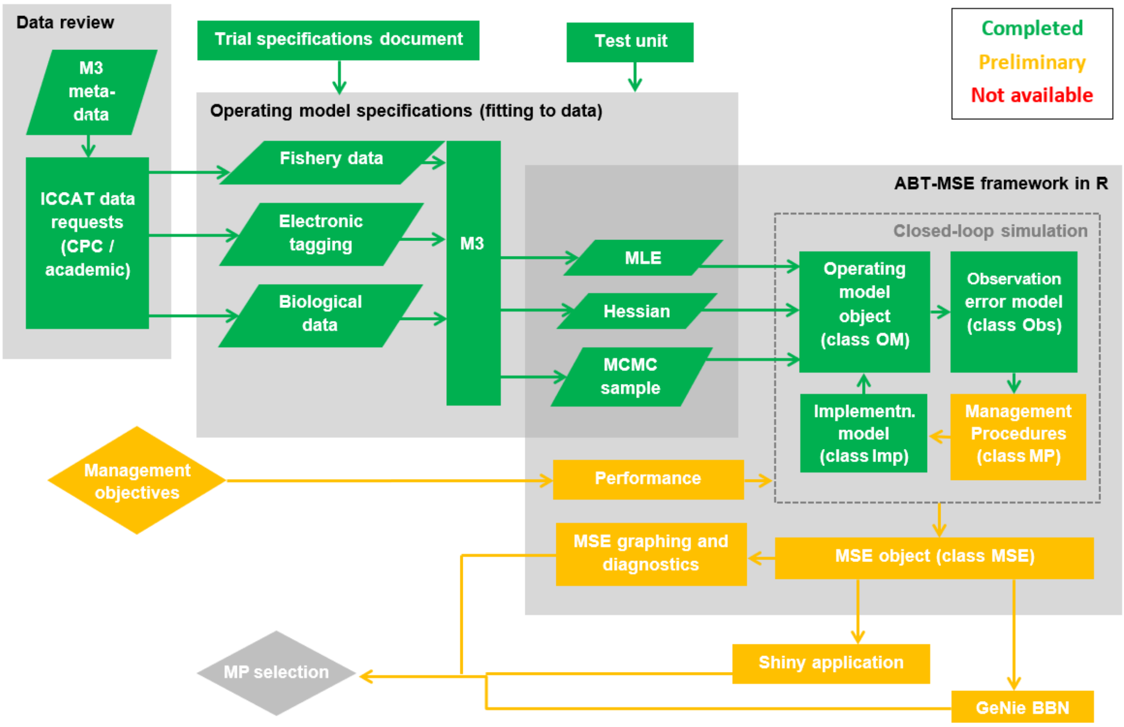

Figure 14. Current status of the components of the ABT MSE framework showing the preliminary nature of Management Procedures and Management objectives (and hence all components downstream).

Annex 1

List of reports and scientific papers in Phase 10

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

1. Aerial survey – January 2021. Short-term contract for the revision of GBYP aerial survey design, implementation and statistical analyses (ICCAT GBYP 12/2020) – Final report. Center for Independent Experts: 1-36.
2. Aerial survey – July 2021. Short term contract for the pilot aerial survey incorporating digital systems for the monitoring of bluefin tuna spawning aggregations in the Balearic Sea (ICCAT GBYP 03/2021). Final report on field operations. Action Air Environnement: 1-44.
3. Biological studies – July 2021. Short term contract for biological studies (ICCAT GBYP 08/2020). Final report. Consortium led by AZTI: 1-109.
4. Biological studies – March 2021. Short term contract for biological studies –sampling of adults (ICCAT GBYP 11/2020). Final report. Taxon Estudios Ambientales: 1-17.
5. Biological studies – January 2021. Short term contract for biological studies –sampling of adults (ICCAT GBYP 11/2020). Final report. Ministry for Agriculture, Fisheries and Animal Rights – Department of Fisheries and Aquaculture MAFA-DFA: 1-21.
6. Biological studies –April 2021. Short term contract for growth in farms study (ICCAT GBYP 04/2020). Final report. AquaBioTech: 1-7.
7. Biological studies –May 2020. Short term contract for growth in farms study (ICCAT GBYP 02/2020). Final report. Balfego & Balfego: 1-5.
8. Biological studies – July 2021. Short term contract for growth in farms study (ICCAT GBYP 07/2020). Final report. Balfego & Balfego: 1-7.
9. Biological studies –26 July 2021. Short term contract for growth in farms study (ICCAT GBYP 05/2020). Final report. Pelagos Net Farma: 1-27.
10. Biological studies –12 February 2021. Short term contract for growth in farms study (ICCAT GBYP 03/2020). Final report. Tunipex: 1-18.
11. Biological studies – 26 July 2021. Short term contract for growth in farms pilot study (ICCAT GBYP 10/2020). Final report. Universitat Politecnica de Valencia UPV: 1-33.
12. Modelling – 9 December 2020. Short term contract for the modelling approaches. Support to bluefin tuna stock assessment (ICCAT GBYP 06/2020). Evaluating Management strategies. Final report. Blue Matter Science: 1-15.
13. Modelling – 24 September 2020. Specifications for MSE Trials for Bluefin Tuna in the North Atlantic. Version 20-03. Anon: 1-51.
14. Tagging – 4 December 2020. Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2020. Final report. DFO Fisheries and Oceans Canada: 1-6.
15. Tagging – April 2021. Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2020. Final report. Consortium led by DTU Technical University of Denmark: 1-13.
16. Tagging – 15 December 2020. Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2020. Final report. IMR Institute of Marine Research: 1-15.
17. Tagging – February 2021. Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2020. Final report. Consortium led by Marine Institute: 1-22.
18. Tagging – 10 August 2021 Memorandum of Understanding for ICCAT GBYP Electronic tagging in 2020. Final report. AZTI Fundacion: 1-4.
19. Coordination – 13 October 2020: ICCAT GBYP Steering Committee Meeting, Report, Anon: 1-3.
20. Coordination – 16 November 2020: ICCAT GBYP Steering Committee Meeting, Report, Anon: 1-7.
21. Coordination – 8 January 2021: ICCAT GBYP Steering Committee Meeting, Report, Anon: 1-3.

22. Meetings - October 2020, Report of the Standing Committee on Research and Statistics (SCRS). SCRS Advice to the Commission, Anon: 1-362.

23. Meetings – May 2020, Report of the 2020 Intersessional Meeting of the ICCAT Bluefin Tuna Species Group. Report. Anon: 1-56.

24. Meetings – July 2020, Report of the 2020 Second Intersessional Meeting of the ICCAT Bluefin Tuna Species Group. Report. Anon: 1-74.

25. Meetings – December 2020, Report of the 2020 Third Intersessional Meeting of the ICCAT Bluefin Tuna Species Group. Report. Anon: 1-36.

26. Meetings – February 2020, Report of the 2020 Intersessional Meeting of the ICCAT Bluefin Tuna MSE Technical Group. Report. Anon: 1-42.

27. Meetings – September 2020, Report of the 2020 Second Intersessional Meeting of the ICCAT Bluefin Tuna MSE Technical Group. Report. Anon: 1-20.

28. Meetings – March 2020, Report of the Intersessional Meeting of Panel 2. Report. Anon: 1-175.

29. Aerial survey – August 2021. Short term contract for the GBYP aerial survey data re-analysis following a model-based approach. The University Court of the University of St. Andrews (CREEM). Design-based inference to estimate density, abundance and biomass of bluefin tuna, Reanalysis of 2010-2019 Aerial Surveys. Final report: 1-30.

30. Aerial survey – August 2021. Short term contract for the GBYP aerial survey data re-analysis following a model-based approach. The University Court of the University of St. Andrews (CREEM). Model-based inference to estimate density and abundance of bluefin tuna: feasibility study. Final report: 1-20.

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

1. Brophy D, Rodriguez-Ezplelta N, Fraile I, Arrizabalaga, H. 2020. Combining genetic markers with stable isotopes in otoliths reveals complexity in the stock structure of Atlantic bluefin tuna (Thunnus thynnus). Sci Rep 10, 14675 (2020). https://doi.org/10.1038/s41598-020-71355-6
2. Carruthers T, 2020. Reference set Operating Models (version 6.5) for Atlantic bluefin tuna assuming priors for area-specific scale and western stock mixing (SCRS/2020/018) Collect. Vol. Sci. Pap. ICCAT, 77(2): 78-95
3. Rodriguez-Marin E., Addis P., Allman R., Bellodi A., Busawon D., Garibaldi F., Luque P.L., and Quelle P. 2020. Calibration of the Fish Ageing Services readings, carried out in GBYP Phase 7, to estimate age of bluefin tuna from the eastern Atlantic stock (SCRS/2020/068) Collect. Vol. Sci. Pap. ICCAT, 77(2): 312-324
4. Alemany F., Tensek S., Pagá García A. 2020. ICCAT Atlantic-Wide Research Programme for Bluefin tuna (GBYP) Activity report for Phase 9 and the first part of Phase 10 (2019-2020) (SCRS/2020/124) Collect. Vol. Sci. Pap. ICCAT, 77(2): 666-700
5. Carruthers T., Butterworth D., and Rademeyer R. (2020.) PART 1: Investigation of the impact of spatial distribution of mean available biomass on Operating Model projection outcomes (SCRS/2020/126). Not published.
6. Anonymous, 2020. The BFT Farm Growth Sub-Group status of activities (SCRS/2020/129) Collect. Vol. Sci. Pap. ICCAT, 77(2): 713-722
7. Carruthers T. 2020. Designing and testing a multi-stock spatial management procedure for Atlantic bluefin tuna (SCSR/2020/150) Collect. Vol. Sci. Pap. ICCAT, 77(2): 7832-840
8. Buckland S.T. 2020. Independent peer review of the revision of GBYP aerial survey design, implementation and statistical analyses (ICCAT GBYP 12/2020) of the Atlantic-wide research programme for bluefin tuna (ICCAT GBYP Phase 10) (SCSR/2020/162) Collect. Vol. Sci. Pap. ICCAT, 77(2): 977-987
9. Vølstad J.H. 2020. Review of the revision of GBYP aerial survey design, implementation and statistical analyses (ICCAT GBYP 12/2020) of the Atlantic-wide research programme for bluefin tuna (ICCAT GBYP Phase 10) (SCSR/2020/163) Collect. Vol. Sci. Pap. ICCAT, 77(2): 988-1005
10. Carruthers T. 2020. Designing and testing a multi-stock spatial management procedure for Atlantic bluefin tuna (SCSR/2020/165) Collect. Vol. Sci. Pap. ICCAT, 77(2): 1015-1032
11. Anonymous. 2021. Report of the 2021 ICCAT GBYP workshop on close-kin mark recapture for Eastern Atlantic bluefin tuna (SCRS/2021/023)
12. Anonymous. 2021. Report of the 2021 ICCAT GBYP workshop on electronic tagging for Atlantic bluefin tuna (SCRS/2021/024)
13. Carruthers, T. 2021. Training an A.I. CMP for Atlantic bluefin tuna (SCRS/2021/028)
14. Carruthers, T. 2021. Updated CMP results following second round of CMP refinements (SCRS/2021/046)
15. Anonymous, 2020. Report of the ICCAT Atlantic-Wide Research Programme for Bluefin Tuna (ICCAT GBYP) (Activity report for the last part of Phase 9 and the first part of Phase 10 (2019-2020)), SCI-???/2020

Annex 2

GBYP Contracts issued in Phase 10

COORDINATION				
ACTIVITY	**RETAINED PROPOSAL**	**working schedule** initial date	final date	**COST**
	Steering Committee External Expert – Ana Parma	02/09/2020	30/06/2021	15.000,00 €
AERIAL SURVEY				
ACTIVITY	**RETAINED PROPOSAL**	**working schedule** initial date	final date	**COST**
12/2020	AS independent review – Center for independent experts (USA)	20/08/2020	30/11/2020	27.996,42 €
03/2021	AS pilot study in the Balearic Sea – Action Communication – Action Air Environnement (France)	03/06/2021	31/07/2021	221.950,00 €
4/2021	University St Andrews – Creem (United Kingdom)	28/06/2021	31/07/2021	26.513,00 £
TAGGING PROGRAMME				
ACTIVITY	**RETAINED PROPOSAL**	**working schedule** initial date	final date	**COST**
MoU	Tagging off Newfoundland - DFO Fisheries and Oceans Canada	31/07/2020	31/07/2021	-
MoU	Tagging in the North Sea - Consortium led by DTU Technical University of Denmark	31/07/2020	31/07/2021	-
MoU	Tagging off Norway - IMR Institute of Marine Research (Norway)	31/07/2020	31/07/2021	-
MoU	Tagging off Ireland - Consortium led by Marine Institute (Ireland)	31/07/2020	31/07/2021	-
MoU	Tagging in the Bay of Biscay - AZTI Fundacion (Spain)	31/07/2020	31/07/2021	-
BIOLOGICAL SAMPLING AND ANALYSES				
ACTIVITY	**RETAINED PROPOSAL**	**working schedule** initial date	final date	**COST**
08/2020	Biological studies sampling and analyses – Consortium led by AZTI (Spain)	20/07/2020	26/07/2021	309.577,00 €
11/2020	Sampling adult BFT in farms – Taxon (Spain)	28/08/2020	31/03/2021	42.700,90 €
11/2020	Sampling adult BFT in farms – Consortium led by MAFA DFO (Malta)	02/09/2020	31/12/2020	43.000,00 €
02/2020	Growth in farms study – Balfego (Spain)	12/02/2020	30/06/2020	6.000,00 €
03/2020	Growth in farms study – Tunipex (Portugal)	27/05/2020	28/02/2021	43.000,00 €
04/2020	Growth in farms study – AquaBioTech (Malta)	07/02/2020	31/12/2020	28.250,00 €

05/2020	Growth in farms study – Pelagos Net Farma (Croatia)	28/02/2020	31/03/2021	58.914,00 €
07/2020	Growth in farms study and sterocams pilot project – Balfego (Spain)	10/06/2020	15/07/2021	62.250,00 €
10/2020	Stereocams pilot project – Polytechnic University of Valencia (Spain)	13/07/2020	26/07/2021	95.855,00 €
MODELLING APPROACHES				
ACTIVITY	**RETAINED PROPOSAL**	**working schedule**		**COST**
		initial date	**final date**	
06/2020	MSE Expert – Blue Matter Science (Canada)	06/02/2020	28/12/2020	100.000,00 €
01/2021	MSE Expert (second contract) – Blue Matter Science (Canada)	28/01/2021	31/03/2021	18.940,00 €