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Report of the ICCAT Atlantic-Wide Research Programme for Bluefin Tuna (ICCAT GBYP)

(Activity report for the last part of Phase 11 and the first part of Phase 12 (2021-2022))

1. Introduction

The ICCAT Atlantic-wide Research Programme for Bluefin Tuna (GBYP) started officially at the end of 2009, with the objectives of improving a) basic data collection, including fishery independent data; b) understanding of key biological and ecological processes and c) assessment models and provision of scientific advice on stock status. The general information about GBYP activities and its results, as well as on budgetary and other administrative issues of the GBYP programme, from the very beginning of the programme until today, are available on the GBYP webpage. All the relevant documents related to programme development, including final reports of every activity and the derived scientific papers, Annual Reports to the SCRS and European Union, GBYP workshops or Steering Committee meetings reports, are also readily available on the GBYP webpage.

The eleventh phase of the GBYP officially started on 1 January 2021 following the signature of the Grant Agreement for the co-financing of GBYP Phase 11 (SI2.839201) by the European Commission. The initial duration of the Phase was one year, but in order to better adjust to the period of bluefin tuna fishing and harvesting operations, and to overcome the delays in some activities caused by mobility constraints derived from the COVID-19 pandemic, it was extended for eight months until 31 August 2022. The activities carried out during the first nine months of Phase 11 and their preliminary results were presented to the SCRS and the Commission in 2021 (Alemany *et al*., 2021) and approved. Following the timing imposed by the new funding agency - European Climate, Infrastructure and Environment Executive Agency (CINEA) – the 12th phase of the GBYP officially started on 24 March 2022, after the signature of the Grant Agreement (Project 101091166) by the European Commission, with a planned duration of one year. Although these two GBYP phases have been partially developed in parallel (as occurred in previous phases), this has not caused any major problems since each phase had specific work plans and budgets, and so costs can be assigned unequivocally to the activities detailed in the respective Grant Agreements.

In general, although several tasks over the last year have continued to be affected by the COVID-19 pandemic, most of the activities planned within Phases 11 and 12 have been or are being implemented successfully. The specific activities in both phases have been structured considering the same main lines of research i.e. data recovery and management; biological studies; tagging; aerial surveys; and modelling. These have been adapted to the SCRS research needs and Commission requests. Furthermore, the methodologies have been continuously improved and the working procedures optimized, to increase the efficiency and quality of the advice. The strategic shifts initiated in Phase 10 to several of these lines have been consolidated. Accordingly, data recovery activities have shifted to data management, focusing on the development of new relational databases, integrating all the information produced and gathered by the programme from the beginning. Aerial surveys have been thoroughly revised and new methodological approaches for data analyses explored (i.e. development of Model-based approaches instead of the classic design-based approach), in order to account for the potential changes in spatial distribution of spawners derived from environmental interannual variability, and hence improving the accuracy of the index time series. Tagging activities have also deepened in the new strategic approach based on close cooperation with national tagging programmes, which has greatly increased the overall efficiency and significantly reduced operational costs. Moreover, in Phase 12 a further strategic shift in biological studies has been implemented, which will progressively focus on reviewing studies based on all the data and results gathered in previous Phases, to get sound scientific conclusions, instead of the continuous generation of new data sets (unless specific requests are needed).

All activities carried out throughout GBYP Phase 11 and those launched during the first part of Phase 12, as well their final or preliminary results and the related coordination activities, are described and summarised in this report.

As mentioned above, the COVID-19 pandemic has continued to affect the development of Phase 11 and the launching of Phase 12 activities, but the experience gained over the 2020-2021 period has allowed GBYP to face successfully the challenges derived from the global scenario. The specific impacts on each line of research are detailed below. Since the temporary closure of the ICCAT Secretariat headquarters in March 2020 has been maintained throughout last year, the GBYP Coordination Team has continued to use telecommuting facilities to manage the programme without any significant impact on the coordination activities.

2. Coordination activities and general issues of GBYP programme management

The GBYP Steering Committee (SC) in Phase 11 and 12 comprises the SCRS Chair, the Western Bluefin Tuna Rapporteur, the Eastern Bluefin Tuna Rapporteur, the ICCAT Executive Secretary and/or his deputy and one contracted external expert. In order to define the workplan and refine the ongoing activities, during Phase 11, the Steering Committee held three online meetings in October, November and December 2021. In addition, its members have been constantly informed by the GBYP Coordination Team about the status of the activities through detailed reports provided on a bimonthly basis, and they have been regularly consulted by email on many issues.

The GBYP Coordination Team comprises the GBYP Coordinator, the Assistant Coordinator and the Database Specialist. The ICCAT Secretariat has provided technical and administrative support for all GBYP activities on a daily basis. In Phase 11, a total of 6 Calls for tenders and 6 official invitations were released, which resulted in 13 contracts awarded to various entities. In addition, one Call of expression of interest was published which resulted in 10 memorandums of understanding.

2.1 Financial aspects

In Phase 11 the total budget was €1,600,000.00, thanks to contributions from the following donors: European Union (Grant Agreement) €1,280,000.00, Morocco €61,981.13, Tunisia €59,028.97, Japan €53,204.87, Türkiye €50,506.30, Libya €23,164.16, Norway €19,000.00, Canada €18,843.04, Korea (Rep.) €8,717.90, United States of America €8,420.00, Albania €3,208.52, Chinese Taipei €2,000.00 and China (P.R.) €1,925.11.

In Phase 12 the total budget is €1,500,000.00, thanks to contributions from the following donors: European Union (Grant Agreement) €1,200,000.00, Morocco €57,882.26, Tunisia €50,109.54, Japan €49,686.39, Türkiye €46,716.69, Algeria €29,170.26, Norway €24,287.66, Canada €21,327.38, Korea (Rep.) €3,525.11, Albania €2,996.34, Chinese Taipei €2,000.00, China (P.R.) €1,797.80 and United Kingdom €500.57.

The residual amounts of previous GBYP Phases were used to better balance the EU contribution and to compensate costs that were not covered by EU funding in various Phases. Additional eventual residuals from the amounts provided in Phase 11 will be used for the following Phases of GBYP. It should be noted that contributions for the current and previous GBYP Phases are still pending from some ICCAT CPCs.

The approved budget for Phase 11 and Phase 12 is summarised in **Table 1**.

Table 1. Approved budget of GBYP Phases 11 and 12.

Item	Phase 11	Phase 12
Coordination	€379,000.00	€523,000.00
Data management	€55,000.00	€55,000.00
Independent indices	€370,000.00	€80,000.00
Biological studies	€380,000.00	€348,000.00
Tagging	€221,000.00	€262,000.00
Modelling	€195,000.00	€232,000.00
Total	€1,600,000.00	€1,500,000.00

3. Summary of Phase 11 and Phase 12 GBYP scientific activities and results by main line of research

3.1 Data recovery and management

The data recovery activity, which was cancelled in Phase 10, has been resumed in Phase 11 to allow the incorporation into the ICCAT DB of a new relevant set of data from 138 pop-up satellite tags deployed on western stock juveniles. However, most of efforts in this line have been devoted to the continuity of the strategic approach initiated in Phase 9, mainly based on in-house work developed within the ICCAT Secretariat through close collaboration between the Departments of Statistics and Science, SCRS scientists and the GBYP Coordination Team, focused on the development of relational databases to allow proper storage and analysis of all raw data collected within GBYP or other relevant data sources for BFT management not included yet in the current ICCAT DBs.

Specifically, the activities carried out under GBYP Phase 11, some of which were initiated in Phase 10, included:

- Update of the database integrating the data related to BFT farming, including those from stereo camera measurements and harvesting operations, and complementing them with data from eBCD and VMS systems. Within this Phase, more than 200 files and 28,000 individual BFT stereo cameras measurements have been incorporated and analysed.

- Update of the database recording the information obtained from the GBYP studies on growth in farms. As a result, a database including more than 25,000 BFT measurements, as well as data on daily feeding and environmental conditions are now available to use.

- The tasks aiming at the implementation of the work plan for the creation of a broad biological data information system have continued, in close coordination with the ICCAT Secretariat Department of Statistics. Thus, a detailed template to get relevant information about the biological sampling activities and storage procedures of biological samples was designed and already filled by some of the contractors involved in GBYP Biological Studies in previous phases. Beside this, the data on biological information and biological sampling of species under the ICCAT Convention carried out by EU countries under the EU Data Collection Framework, have been downloaded from EU portal https://datacollection.jrc.ec.europa.eu/ars, and is being processed for its inclusion in the new ICCAT biological data and information system.

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

- A new project for developing an integrated electronic tagging management system capable of managing the data from all the electronic tags released by ICCAT, or provided by CPCs' scientific teams, has been initiated in close collaboration with the Secretariat Department of Statistics. This system, called ETAGS, will be used to manage both the metadata on electronic tagging operations and the raw data generated by these electronic tags, will allow storage of data from all other ICCAT tagging programs in the future. For this purpose, a contract was signed with Dr Chi Hin Lam (Big Fish Intelligence Company Limited), to adapt a system previously developed by this company to ICCAT needs.

3.2 Stock indices: Aerial Survey on Bluefin Tuna Spawning Aggregations

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

Considering the results from the aforementioned pilot survey and those from the global revision and reanalysis of the time series carried out in 2021, as well logistic constraints, in 2019, all historical GBYP aerial survey data were re-analysed for all the areas and years in a homogeneous way, producing a new fully standardised index time series. However, the new index time series exhibited substantial differences in relation to prior time series, and still showed a high interannual variability between and within areas, which raised new concerns about the estimation procedures and the overall efficacy of the survey. Therefore, in 2020 an in-depth revision of the whole GBYP AS programme was carried out by two external experts, who provided several recommendations for its improvement, such as exploring the feasibility of incorporating automated digital observing systems, to extend, if possible, the surveyed areas, and to move from the classic design-based approach to a model-based approach aiming at overcoming the potential impact of interannual environmental variability on BFT spawners distribution and hence on index accuracy. Consequently, in 2021, under GBYP Phase 10, a pilot survey incorporating, in addition to the standard human observers-based methodology, digital systems for automatic recording of images along the transects, and covering not only the usual core area but also a extended area around it, was performed in the Balearic Sea area. In addition, a global reanalysis of the whole time series, applying both the design-based approach used from the beginning of the GBYP aerial surveys, but also exploring a new model-based approach aiming at overcoming the potential impact of interannual environmental variability on BFT spawners distribution and hence on index accuracy, was carried out by CREEMs team of the University of Saint Andrew, which is the original developer of the DISTANCE methodology applied for the design and analysis of GBYP aerial surveys from the beginning of the programme. With the available budget, the GBYP Steering Committee decided to resume, within GBYP Phase 11, the aerial survey for bluefin tuna spawning aggregations in the core areas of the Western and Central Mediterranean Sea in 2022, following the standard human observers-based methodology. It was decided that the Levantine Sea sub-area (Area G) would not be surveyed because the results obtained in previous campaigns suggest that one of the basic assumptions to apply this methodology i.e. that the BFT spawners are fully available for aerial observations, is not accomplished.

So, the three core spawning areas in the Western and Central Mediterranean are the Balearic Sea (Area A), the Southern Tyrrhenian Sea (Area C) and the Central-southern Mediterranean Sea (Area E), which have been successfully surveyed in June 2022, by ActionAir (Western Med) and Unimar/Aerial Banners (Central Med). The results from these surveys will be analyzed within GBYP Phase 12.

In parallel, in 2022 it has been signed a new contract with the Centre for Research into Ecological Environmental Modelling (CREEM) team, identified as a leading institution in the design and analysis of distance sampling surveys, for the analysis of the data from the pilot aerial survey in 2021 in the Balearic Sea area (Area A), as the complete re-analyses of GBYP aerial survey data up to 2021, providing the updated index time series following both design-based and model based approaches.

3.3 Tagging activity

The initial objectives of GBYP tagging activities were the estimation of the natural mortality rates of bluefin tuna populations by age or age-groups, the evaluation of habitat utilization and large-scale movement patterns (spatio-temporal), including estimates of mixing rates between stock units by area and time strata, of both juveniles and spawners. However, this line of research faced two important problems which limited the full achievement of these objectives: i) the very low recovery rate of conventional tags, which impeded the use of these data to estimate reliable mortality rates; and, the relatively short time that most of the electronic pop-up tags remained on the fish. Therefore, some new actions to overcome the problems were initiated in Phase 9, such as improving the deployment methodology and provision of specific training to the e-tagging teams, and developing specific actions focused on increasing the involvement of ICCAT observers and farms' staff in tag detection and reporting. The results of these activities have become evident from 2019, with the average time that the tags remain attached to the fish (programmed for 1 year) increasing from 48 days in Phases 2 to 8, to an average of 245 days in Phases 9 and 10. The first results from e-tagging surveys performed within Phase 11 showed the consolidation of this trend, since many tags have remained on fish the whole programmed one-year period. Regarding actions to improve the recovery rates, these have resulted in an increase of recoveries in the Mediterranean area. In total, from March 2021 to March 2022 a total of 154 conventional and 29 e-tags have been recovered.

As in the previous season, the specific objectives of the 2021 electronic tagging campaigns 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 knowledge of the bluefin spatial patterns, focusing on filling the current knowledge gaps in the spatial patterns of juvenile and young adult fish of the western stock and those of the BFT populations inhabiting the eastern Mediterranean. Therefore, considering the good results of the new strategic approach for implementing the GBYP e-tagging programmes initiated in Phase 10, a new Call for expressions of interest was published within Phase 11 (ICCAT Circular #G-0471-2021), for deployment of a total of 70 pop-up satellite tags by experienced tagging teams in the Mediterranean and/or North Atlantic Ocean, targeting eastern stock individuals. As a result, 9 proposals were awarded, and MoUs were signed with:

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

Most of these campaigns were finished between August 2021 and March 2022 (reports available at GBYP web page), but 2 are still ongoing (MoU with IEO and Genoa University).

Moreover, in 2021 GBYP had agreed with Mediterranean Fisheries Research, Production and Training Institute (MEDFRI) from Türkiye, for deployment of 20 electronic tags in the Levantine Sea, since tagging in the Levantine Sea has been identified as one of the priorities by the Steering Committee since 2019. Unfortunately, it was not possible finally to sign the MoU and carry out the campaign due to mobility restrictions derived from the COVID-19 pandemic. Finally, in June 2022, it was possible to carry out the campaign, within the framework of a MoU signed to this end, in close collaboration with local scientists (MEDFRI), and 13 tags were successfully deployed.

A new Call for expressions of interest to collaborate with GBYP e-tagging programme was launched in April 2022, under GBYP Phase 12. As a result, 8 new proposals were received, which were awarded, and consequently 8 MoUs have been signed. These MoUs will allow to deploy 55 additional GBYP owned tags and incorporate the data in the ETAGS database in the future.

Besides these activities, GBYP has supported exceptionally e-tagging activities whose results were considered as a priority research need for the SCRS, which were carried out independently by other institutions. Such support implied sharing the relevant results with ICCAT and the permission of use of GBYP RMA in the case of BFT casualties during tagging operations. In other cases, such as that of the Italian branch of WWF Mediterranean Marine Initiative, the support consisted in the use of GBYP Argos system accounts for data transmission so that the resulting data were integrated directly in the GBYP database.

As regards conventional tagging, the GBYP programme has been maintained as a complementary activity, providing logistical support to several institutions. From March 2021 to March 2022, a total of 3,725 conventional tags have been delivered to 5 institutions.

3.4 Biological studies

One of the core activities of ICCAT GBYP are the so-called Biological Studies, including biological sampling and a series of studies based on the analysis of these samples, such as microchemical and genetics analyses to investigate mixing and population structure, with a particular focus on identifying the age structure and the probable sub-populations. Population structure is a key uncertainty for bluefin tuna, given the possibility that more than two populations or contingents coexist in the Atlantic Ocean, while ICCAT managers so far assume two separate populations with no mixing, in contrast with the fact that the stock structure assumed for the stock assessment and management purposes must be in line with the real population structure. If not, overfishing of less productive populations and under exploitation of the most productive ones can occur. Therefore, in Phase 11 several activities initiated in previous phases aiming to allow a deeper understanding of the implications of the new spawning grounds in the Atlantic Ocean (Slope Sea and Bay of Biscay) and to mixing analyses to provide accurate information and more clear alternative hypotheses to the MSE process have been maintained. In addition, GBYP has continued to support the broad study to determine BFT growth in farms, in connection with ICCAT Rec. 20-07, paragraph 8.

3.4.1 Biological sampling and analyses

- Biological sampling

During Phase 11, a total of 3198 biological samples were collected (1046 otolith samples, 995 fin spines and 1157 genetic samples) from 1189 individuals, aiming at providing data to fill the remaining knowledge gaps on BFT biology, ecology and population structure, or to update such information. All these samples have been catalogued and stored together in the GBYP biological tissue bank hosted by AZTI. In addition, the tissue bank and related information system have undergone a restructuring process to revise and standardize all the information gathered over the last 10 years of the project, with the ultimate goal of creating a database with an interface that is easily manageable for any user who requires it.

- Biological analyses: Microchemistry

Within Phase 11, the baseline for Mediterranean vs. Gulf of Mexico origin was improved, by combining stable isotope and trace element analyses and the area of otolith transverse sections best discriminating between two stocks was identified. The analyses of Sr, Ba Mg and Mn concentrations over the life cycle have allowed to develop, an effective neural network application which successfully predicted the origin of bluefin tuna with a classification accuracy of 98%. Therefore, it has been concluded that a two-dimensional mapping of trace elements allows a refined identification of individual bluefin tuna origin, which can serve to answer ecological questions, such as controversies between genetic and otolith stable isotope data. Moreover, two-dimensional mapping of trace elements allows also to identify fluctuations in specific tracers, such as Sr, Ba and Mn which provide a better understanding about stock dynamics, migration patterns or connectivity between habitats of bluefin tuna.

To further assess the spatial and temporal variability of mixing proportions, new carbon and oxygen stable isotope (δ13C and δ18O) analyses were carried out in 119 otoliths of Atlantic bluefin tuna captured in the Central North Atlantic, Norwegian Sea and western Moroccan coast. Results from these and previous analyses have allowed to conclude that the Mediterranean population is the main component of Japanese fisheries operating East of the 45ºW management boundary. Regarding the samples from the Norwegian Sea, the results showed that the Mediterranean population may be the only contributor to the Norwegian fisheries. As for the Northwest African coast (Moroccan traps), it has been identified as a putative mixing area of eastern and western populations. The contribution of western individuals to the East Atlantic fisheries is of particular interest to resource managers because of the strong asymmetrical production between the two populations.

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

- Biological analyses: Genetics

Previous research had shown that population structure of Atlantic Bluefin tuna (A-BFT) is more complex than the previous assumption of two reproductively isolated populations (Gulf of Mexico and Mediterranean Sea) that mix for feeding in the Atlantic, and that, contrastingly, individuals from the Gulf of Mexico and Mediterranean Sea interbreed. Yet, the frequency in which this interbreeding occurs in still unknown. Understanding the phenomena driving existing genetic differentiation between the Gulf of Mexico and Mediterranean populations despite this interbreeding is paramount for developing appropriate management and conservation measures. To further understand the phenomena driving genetic differentiation despite gene flow, the mixing and interbreeding dynamics of A-BFT, and to evaluate the potential epigenetic approaches for ageing in A-BFT samples, five main tasks have been carried out within Phase 11:

Task 1 - The reference dataset, which reflects better the genetic variability of Atlantic bluefin tuna, has been improved by replacing the least informative markers of the 96 SNP traceability panel by 10 newly selected ones (including 3 genetic markers for sex identification), and has been enlarged incorporating the data from the genotyping of 564 individuals using the improved 96 SNP traceability panel.

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

Task 3 - Consisted of the analysis of genetic variability at different feeding aggregates by combining genetic information based on different types of markers with otolith microchemistry data. The results showed that some samples were assigned to different origin based on otolith microchemistry and genetic markers, where the most common mismatch is Mediterranean genetic profile and Gulf of Mexico otolith origin. These individuals could correspond to individuals of Mediterranean origin performing early (yearling individuals) departures from the Mediterranean Sea, or to individuals of different origin, such as alternative spawning areas used by eastern individuals, such as the Bay of Biscay.

Task 4 - Consisted of the evaluation of the performance of the genetic sex markers included in the SNP array and the 96 SNP traceability panel for sex identification using genetic tools. Genetic markers for sex identification were successfully included in the origin traceability panel and genetic profile array, with a success rate of 80.55% with the SNP array and 89% with the 96 SNP panel. Comparison of the most frequent genotype combination in visually identified female and male individuals obtained with both methods show some differences with the expected outcomes.

Task 5 - Consisted of an evaluation of the potential of epigenetic approaches for ageing of Atlantic bluefin tuna samples to be applied for the Close-Kin Mark Recapture studies, based on an in-depth review of available bibliography. It was concluded that the development of an epigenetic clock in Atlantic bluefin tuna requires a sampling scheme that ensure good representation of the species population in terms of environment, genetic component, sex and age classes. It should be further evaluated if the expected error rates (based on previous studies on long lived species) are compatible with the application of the CKMR and if the reduced cost and logistics implied in epigenetic clock ageing compensate the implicit error rates.

- Biological analyses: Ageing

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

In Phase 11 a determination of annual periodicity in *annuli* formation in Atlantic bluefin tuna otoliths has been carried out applying the Marginal Increment Analysis (MIA) method, since controversies remain regarding the periodicity, or seasonality, of otolith growth band formation which directly influences a correct age determination of Atlantic bluefin tuna using otoliths. Results indicated that the opaque bands begin to form in July and continue to form up until October and that the *annulus* in the Atlantic bluefin tuna otolith start to form in November and peaks in May and June, with the highest percentage of wide translucent bands. This would mean to delay the date of the current 1 July adjustment criterion to 30 November. The change in the date of the otolith fitting criterion allows for a better outline of the strong 2003-year class. Consequently, ageing results based on otolith counts have been updated accordingly in the ICCAT catalogue, which also allowed to obtain a new growth curve.

- Larvae relates studies

Aiming to assess the role of the Bay of Biscay as an alternative spawning area for BFT East stock, in summer 2021, taking advantage of the BFT index acoustic survey some plankton samples were collected and analyzed under the microscope in search of BFT larvae, but there was no evidence of bluefin larvae. However, the low number of samples prevent to get any sound conclusion about the importance of this spawning site.

On the other hand, BFT 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.

3.4.2 Study on BFT growth in farms

Pursuant to a special request by the Commission to 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 (initially requested under Rec. 18-02, paragraph 28, amended by Rec. 19-04, paragraph 28, and more recently by Rec. 20-07, paragraph 8), the GBYP launched in Phase 9, following the preparatory work finished in Phase 8, several lines of research on this topic, involving ad hoc experiments in selected farms along the eastern Atlantic and Mediterranean, which included individual tagging experiments in two areas (Atlantic Portuguese southern coastal waters and Adriatic Sea) and intensive monitoring of farmed fish growth by means of stereoscopic cameras in four Mediterranean BFT farming areas (Spanish Western Mediterranean, Central Mediterranean - Malta, Adriatic - Croatia, and Levantine Sea - Türkiye), besides desk work for database generation. Final results from these studies were carried out and reported within Phase 10. Over the last year these results have been provided to and discussed within the BFT Sub-group on Growth in Farms, in order to integrate them with those from other research lines for a single and coherent answer to the Commission.

In parallel, throughout Phase 11, the GBYP team continued to support the in-house work developed at the ICCAT Secretariat oriented to the consolidation of data from stereo-cameras reported to ICCAT which has allowed to build up an operative relational data base, linking data on estimated initial lengths and weights from stereo-cameras at caging with measures of real final weights and lengths at harvesting from the e-BCD system, as well VMS data, which at the same time provide crucial information for stock assessment (length distributions of the captures of purse seine fisheries). Based on such DB, the ICCAT Secretariat Department of Research has performed a broad study on the growth of caged fish in all the areas where BFT farming takes place, based on modelling the differences between weights at harvesting and at caging, as a function of fish size and duration of farming. The final and integrated results from GBYP and ICCAT Secretariat studies will be presented at the September 2022 BFT SCRS Species Group meeting, and based on them the SCRS Technical Sub-group on Growth in Farms will elaborate the proposal of answer to the Commission.

3.5 Modelling approaches

The modelling programme addresses the GBYP general objective 3, which is "Improving assessment models and providing scientific advice on stock status through improved modelling of key biological processes (including growth and stock-recruitment), further developing stock assessment models including mixing between various areas, and development and use of biologically realistic operating models for more rigorous management option testing". The modelling activities started in Phase 2, and very soon it became evident that this line of study had greater importance than perceived at the time when the GBYP was

conceived and that the amount of effort for this activity should be much larger than initially considered. In addition, the MSE process embarked upon by ICCAT has been an important initiative which has represented a significant investment of time and resources by the Commission, CPCs and the scientists involved.

In Phases 11 and 12 the GBYP support to stock assessment and MSE process has been provided through several actions, such as the contract of the expert in charge of MSE, the contract of external reviewers of the MSE code and the 2022 BFT East Atlantic and Mediterranean stock assessment, and the support to the BFT Technical Sub-group on MSE, funding the travel of MSE process coordinator (Dr Doug Butterworth) whenever required.

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

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

Consistent with the MSE implementation Roadmap adopted by the Commission, in Phase 11 GBYP has funded an external review of MSE code. The contracted expert was Dr Emil Aalto (The Ocean Foundation), who reviewed the code and checked it for mathematical correctness (i.e. all formulae matched the equations specified in the TSD) and programming correctness (i.e. no coding errors). He also analyzed the ABTMSE package for improvements in computational efficiency, with particular focus on speeding up the MSE process which will be used by third parties to develop and test candidate management proposals (CMPs).

The reviewer found that the M3 model and ABTMSE code base were correctly implemented at every level, with generally accurate (if occasionally insufficient) description in the TSD. A few minor errors were found and described, including typos in the TSD. Many minor improvements to the code were suggested, mainly for readability and maintainability. Although major gains in speed would require reimplementation of core code in a faster language such as C, widespread replacement of the apply function with a faster alternative promise to substantially improve runtime. Nothing was found in the review to suggest any reservations for the use of this package in ICCAT management.

In addition to MSE development, the SCRS in 2022 was committed to conduct a full stock assessment for the Eastern Atlantic and Mediterranean bluefin tuna. In order to provide the most robust scientific advice, it was decided to contract an independent external expert who would assist the SCRS in the process and provide constructive advice. For that purpose, GBYP issued a contract with the expert Dr James Ianelli. The reviewer participated actively in the full process, from data preparation to the projections and in the discussions on the results, providing advice and expert opinion where he considered that to be warranted in time to support the process. As such, he attended several online meetings and provided a brief report or presentation during each meeting. The final report showing the conclusion of this external review was presented to September 2022 BFT Species Group meeting.