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

(Activity report for the last part of Phase 12 and the first part of Phase 13 (2022-2023))

1. **Introduction**

The ICCAT Atlantic-Wide Research Programme for Bluefin Tuna (GBYP) officially started 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 results, as well as information on budgetary and other administrative issues of the GBYP programme, from the 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 (SC) meeting reports, are also readily available on the GBYP webpage.

Phase 12 of GBYP officially started on 24 March 2022 following the signing of the Grant Agreement for the co-financing of GBYP Phase 12 (Project 101091166) by the European Commission. The initial duration of Phase 12 was one year, but in order to hold all the workshops envisaged during this Phase, which were initially delayed until the end of the restrictions resulting from the COVID-19 pandemic, and to complete new priority research activities requested by SCRS, this Phase was extended for four months, until 23 July 2023, through a Grant Amendment. The activities carried out during the first five months of Phase 12 and their preliminary results were presented to the SCRS and the Commission in 2021 (Alemany *et al.*, 2022) and approved. Following the timing imposed by the new funding agency — the European Climate, Infrastructure and Environment Executive Agency (CINEA) — Phase 13 of GBYP officially started on 1 May 2023, after the signing of the Grant Agreement (Project 101133291) by the European Commission, with a planned duration of one year. Although these GBYP phases have been partially administered in parallel (as has 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 unequivocally assigned to the activities detailed in the respective Grant Agreements.

Although some tasks over the last year have continued to be affected by the COVID-19 pandemic, such as the workshops that were postponed until the end of the COVID 19 restrictions, most of the activities planned within Phases 12 and 13 have been or are being implemented successfully. The specific activities in both Phases have been structured along the same main lines of research, i.e., data recovery and management, biological studies, tagging, aerial surveys (AS), and modelling. These have been adapted to SCRS research needs and Commission requests. Furthermore, the methodologies have been continuously improved and working procedures have been optimized to increase the efficiency and quality of the advice. The strategic shifts in several of these lines, initiated in Phase 10, have been consolidated. Accordingly, data recovery activities have shifted to data management, focusing on the development of new relational databases (DB), integrating all the information produced and gathered by the programme from the beginning. AS have been thoroughly revised and new methodological approaches for data analyses explored (i.e., development of new model-based approaches considering numerous environmental variables in order to account for the potential changes in spatial distribution of spawners derived from environmental variability. These changes will improve the accuracy of the index time series. Tagging activities have also been expanded in the new strategic approach following close cooperation with national tagging programmes. This change 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 in order to reach sound scientific conclusions, instead of continuous generating new data sets (unless specific requests are needed).

All activities carried out throughout GBYP Phase 12 and those launched during the first part of Phase 13, 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 continued to affect the implementation of Phase 12, but the experience gained over the 2020-2022 period has allowed GBYP to successfully face the challenges derived from this scenario, successfully organizing workshops in hybrid format and adapting day-to-day work to teleworking conditions. Given that the temporary closure of the ICCAT Secretariat headquarters in March 2020 has been maintained throughout 2022 and in-person work has only been partially resumed during 2023, as mentioned above, the GBYP Coordination Team has continued to use teleworking facilities to manage the programme, and this has not had any significant impact on the coordination and implementation of the activities.

2. Coordination activities and general issues of GBYP programme management

In Phase 12 and 13, the GBYP SC comprises the SCRS Chair, the Rapporteur for western bluefin tuna, the Rapporteur for eastern bluefin tuna, the ICCAT Executive Secretary and/or his deputy, and one contracted external expert. In order to define the Phase 12 work plan and refine ongoing activities, the SC held an in-person meeting in Madrid, back to back with the SCRS Plenary meeting, in September 2022. In addition, SC members have been constantly informed by the GBYP Coordination Team about the status of the activities through detailed reports provided on a quarterly 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, in addition to an Administrative Assistant during 7 months of Phase 12. The ICCAT Secretariat has provided technical and administrative support for all GBYP activities on a daily basis. In Phase 12, a total of three calls for tenders and six official invitations were released, which resulted in 11 contracts awarded to various entities. In addition, one call for expressions of interest was published, which resulted in eight memorandums of understanding (MoU). During the first three months of Phase 13, two calls for tenders, one call for expressions of interest and one invitation have been launched. As a result, three contracts have already been signed and two contracts are in the process of being signed, and 11 MoUs have also been signed or are in the process of being signed.

2.1 Financial aspects

In Phase 12, the total budget was €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 €40,626.86, Algeria €29,170.26, Norway €24,287.66, Canada €21,327.38, Libya €12,917.23, Korea €3,525.11, Iceland €3,172.60, Albania €2,996.34, Chinese Taipei €2,000.00, China €1,797.80, and the United Kingdom €500.57.

In Phase 13, the total budget is €1,250,000.00 thanks to contributions from the following donors: European Union (Grant Agreement) €900,000.00, Morocco €66,280.30, Japan €55,782.93, Tunisia €47,258.00, Türkiye €46,575.34, Libya €45,643.84, Algeria €36,239.20, Canada €20,529.68, Norway €19,000.00, Albania €4,719.17, Iceland €4,012.64, and Korea €3,958.90.

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 12 will be used for the following GBYP phases. It should be noted that contributions for current and previous GBYP phases are still pending from some ICCAT CPCs.

The approved budget for Phase 12 and Phase 13, as well the final expenditures of Phase 12, are summarised in **Table 1**. The percentage of executed budget in Phase 12 has been of 92,7%. The final costs were a bit lower than initially envisaged mainly because the workshops were finally organized as hybrid meetings, and not only presential as initially envisaged, and this has lowered the required budget. Other reasons have been the delay in the global review by external experts of the ICCAT MSE processes and the cancellation, due to force majeure reasons, of a tagging survey in Türkiye.

Table 1. Detailed funds available for GBYP Phases 12 and 13 and respective expenditures as of 11 September 2023

	Budget Phase 12 (24 March 2022-23 July 2023)	Expenditures	Budget Phase 13 (1st May 2023-23rd July 2023)	Expenditures
Electronic and conventional tagging, rewarding and awareness	247,000	269,550	160,000	1,583
Biological studies, including microchemistry, ageing and genetic	334,200	269,221	120,000	
Fisheries independent indices: Aerial surveys	60,000	67,657	385,000	208,549
Sample collection and shipping	115,800	151,899	80,000	
Workshops/meetings	117,000	66,243	20,000	
BFT MSE	142,000	109,594	35,000	
Programme coordination (include staff salaries, SC external member contract, SC members and Coordination team travels, equipment, consumables, overhead and ICCAT staff participation)	484,000	455,807	440,000	37,151
TOTAL	1,500,000	1,389,970	1,250,000	247,283

3. Summary of Phase 12 and Phase 13 GBYP scientific activities and results by main line of research

3.1 Data recovery and management

No data recovery activities have been carried out in Phases 12 and 13, given that no new relevant old data sets have been detected. Thus, all the 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 to improve data management through close collaboration between the Departments of Statistics and Science, SCRS scientists and the GBYP Coordination Team. Specifically, the work has focused on the development of relational DBs to allow proper storage and analysis of all raw data collected within GBYP or other relevant data sources for BFT management not yet included in the current ICCAT DBs.

Specifically, the activities carried out under GBYP Phase 12 included:

- The tasks aimed 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. These activities, initiated in previous phases, have mainly consisted of in-house desk work. In the case of the biological data information system, the work has been focused on data modelling and a data warehouse, progressing in the creation of structures to facilitate data sharing between different CPCs' research teams and ICCAT science programmes and a proper data warehouse of both the biological data and the results from the analyses carried out on these samples. Moreover, significant progress has been made on the definition and concentration of data types, data needs and uses. Simultaneously, a review of the condition of the samples collected in previous years and its recording in the inventory has been carried out.

- The update of the data repository to store the information from the AS activity.

- The project for developing an integrated Electronic Tags Management System (ETAGS) capable of managing the data from all the electronic tags released by ICCAT, or provided by CPCs' scientific teams, initiated in Phase 11 in close collaboration with the ICCAT Secretariat Department of Statistics., has been continued. This system–will be used to manage both the metadata on electronic tagging operations and the raw data generated by these electronic tags, and will allow for the storage of data from all other ICCAT tagging programmes in the future. For this purpose, a second contract was signed with Dr Chi Hin Lam (Big Fish Intelligence Company Limited) to complete the adaptation of the system previously developed by this company to ICCAT needs. The design and programming of the final DB structure has been completed, and a trial has also been developed to confirm that different types of raw data set can be uploaded. This new DB was presented to the scientific etagging community within the framework of the GBYP workshop on electronic tagging in July 2023.

3.2 Stock fishery independent indices: GBYP Aerial Survey on Bluefin Tuna Spawning Aggregations and BFT larval surveys

3.2.1 Aerial surveys

The ICCAT GBYP AS on bluefin spawning aggregations was initially identified by the Commission as one of the three main research objectives of the programme. The survey provides fishery-independent trends on the minimum spawning stock biomass (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 implemented 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. Thus, in 2019, all historical GBYP AS data were revised and 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 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 independent experts, who provided several recommendations for improvement. Recommendations included 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 aimed at overcoming the potential impact of interannual environmental variability on BFT spawner distributions and hence on index accuracy. Consequently, in 2021, under GBYP Phase 10, a pilot survey was performed in the Balearic Sea area incorporating both the standard human observers-based methodology and digital systems for automatic recording of images along the transects, and covering the usual core area as well as an extended area. In addition, a global reanalysis of the whole time series, applying both the design-based approach used from the beginning of the GBYP AS as well as a new model-based approach was carried out by the Centre for Research into Ecological and Environmental Modelling (CREEM) of the University of Saint Andrew, which was the original developer of the DISTANCE methodology applied for the design and analysis of GBYP AS at the beginning of the programme. With the available budget, the GBYP SC decided to resume, within GBYP Phase 11, the AS for bluefin tuna spawning aggregations in the core areas of the western and central Mediterranean Sea in 2022, specifically in the Balearic Sea (Area A), the Southern Tyrrhenian Sea (Area C) and the central-southern Mediterranean Sea (Area E), 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 realized. These 2022 GBYP AS were carried out without major problems, and recently, in June 2023, the same surveys were developed in the same areas of the western and central Mediterranean under Phase 13. The latter have faced some administrative problems as Maltese aerial authorities denied authorization for the embarkment of scientific observers as members of the working team and not as passengers in Malta, thus requiring the contracted company, Aerial Banners, to provide a special certificate which it did not have. This situation was totally unexpected, given that this and other companies contracted by GBYP have always obtained all the permits to perform the AS in Malta presenting exactly the same certificates as those presented this year. In addition, the same documentation was enough to get these permits in other countries (Spain, Italy, and Türkiye), not only in previous years, but also in 2023, indicating that there has not been any change in the international regulations, and that the

problem was solely due to a change in the criteria of Maltese aerial authorities. As a result, approximately one third of area E, the one that necessarily must be covered from Maltese airports, has not been surveyed in 2023.

The results from 2022surveys have been analysed within GBYP Phase 12, and those from 2023 surveys will be analysed during Phase 13. A new contract with the CREEM was signed to perform the analysis to update the aerial index time series until 2022 following the design-based approach and to reanalyse, in collaboration with the team from the Instituto Español de Oceanografía (IEO) and Consejo Superior de Investigaciones Científicas (CSIC) in charge of BFT larval indices, who are experts in BFT spawning habitat modelling, all the data set between 2017 and 2022 following a new model-based approach considering a wide pool of environmental variables. This work aims to produce in the near future a more accurate and fully standardized AS index time series, which is able to account for interannual variability in the spatial and temporal distribution of BFT spawners in the surveyed areas of the western and central Mediterranean derived from changes in the environmental scenario and not strictly from real changes in spawning stock abundance.

3.2.2 Larval surveys

In Phase 12, in addition to the direct funding of AS and AS data analyses, GBYP also directly supported the improvement of larval indices based on surveys developed by ICCAT CPCs by organizing and funding an ad hoc workshop on Atlantic bluefin tuna larval indices, which took place in Palermo, Italy, from 7-9 February 2023. It was organized in a hybrid format. The specific objectives were identifying potential sources of uncertainty or inaccuracy in tuna larval surveys, agreeing on a standard survey methodology to minimize potential sources of error or bias, and exploring the possibilities for expanding surveys aiming at producing larval indices for other bluefin tuna spawning areas. The survey strategies and sampling methodologies, as well those applied to the analyses of biological samples and data, were presented by all the research teams currently involved in studies on Atlantic bluefin tuna larval stages and discussed by the Group. Finally, a series of specific points aiming at standardizing methodologies and exploring the possibilities for implementing new BFT larval index surveys were addressed by the Group, producing a list of action points toward the achievement of this objective.

The workshop was attended by more than 40 scientists from five CPCs. The detailed report will be presented to BFT Species Group in September as the document SCRS/2023/042.

3.3 Tagging activities

The initial objectives of GBYP tagging activities were a) to estimate the natural mortality rates of bluefin tuna populations by age or age groups, and b) to evaluate habitat utilization and large-scale movement patterns (spatial-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 that 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 ii) the relatively short time that most of the electronic pop-up tags remained on the fish. Therefore, some new actions to overcome these problems were initiated in Phase 9, such as improving the deployment methodology, providing specific training to the e-tagging teams, and developing specific actions focused on increasing the involvement of ICCAT observers and farm 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 one 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 continuation of this trend, since many tags have remained on fish for the whole programmed one-year period. These actions to improve the recovery rates have resulted in an increase in recoveries in the Mediterranean area. From March 2022 to March 2023, a total of 123 conventional and 30 e-tags have been recovered.

As in previous seasons, the main specific objective of the Phase 12 e-tagging campaigns was 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 management strategy evaluation (MSE) modelling process. The aim was to improve knowledge of 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. In light of 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 as part of Phase 12 (ICCAT Circular #G-0433-20) for the deployment of a total of 54 pop-up satellite archival tags (PSAT) by experienced tagging teams in the Mediterranean and/or North Atlantic Ocean, targeting eastern stock individuals. As a result, seven proposals were awarded and MoUs were signed with:

- Technical University of Denmark (DTU) - six PSAT tags to be deployed in northeastern Atlantic waters (eastern North Sea, Skagerrak, Kattegat and Øresund).
- Institute of Marine Research (IMR) of Norway - five PSAT tags to be deployed in Norwegian waters.
- University of Maine - ten PSAT tags to be deployed on Atlantic bluefin tuna <185 cm CFL along the east coast of the United States (western Atlantic).
- The Marine Institute - five PSAT tags to be deployed in coastal waters off Ireland.
- Swedish University of Agricultural Sciences (SLU) - six PSAT tags to be deployed in Skagerrak, Kattegat or the Sound Straight.
- Stanford University in collaboration with Fisheries and Oceans Canada (DFO) and Acadia University - 18 PSAT tags (including nine Lotek and nine wildlife computers (WC) tags) to be deployed in Canadian waters.
- Government of Jersey in collaboration with Thunnus UK (a collaboration between the Centre for Environment, Fisheries and Aquaculture Science and the University of Exeter) - five PSAT tags to be deployed in Channel Island waters (waters of Jersey and Guernsey).

Most of these campaigns were completed before the end of Phase 12 (reports available on the GBYP web page), but one is still ongoing (MoU with the University of Maine) due to technical problem with the batteries, which obliged to send back the undeployed tags to the manufacturer for software upgrading when the problem was detected.

In Phase 13, a new call for expressions of interest to collaborate with the GBYP e-tagging programme was launched in July 2023. As a result, eleven MoUs will be signed, for the deployment of 75 additional GBYP-owned tags, as follows:

- Acadia institute, in collaboration with DFO and Stanford University - eight PSAT tags to be deployed in Canadian waters.
- Fundación AZTI - six PSAT tags to be deployed in the Bay of Biscay.
- DTU - eight PSAT tags to be deployed in northeastern Atlantic water (eastern North Sea, Skagerrak, Kattegat and Øresund).
- University of Exeter, in collaboration with the Centre for Environment Fisheries and Aquaculture Science (CEFAS) and the Government of Jersey - four PSAT tags to be deployed in Jersey territorial waters.
- University of Exeter - four PSAT tags to be deployed in southwest England.
- Institute of Marine Research - eight PSAT tags to be deployed in Norwegian waters.
- The Marine Institute - eight PSAT tags to be deployed in the coastal waters off Ireland.
- SLU - eight PSAT tags to be deployed in Skagerrak, Kattegat and Öresund.
- Stanford University, in collaboration with Barcelona Zoo and the Centro Tecnológico Experto en Innovación Marina y Alimentaria (AZTI) - eight PSAT tags to be deployed off the Canary Islands.
- Stanford University - eight PSAT tags to be deployed in the waters off North Carolina.
- University of Genova - five PSAT tags to be deployed in the Ligurian Sea.

Besides these activities, GBYP has supported e-tagging activities carried out independently by other institutions, whose results were considered a priority research need for the SCRS. Such support implied the sharing of relevant results with ICCAT and the permission of use of the GBYP Research Mortality Allowance (RMA) for any BFT casualties occurring during tagging operations. In other cases, such as the deployment of five PSAT tags in caged BFT before release by the farming company Balfegó S.L., the support consisted of the use of the GBYP Argos system accounts for data transmission so that the resulting data were integrated directly in the GBYP DB.

In addition, in Phase 12, GBYP has organized a workshop on Atlantic bluefin tuna e-tagging in hybrid format, aiming at reaching a broad consensus on the strategic planning of future e-tagging and the best use of available tagging data. The workshop was attended by more than 60 scientists from 12 CPCs. During the workshop, multiple subjects were discussed and a list of priorities for future tagging campaigns were identified. The detailed report will be presented to BFT Species Group in September as the document SCRS/2023/133.

The GBYP programme has also provided logistical support to several institutions engaged in conventional tagging. From March 2022 to March 2023, a total of 2,675 conventional tags were delivered to 4 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, including microchemical and genetic analyses to investigate mixing and population structure, with a particular focus on identifying age structure and the existence of probable sub-populations. Population structure is a key uncertainty for bluefin tuna. Up to 2022, ICCAT managers acted under the assumption that there were two separate populations with no mixing. However, taking into account, among others, the outputs from GBYP biological studies, for years the possibility that two populations or contingents coexist in the Atlantic Ocean has been considered. Moreover, e-tagging studies, with an important contribution from GBYP, have demonstrated important mixing between both historically recognized East and West Atlantic BFT stocks. It is important that the stock structure assumed for stock assessment and management purposes 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, during its 2022 meeting, ICCAT adopted a new management system for BFT stocks based on the MSE approach, developed from 2014 thanks to GBYP support, in which the operating models (OMs) explicitly consider the existence of mixing.

Therefore, in Phase 12 several GBYP lines of research in BFT biology and ecology were continued from previous phases with the goals of allowing a deeper understanding of the implications of the new spawning grounds in the Atlantic Ocean (Slope Sea and Bay of Biscay) and to developing mixing analyses to provide accurate information and more clear alternative hypotheses about stock structure and spatial patterns to inform the MSE process. Moreover, in this Phase special attention has been paid to the consolidation of the new knowledge generated in the different lines of research developed throughout the last decade, carrying out necessary global reanalyses of available data and synthesizing the results generated in previous phases, in order to provide sound conclusions that can be directly applied to improve stock management.

3.4.1 Biological sampling and analyses

Biological sampling

During Phase 12, a total of 4,555 biological samples were collected (1,514 otolith samples, 1,221 fin spines, and 1,820 genetic samples) from 1,867 individuals. The goal of these activities was to provide 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 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 ten years of the project, with the ultimate goal of creating a DB with an interface that is easily manageable for any user who requires it. In addition, 7,638 BFT larvae from the IEO-CSIC BFT 2022 larval survey (co-funded by the EU data collection framework (DCF)), were identified, sorted, and fixed following protocols to allow their future use in genetic analyses, making it possible in the short term to develop pilot studies aiming at determining the feasibility and improve the design of a close-kin mark-recapture (CKMR) study for the eastern BFT stock.

Biological analyses: Microchemistry

Regarding otolith microchemistry, in Phase 12, new carbon ($\delta13C$) and oxygen ($\delta18O$) stable isotope analyses were carried out on Atlantic bluefin tuna samples captured in the foraging grounds of the Atlantic Ocean. Results suggest that individuals from both the Gulf of Mexico (GOM) and Mediterranean (MED) cross the 45°W management boundary, mixing with the other population in feeding aggregates of the Atlantic Ocean, with this rate being different among years. The proportion of GOM-origin fish found to cross to the east is smaller than the proportion of MED-origin fish found to cross to the west. There may be two

explanations for this finding: (1) fish originating in the GOM tend to move less, and (2) being a smaller stock in terms of production, the chances of finding a fish from the GOM are lower, or it could be a combination of both.

Individual origin has also been evaluated geographically to get an overview of the last decade. The results showed a spatial separation of catches within the North Atlantic Ocean: fisheries operating in the eastern North Atlantic dominated by MED-origin fish, western Atlantic coast dominated by GOM-origin fish, and central North Atlantic catches composed by a mixture of stocks. These results provide strong evidence of longitudinal population structuring of bluefin tuna in the North Atlantic Ocean and demonstrate the capacity of otolith chemistry to determine their natal origin, at both spatial and interannual time scales. Therefore, for effective stock management, it is important to monitor temporal variations in mixing ratios, especially in the current scenario of changing environment.

Biological analyses: Genetics

Regarding genetic analyses carried out within Phase 12, the results show that interbreeding dynamics in the Slope Sea confirm a gene flow from the Mediterranean into the Slope Sea, which is probably a relatively recent event from the evolutionary point of view (less than approximately 80 generations). The genetic mixing of Mediterranean and western origin individuals in the Slope Sea could have happened repeatedly in different years during the last decades. An increase in gene flow from 2008 to 2018 could not be confirmed, although this hypothesis could not be rejected. Also, genomic regions of albacore origin were found in the genome of Slope Sea and Mediterranean individuals for which whole genome sequencing data was available. The data suggested that variants of albacore origin are associated to adaptive traits. The identification of these regions will make it possible to search for specific genes and derived functions to understand how these affect the adaptive capability of the Atlantic bluefin tuna to the environment.

In this Phase, complete assignments of Atlantic bluefin tuna individuals from feeding aggregates along the North Atlantic captured in the different ICCAT areas, genotyped with the 96 single nucleotide polymorphism (SNP) traceability panel from GBYP Phase 6 to Phase 11, have been updated based on the knowledge on the population structure acquired during the GBYP programme. Overall, > 3,200 individuals captured at feeding aggregates showed varying mixing proportions of MED, GOM, and unassigned individuals across catch years, supporting the hypothesis that migratory patterns of Atlantic bluefin tuna are dynamic.

Finally, a new tool for kin pair identification for future CKMR studies in Atlantic bluefin tuna, based on an array of more than 8,000 SNPs have been developed and tested, analysing a set of 359 samples, in which four half and one full sibling pairs were identified. This study makes it possible to conclude that at least 2,000 SNP markers, among those included in the custom SNP array, were required for effective kin finding among eastern individuals. It was also found that the sex markers included in the 96 SNP traceability panel and the custom SNP array made it possible to correctly identify sex with a rate of 94%

Biological analyses: Integrated analyses

During this phase, further efforts have been made to combine genetic and chemical markers to develop a combined method of population assignment. Over the last ten previous Phases of the GBYP programme ABFT individuals had been routinely analyzed to assign stock of origin based on otolith chemistry and genetic markers separately to investigate the degree of eastern and western population contribution to different mixing areas in the Atlantic Ocean. However, the use of both methods together can provide further insights into the complexity of the stock structure of the species and enhance the understanding of ecological and evolutionary processes that may help to identify stock units with a high degree of confidence. Here, two different approaches were followed: (1) Individual origin was re-assigned using an integrated classification model that includes both genetic and stable isotope data (i.e., Integrated approach) and (2) genetic and stable isotope data was used complementarily (i.e., Combined approach). The integrated method proved to increase the resolving power of stock discrimination in comparison to single approaches and resulted in lower numbers of unassigned individuals than otolith stable isotope only and genetic markers only models. The combined approach showed that insights into ABFT population structure can be provided and can be masked when a single technique is used, or when both techniques are integrated, as it considers processes occurring at different temporal scales (i.e., individual life span vs evolutionary).

Biological analyses: Ageing

Regarding direct ageing, three subtasks have been completed. First, a review and update of bluefin tuna growth studies using calcified structures and methods combined with these structures has been carried out. It resulted in detailing the status of validation and standardization of the reading of each structure. Next, two reference collections of 200 samples have been prepared for otoliths and for spines (first spiny ray of the first caudal fin) to serve as quality control of these structures. Finally, a selection of otolith samples has been made to carry out the epigenetic study for the ABFT of the East Atlantic and Mediterranean Sea. This selection has considered all possible factors that may influence the analyses.

3.4.2 Epigenetic Ageing

Although the Close-Kin Mark-Recapture method has already been implemented on Western ABFT, the ICCAT SCRS is still evaluating the financial, logistic and scientific feasibility of implementing it on Eastern stock. One of the main issues that could prevent the implementation of CKMR is the high cost of age determination by means of classic schlerochronological methods. A potential solution would be the DNA methylation-based epigenetic ageing method, which has shown promising result in other commercial fish species. Yet, obtained age estimates may have quite high error margins compared to otolith derived ages.

Therefore, in Phase 12, GBYP has carried out a pilot study to evaluate the potential of using the epigenetics for ageing Atlantic bluefin tuna individuals, with the aim to evaluate both the accuracy and the feasibility of the epigenetic method compared to direct ageing by otoliths readings. The need for implementing this task was identified rather late, after the initial plan for Phase 12 was drafted so it implied reallocating funds dedicated to other activities and extending the duration of Phase 12.

Although several sub-tasks of this study have been completed, due to unexpected logistic problems, the overall study has not been terminated by the end of Phase 12. However, it is envisaged that all the pending tasks will be completed by September 2023 and the results will be available at the September 2023 BFT Species Group meeting.

3.4.3 Workshop on Close-Kin Mark Recapture, including biological sampling coordination

In relation to the support of Biological Studies in Phase 12, GBYP organized a workshop on CKMR and biological sampling coordination, which took place in Madrid from 14-16 March 2023, following a hybrid format. It focused on the analysis of relevant factors for the implementation of the approach in the eastern Atlantic bluefin tuna stock, with the goal of presenting a feasibility study, including a workplan with cost estimations, to the SCRS in 2024. The requirements for CKMR and the current knowledge of Atlantic bluefin tuna reproduction and population structure were reviewed, and examples of applications of CKMR methodologies in other fish species were provided. The genetic studies carried out to date for ABFT stock identification, kinship analyses, sex determination and epigenetic ageing, were summarized and discussed. It was proposed that a comparison be made between the two methodological approaches applied thus far for kinship determination in ABFT, i.e., the one applied in the ongoing Western stock CKMR study and the one developed under the GBYP programme, and that the possibility of including alternative techniques be explored. Sampling opportunities for ABFT Eastern stock CKMR implementation were discussed. Finally, a list of recommendations for future steps and a tentative timeline for their implementation was elaborated.

The workshop was attended by more than 50 scientists from eight CPCs. The detailed report will be presented to BFT Species Group in September 2023 as document SCRS/2023/043.

3.5 Modelling approaches

The modelling programme addresses the GBYP general objective 3 "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". Modelling activities started in Phase 2, and it soon became evident that this line of study had greater importance than perceived at the commencement of GBYP 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 that has represented a significant investment of time and resources by the Commission, CPCs and the scientists involved.

In Phase 12, GBYP support has been provided to stock assessment and MSE processes through the contract of the expert in charge of MSE, and support has been provided to the BFT MSE Technical Sub-group by funding the travels of the MSE process coordinator (Dr Doug Butterworth) whenever required.

In this Phase the contract for modelling approaches providing support to bluefin tuna stock assessment was again awarded to Dr Tom Carruthers (Blue Matter Science, Canada), who initiated work on MSE and modelling in 2014. The contract was envisaged to cover the activities until the end of 2022. Nevertheless, in February 2023 the MSE Technical Sub-group defined further MSE tasks necessary to meet the planned SCRS schedule. Therefore, another contract was provided to the modelling expert to cover the period until July 2023. Therefore, the contracts in Phase 12 covered the final stages of MSE development in support of management procedure (MP) adoption, including final tuning of candidate management procedures (CMPs), rescaling of latest index data, drafting of exceptional circumstances protocols and additional presentation materials in support of MP selection. In addition, they included the development of an exceptional circumstances app that can help to design effective protocols given the various data types available to Atlantic bluefin tuna. Also, the computer code was commented and supporting documentation was developed to guide a technical user on how to reproduce and rebuild the ABTMSE R package from scratch.

More specifically, the principal developments in Phase 12 were the following:

- Finalization of shiny apps.
- Finalization of the trial specific document (TSD).
- Rescaling of analyses allowing for an update of indices.
- A variety of presentation and communications materials in support of MP adoption.
- Documentation for building the ABTMSE R package and ECP app.
- Open-source ECP R package that contains all code, functions and diagnostics.
- A new ECP Shiny app for exploring and developing ECP for bluefin tuna.
- Draft SCRS on ECP background and proposals for bluefin tuna.
- Adopted MP code check.

Summing up, all MSE processes upstream of MP adoption are complete. Identification of exceptional circumstances protocols is outstanding and provides a link back to operating model specification if triggered.