SCRS/2021/145 Collect. Vol. Sci. Pap. ICCAT, 78(3): 1006-1023 (2021)

MODAL PROGRESSION ANALYSES (MPA) TO DETERMINE BFT SEASONAL GROWTH RATES IN FARMS

Francisco J. Alemany[1], Alfonso Pagá[1], Simeon Deguara[2] and Stasa Tensek[1]

SUMMARY

As part of the studies carried out by GBYP in response to the Commission's Recommendation 18-02, paragraph 28, concerning BFT growth in farms, Modal Progression Analyses (MPA) were carried out on the length distributions of farmed BFT obtained from bi-tri monthly stereo-camera footages and direct measures taken at harvesting. This has been carried out using data from growth trials performed in most of the areas where tuna farming takes place (Western Med, Adriatic Sea, Central Med and Levantine Sea). The objective was to determine the seasonal growth rates by modal groups. Results have shown that growth rates of farmed fish, not only in weight but also in length, are higher than in wild fish, both in juveniles and adult fish, and that most of growth occurs during the warm season, from early Summer to mid-Autumn.

RÉSUMÉ

Dans le cadre des études menées par le GBYP en réponse à la Recommandation 18-02, paragraphe 28, concernant la croissance du thon rouge dans les fermes, des analyses de progression modale (MPA) ont été réalisées en ce qui concerne les distributions de longueur du thon rouge d'élevage obtenues à partir de séquences bi-trimestrielles filmées par des caméras stéréoscopiques et de mesures directes prises lors de la mise à mort. Ces analyses ont été réalisées à partir de données provenant d'essais de croissance effectués dans la plupart des zones d'élevage du thon (Méditerranée occidentale, mer Adriatique, Méditerranée centrale et mer du Levant). L'objectif était de déterminer les taux de croissance saisonniers par groupes modaux. Les résultats ont montré que les taux de croissance des poissons d'élevage, non seulement en poids mais aussi en longueur, sont plus élevés que ceux des poissons sauvages, tant chez les juvéniles que chez les poissons adultes, et que la majeure partie de la croissance a lieu pendant la saison chaude, du début de l'été à la mi-automne.

RESUMEN

Como parte del estudio realizado por el GBYP en respuesta a la Recomendación 18-02, párrafo 28, relativo al crecimiento del BFT en las granjas, se llevaron a cabo Análisis de progresión modal (MPA) sobre las distribuciones de talla del atún rojo de granja obtenidas a partir de grabaciones bimensuales o trimestrales con cámaras estereoscópicas y de medidas directas realizadas durante el sacrificio. Para ello se utilizaron los datos de las pruebas de crecimiento realizadas en la mayoría de las zonas donde se cría atún (Mediterráneo occidental, mar Adriático, Mediterráneo central y mar de Levante). El objetivo era determinar las tasas de crecimiento estacional por grupos modales. Los resultados han demostrado que las tasas de crecimiento de los peces de granja, no sólo en peso sino también en talla, son superiores a las de los peces salvajes, tanto en los juveniles como en los adultos, y que la mayor parte del crecimiento se produce durante la estación cálida, desde principios de verano hasta mediados de otoño.

KEYWORDS

Atlantic Bluefin tuna, Thunnus thynnus, BFT farming, seasonal growth rates, Stereo-camera, Modal Progression Analysis

1 ICCAT, GBYP – Calle Corazón de Maria 8, 6ª – 28002 Madrid (España); francisco.alemany@iccat.int
2 AquaBioTech Ltd, 'Central Complex', Naggar Str., Mosta MST1761, Malta, dsd@aquabt.com

1. Background

The issue of BFT growth in farms was first explicitly considered by the ICCAT Commission in 2002, through the Rec. 02-10 on Bluefin tuna farming, which stated that the CPCs, Cooperating non-Contracting Parties, Entities or Fishing Entities should adopt the necessary measures such that the tuna farms and the scientific institutes obtain data on the size of the fish caught and estimates of the growth while in captivity. In 2004, through Commission Rec. 04-06, the SCRS was, for the first time, directly committed to undertake trials to identify growth rates including weight gains during the fattening or penning period.

Successive Commission recommendations about estimates of the BFT growth in farms were issued between 2004 and 2017. In general, such recommendations were centered on the same objective as the previous ones, i.e. to determine the growth rates of caged fishes after getting the basic data to do it, and focusing on methods to estimate the initial sizes at caging. Thus, during this period, the Commission asked first the CPCs to define the growth factors to be applied to bluefin tuna farmed in their cages and to carry out pilot studies to better estimate both the number and weight of bluefin tuna at the point of capture and caging, through the use of stereoscopical camera systems, and then, from 2014, to implement such a system following standardized protocols. In parallel, the SCRS was committed first to further analyze the growth factors defined by CPCs to provide advice to the Commission for its annual meeting in 2010. The Committee pointed out that by the time of the 2009 SCRS meeting, Contracting Parties had not notified the ICCAT Secretariat or the SCRS the growth factors for tuna kept in their farms, as requested in the paragraph 96 of the Rec. 08-05. Nevertheless, the Committee reviewed several industry-sponsored studies (Anon. 2010 and references therein) and concluded that the gain in weight of bluefin tuna in farms can be significantly higher than the values which had been used to-date. As a result, the Committee provided a table of maximum expected growth in weight for farmed Bluefin tuna as a function of size/age at caging and number of months in farm based on five different growth studies done in Spanish, Maltese and Croatian BFT farms between 2006 and 2009, each study focusing on different size/age group and time of caging. In the following years the SCRS was requested to review information from BCDs and other submitted data and further study growth rates, so as to provide advice to the Commission. All these Commission Recommendations related to growth in farms and the actions carried out by CPCs and SCRS in relation to such recommendations were reviewed in detail in Alemany et al. (2020).

In 2018, through the recommendation 18-02, Paragraph 28, adopted by the Commission during the 21st Special meeting, which was renewed through the Rec. 19-04 and later amended by the Rec. 20-07, the SCRS was asked again to undertake trials to identify growth rates in farms, but following a new methodological approach, since it was specifically requested to perform studies based on the monitoring of recognizable individual fish and to consider the differences among geographic areas (including Atlantic and Mediterranean). Based on the results from these trials and other scientific information available, the SCRS should review and update the reference growth in farms table published in 2009 and, according to recommendation 20-07, provide it to the Commission by 2022.

In relation to recommendation 18-02, paragraph 28, the SCRS requested GBYP to develop studies providing scientific data to be used to answer the Commission's request. Therefore, GBYP team, in close coordination with ICCAT Secretariat and under the advice of GBYP Steering Committee, carried out at the beginning of 2019 a scoping study to design a work-plan to address this request, adapted to the available resources and logistic constraints. As a result of this scoping study, GBYP designed a work plan based on three complementary methodological approaches: studies on individual growth trajectories, as specifically requested by Rec. 18-02 and Rec 19-04, based on tagging; modal progression analysis for the determination of seasonal growth and possible correlations with environmental factors and food supply, based on non-invasive methods such as stereo-camera footages in selected representative cages located in different areas where Atlantic BFT farming operations take place and, finally, analysis of the databases held by the Secretariat from official stereo-cameras measurement at caging and from harvest data. This scoping study and the resulting work-plan were described also in Alemany et al. (2020).

This paper deals with the first phase of the second approach, i.e. the Modal Progression Analyses carried out with the data provided by the field trials carried out between 2019 and 2021 in farms located in four Mediterranean regions: Western Mediterranean, Central Mediterranean, Adriatic Sea and Levantine Sea.

2. Data and methods

2.1. Location of study areas and methods for base data recording

The studies were initiated in 2019, under GBYP *ad hoc* contracts, in four areas of the Mediterranean with contrasting environmental conditions. It had also been envisaged to carry out a similar study in Morocco in 2020, but it had to be cancelled due to COVID 19 restrictions. Specifically, one study was performed at the Akua Group farm (Levantine Sea, Turkey), with the scientific support from Ege University, another was managed by AquaBioTech Ltd. in MFF Ltd. Farm (Central Mediterranean, Malta), a third study was carried out at Pelagos farm, with the scientific support from IZOR (Adriatic Sea, Croatia). The fourth study was initiated also in 2019, at the Balfegó farm (Western Mediterranean, Spain) by the company's scientific staff, but the initial trial couldn´t be completed because a strong storm destroyed the experimental cage before harvesting and the study had to be repeated in 2020-2021. The geographical location and timing of these studies is summarized in **Figure 1**. The descriptions of monitored cages and the fish populations under study (dates of capture, transfer and caging), as well the timing of the different operations and methodologies to produce or compile the required basic data (length distributions along the farming period and length and weight distributions at harvesting (all fish), as well as the recording at appropriate time scales of environmental parameters (T) and precise data on food supply), are detailed in the final reports of each of these studies, available at https://www.iccat.int/gbyp/en/biostu.asp .

To carry out length Modal Progression Analyses three sources of base data, with a resolution of 1 cm, were considered:

-Length frequency distribution from the official stereo-camera measurements taken at the monitored cages at caging.
-Length frequency distributions of the monitored cages during the farming period, taken from the analysis of footages, taken with the same system AQ1 used for official measurements at caging, every two or three months, in such a way that the footages be representative of the monitored caged population (see Final Reports for details). A minimum of 20% of fish in the monitored cage was measured.
-Length and weight measurements of 100% of the fish in the monitored cages at harvesting.

The main characteristics of caged monitored fish and the timing of the successive operations is summarized in **Table 1**.

2.2. Methods for data analyses

As a first step to determine the growth rates of monitored caged fish, the modal groups in the available length frequency distributions were identified and characterized following Bhattacharya's method (Battacharya, 1967), by means of the FAO FISAT II software package (http://www.fao.org/fishery/topic/16072/en).

In most of the cases (except in the Adriatic Sea trials, where the caged population was only composed of juvenile fish and hence included only few modal groups over a relatively narrow range of sizes), the raw length distributions measured with a resolution of 1 cm, due to the relatively low number of measured individuals and the wide range of sizes in which they were distributed, were not appropriate to perform this type of analysis, consequently a preliminary raw data treatment was applied. So, new length distributions suitable for modal group detection analyses were derived from original length distributions by grouping the raw data in wider length bins, from 2 to 10 cm, and smoothing of resulting length distributions by applying running averages.

Prior to that, in the cases when the raw data sets had not been obtained in a single operation, such as in the case of more than one caging operation supplied fish to the experimental cage, and with harvesting data (since the can last several days or even weeks), the raw data sets were pooled in a single length distribution to which it was assigned the mean date of the operations. In the case of Croatian farm, in which two cages were monitored in parallel as replicates, and since preliminary analyses showed that no significant difference between modal group in cages occurred, the data from both cages were also pooled.

Finally, two raw data treatments were selected for final analyses, one consisting in using a bin of 2 cm and applying a double running average over 3 data to smooth the length distributions, and the second using a bin of 10 cm and a single smoothing process by running average over 3. The first was proven to be adequate to detect and characterize annual cohorts, whereas the second was used to characterize the two or three large modal groups, composed by different annual cohorts, which sometimes can be visually detected in the length distributions of purse seine BFT catches: small (juveniles < 120 m), medium (young adults between 120 and 165 cm) and large fish (older adults). These two contrasting preliminary data treatments were applied in order to test the coherence of the results by cross checking the growth rates derived from both approaches.

The identification of modal groups applying the Battacharya's method by means of FISAT II software is an interactive process, and hence, even if clear and objective criteria to allow the identification of the Gaussian groups within the analyzed length distributions are established a priori, in some cases slightly different results can be obtained depending on decisions made by the analyst. So, to ensure the consistency between analyses and minimize the potential subjectivity associated with them, all the analyses were carried out by a single analyst with previous contrasted experience in the field of fish growth, and specifically in the use of this software (first author), who developed the analyses following always the same criteria. Moreover, the software provides complementary information (standard deviation of identified modal groups, number of individuals within each group, separation index between modal groups) which, besides expert's knowledge on target species growth, help in getting accurate results.

As a second step of the modal progression analyses, the modes detected in the initial length distribution were related to the corresponding modes in the subsequent length distributions. This process does not usually present any difficulty when clearly separated and well-defined modal groups are characterized in the analyses, as it was the case of the experiment in the Croatian farm, which had only three annual cohorts of juvenile fish, or when large modal groups, well represented along the whole time series, as those obtained using 10cm length class bins, have been defined. However, if many different cohorts are present in the monitored population and not all of them are clearly represented in the successive raw length distributions (and consequently the number of detected cohorts change between successive analysis), this process is not so straightforward. So, to prevent errors, several criteria based on complementary information, such as the relative abundance of each cohort along time and a detailed review of raw datasets looking for groups of individuals in the tails of the length distributions that due to its low abundance would have not been identified as a modal group in a given distribution, were applied. Moreover, some of such modal groups in the extremes of the length distribution (composed by a low number of individuals (<10)), even if they could be detected, were not considered in this phase of the analyses, because the modal lengths calculated for these groups could not represent the real modal length of this cohort of fish in the cage. The seasonal growth rates by size group obtained from the analysis of large groups, which are consistent and in which the modal progression is obvious, were also used as a reference to determine the real modal progression of annual cohorts.

3. Results and discussion

The initial length distributions from official stereo-cameras measurements at caging (Figure 2) showed that the length frequencies are representative of the length distributions of the farmed BFT usually observed in each of the areas considered: only juvenile fish, mostly 2 and 3 years old, in the Adriatic Sea; predominantly young adults from 4 to 7 years old, but including some older specimens mostly up to 12 years old, in the Levantine Sea; the opposite distribution in the Central Med, including some young adults less than 180cm SFL but predominantly larger fish between 180 and 260 cm SFL, and finally, a more balanced mix of adult BFT between 120 and 260 cm SFL in Western Mediterranean, but with higher proportion of fish around 180 cm SFL.

The use of Battacharya's method to identify Gaussian components within each of these distributions, considering a class length bin of 2cm and applying a double running average over 3 smoothing to raw data, allowed the detection of up to 13 clearly defined modal groups, of which the first 10 probably correspond to annual cohorts of ages 2 to 11 and the rest to mixtures of older specimens between ages 12 and 20 years. In all areas, most of the modal groups which included enough individuals to determine accurately the real modal length of each cohort (so, excluding those individuals in the tails of the distributions, and sometimes in the transition between main groups (small and large individuals)), have been characterized with a high degree of confidence. Detailed results by area are described below.

3.1. Adriatic Sea

In this area, given that only three well separated cohorts were identified in the length distributions, only analyses using a size class bin of 2 cm were performed. The results from MPA analyses of the length distributions provided by the experiment carried out at Pelagos farm (Croatia) are summarized in **Table 2** and **Figures 3 and 4**. The two first modal groups, perfectly separated between them at the beginning of the study, started mixing one year after caging, due to higher relative growth of smaller individuals. Since both groups included in all the analyses a high number of individuals (several hundreds), it can be considered that the modal lengths represent accurately the real modal lengths in the caged population. The third group included always much less individuals, around 30, and even less than 10 in some cases. Because of this, the successive modal lengths calculated for this group are not as reliable, and this would explain some strange results, such as the higher growth rate of this larger group during the first months in relation to that of the younger fish which should be theoretically higher. However, the results are generally coherent, and those referring to the two first more abundant groups can be considered as highly accurate. According to available information from wild fish ageing studies (Cort et al. 1991) these modal groups correspond to ages 2, 3 and 4 at caging. Total growth in length (SFL) of the age 2 and 3 classes (at caging) during the whole farming period (19 months) was approximately 59 and 52 cm respectively, with a growth during the first year of 41 and 35 cm, respectively. This is almost double what is seen in the wild, since according to the Von Bertalanffy equation proposed by Cort (1991), the annual growth in the wild would have been 21.48 and 19.57 cm (SFL), respectively. This result is in line with the results from Katavic et al. (2001), who from a similar pioneer experiment carried out in the same area concluded that juvenile BFT showed a much faster growth in length and weight in farms than in the wild.

These results also indicate that the growth rates during the farming period show a marked seasonality, with higher growth rates in summer months and a slowdown of these growth rates in winter, especially during the first winter after caging, which is in line with the findings of Cort (2003), who stated that summer growth in wild Atlantic BFT aged 1-3 years is 5-6 times more intensive than their winter growth.

It is worth noting that the modal lengths at harvesting were between 3 and 5 cm lower than those obtained from the analysis of the stereo-camera footage taken only 10 days prior to harvesting. This could be due to problems related with the calibration of the AQ1 system, the way in which the SFL are obtained at harvesting or reflect a real shrinkage of individuals after slaughtering. Information available at this moment does not allow the testing any of these hypotheses, and hence this issue, with important implications on growth rate estimations from MPA analyses, should be further investigated.

3.2. Levantine Sea

The results from MPA analyses of the length frequency distributions, carried out with the data provided by the 6 months trial carried out at the Akua Group farm (Turkey), using size bins of 2 and 10 cm, are summarized in **Tables 3 and 4** and **Figures 5 and 6**. As regards analyses of the 2 cm size class bin length distributions, between 8 and up to 13 modal groups were detected (the latter figure determined from the harvesting dataset), but in some SC footages the number of individuals of sizes over 180 cm was low, which made it more difficult to follow the modal length progression of all the cohorts. Therefore, only data relative to the most abundant modal groups, those corresponding to ages 4 to 7 at caging, have been considered. These young adults showed length increases, in only 6 months, between 32 cm (age 4 cohort) to 26 cm (age 7 cohort). The results from the analysis of modal groups using the 10 cm size class bin confirm the accuracy of these results, since the length increase of the first groups, which consists of these young adults (around 140 cm at caging), is just in the middle of these values, 29 cm. In these analyses the growth rates of older specimens, which were integrated in a second modal group, were also around 30 cm when considering only the data from stereo-camera footages from caging till 10 days prior to harvesting. The data from harvesting could not be used in this case for estimating the total growth because in the harvesting length distribution several cohorts of fish with modal lengths higher than the bigger ones detected in the stereo-camera footages taken prior to harvesting were detected, which made the modal length of this second group not comparable to that from the stereo-camera footage.

According to Cort (1991) Von Bertalanffy growth equation, the annual growth rates of 4 to 7 years old fish in the wild ranges between 18 and 13 cm. So, in this area, the growth rates in length of farmed fish also double that of wild fish.

In this area the growth rates during the whole caging period were similar, not showing a clear decrease in colder months. This can be due to the fact that fish were harvested in early winter, prior to the season with lower temperatures. On the other hand, the mean temperatures during the whole year cycle in the Levantine Sea are higher than in the rest of study areas.

In this area a decrease of 1 to 6 cm between the modal lengths obtained from the last stereo-camera footage prior to harvesting and those from direct measurements during the harvesting operations was also observed for the 5 to 7 year old fish cohorts. On the other hand, the younger group showed a slight increase of around 3 cm.

3.3. Central Mediterranean

The results from MPA analyses of the length frequency distributions carried out with the data generated in the experiment monitored by AquaBioTech in the Central Mediterranean (Malta) over a period of only 3.5 months, at MFF Ltd farm, using both size bins of 2 and 10 cm, are summarized in **Tables 5 and 6** and **Figures 7 and 8**. Analyses of the 2 cm size class bin length distributions enabled the detection of up to 10 well-defined modal groups, with modal lengths between 122 and 222 cm, which would correspond, according to Cort (1991) Von Bertalanffy growth equation, to individuals between 4 and approximately 12 years old. Some larger individuals were present in the length distribution, but in low numbers, which prevented the inclusion of these larger specimens in well-defined Gaussian groups. The growth rates of these cohorts ranged from 23-21 cm in the younger groups (4-5 years old) to around 10 cm in the older age groups. The analyses of 10 cm size class bin length distributions allowed the characterization of two main large modal groups, with modal lengths at caging of 139 and 179 cm SFL, respectively. The obtained growth rates were similar, with length increases over 20 cm for smaller fish and 10cm for larger ones. These figures are similar to the growth of the same age groups which, according to Cort (1991) equation, is expected to occur during a complete year cycle, indicating again higher growth rates in length in farmed versus wild fish. In a study carried out along a similar time lapse in the same area, Deguara et al. (2010) observed length increases in 5-6 years old individuals of around 15 cm, concluding also that in only 4 months in a cage the fish growth is the same than along the whole year cycle in the wild.

Due to the short duration of the experiment, seasonal changes in growth rates could not be observed. As had been seen in other regions, the modal sizes at harvesting were between 2 and 6 cm lower that those calculated for the same cohorts from the SC footage taken two weeks prior to harvesting.

3.4. Western Mediterranean

The experiment carried out in the Western Mediterranean, at Balfego S.L. farm, lasted a complete year, making it possible direct comparisons between annual growth rates in farmed fish and those available for wild fish. The results from MPA analyses of the length frequency distributions carried out with the data generated in such study are summarized in **Tables 7 and 8** and **Figures 9 and 10**. Intermediate SC footages between caging and harvesting were taken every 2 or 3 months. However, some of these intermediate footages, mainly those of winter months, were taken under high turbidity conditions (the farm is located near an important river plume), which made it difficult to obtain representative data from stereo-camera measurements, since in such conditions smaller fish are measured more frequently. This is because only fish located at shorter distances from the camera can be recorded, and at these short distances larger fish sometimes are partly out of frame and cannot be measured. So only data from the official measurement at caging, from footage taken in September 2020 under optimal visibility conditions (and in which 40% of fish were measured, not only 20%, thereby increasing representativity of the resulting raw length frequency distribution), along with the length frequencies from direct measurements at harvesting, have been considered in this paper. Analyses of the 2 cm size class bin length distributions allowed (similarly to the case of Central Mediterranean) the detection of up to 10 well-defined modal groups, with modal lengths at caging between 120 and 225 cm (ages 4 to 12+ years according to Cort (1991) Von Bertalanffy growth equation). Some larger individuals were also present in the length distributions, but they didn’t define clear Gaussian groups. The growth rates of these cohorts were 47 and 37 cm in the younger groups (4 and 5 years old respectively) and decreased progressively to 10 cm in the older age group. The results from the analyses of 10 cm size class bins, which similarly to Levantine Sea and Central Mediterranean areas enabled the characterization of two main large modal groups with modal lengths at caging of 157 and 208 cm SFL respectively, produced similar figures, with length increases of 37 cm for the first group and 25 cm for the second one. These annual growth rates result in growth increases, according to Cort (1991) equation, that are double than those seen in the wild. Most of the growth occurred along the first three/four month after caging, during the summer period.

Modal lengths at harvesting cannot be compared to those from the SC footage taken prior to harvesting because of the aforementioned potential bias induced by suboptimal environmental conditions, but it is worth mentioning that in the pilot study developed in the same cage using stereo-cameras placed in the bottom of the net, which recorded automatically and continuously thousands of SFL data (see Biological Studies Phase 10 Growth Farms Pilot UPV, available from GBYP web page (https://www.iccat.int/gbyp/en/biostu.asp), a clear decrease of some cm in the modal lengths at harvesting in relation to those obtained from stereo-cameras measurements was also observed.

4. Conclusions

The more relevant conclusions from this study can be summarized as follows:

- MPA can provide accurate seasonal growth rates, at least of the main annual cohorts, in farming cages.

- Growth rates in farms change during the year (higher in warmer months), probably as a result of seasonal variations in temperature.

- Growth rates in length and not only in weight, during the farming period are higher than in the wild, even more than double, both in juveniles and adults.

- SC footages measuring only 20% of fish are not fully representative of all the cohorts present in the cages, as suggested by the fact that modal groups that are detected at harvesting when measuring 100% of individuals or by stereo-camera system when higher percentages of caged fish (40-60%) are measured, are not picked up in the SC footage analysis when the percentage of measured fish is 20%, making MPA analyses difficult.

- Changes in the equipment and methodologies used for recording the SC footage, as well as environmental conditions, mainly turbidity, which can vary the range of distances at which the fish can be measured, can result in unexpected changes in the length distributions obtained from stereo-cameras.

- In all areas studied, modal sizes from the analysis of length distributions obtained through direct measurements at harvesting have been systematically a few cm lower that those obtained from stereo-camera footages taken just prior to harvesting, indicating a bias, the cause or causes of which should be further investigated.

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Table 1. Summary of the main characteristics of the caged populations in the different study areas.

	AREA				
	Adriatic	Adriatic	Levantine sea	Central Med	Western Med
Mean date of capture	04/06/2019	01/07/2019		04/06/2019	30/05/2020
Mean date of caging	11/06/2019	06/07/2019	02/07/2019	20/06/2019	29/07/2020
Initial N of caged fish	1506	1688	2245	2736	1196
Mean length at caging (from official SC)	76	86	146	203	211
Minimum length at caging (from official SC)	68	72	116	114	103
Maximum length at caging (from official SC)	84	131	233	274	245
Mean weight at caging (from official SC)	9.5	13.8	69.7	156.5	118.3
Mean date of massive harvesting	15/02/2021	15/02/2021	15/02/2020	05/10/2019	15/06/2021
N of fish measured at massive harvesting	395	386	1695	2580	649
Mean length at harvesting	136	140	171	217	217
Minimum length at harvesting	115	109	136	135	139
Maximum length at harvesting	166	169	287	277	278

Table 2. Adriatic Sea Modal Lengths Progression (size class bin 2 cm).

	13/07/2019	28/08/2019	08/12/2019	09/04/2020	11/08/2020	11/11/2020	05/02/2021	15/02/2021
Age 2	79.23	89.95	104.87	106.23	120.14	131.64	137.81	134.32
Age 3	102.49	109.12	123.9	125.47	137.28	147.04	154.31	148.98
Age 4	109.82	121.78	138.3	139.34	145.73	157.08	163.92	160.48

Table 3. Levantine Sea Modal Lengths Progression (size class bin 2 cm).

	02/07/2019	02/09/2019	02/11/2019	02/01/2020	15/01/2020
Age 4	122.49	134.45	144.15	151.78	154.94
Age 5	132.93	148.62	156.47	166.45	165.73
Age 6	145.49	161.84	166.66	179.64	173.70
Age 7	158.77	174.05	181.02	190.75	184.57

Table 4. Levantine Sea Modal Lengths Progression size (class bin 10 cm).

	02/07/2019	02/09/2019	02/11/2019	02/01/2020
Young adults 3-9 years old	138.93	148.95	158.86	168.11
Larger adults >10 years	179.22	189.61	198.63	209.45

Table 5. Central Mediterranean Modal Lengths Progression size (class bin 2 cm).

	20/06/2019	18/09/2019	05/10/2019
Group 1	122.69	147.74	145.48
Group 2	134.19	156.84	155.56
Group 3	146.31	168.97	163.47
Group 4	159.52	178.87	172.31
Group 5	170.69	189.46	184.72
Group 6	183.91	200.65	195.87
Group 7	194.09	209.78	204.41
Group 8	203.33	220.09	213.7
Group 9	212.88	230.02	224.01
Group 10	222.60	238.02	234.31

Table 6. Central Mediterranean Modal Lengths Progression size (class bin 10 cm).

	20/06/2019	18/09/2019	05/10/2019
Young adults	132.31	159.57	158.59
>10 years old	211.30	217.00	220.96

Table 7. Western Mediterranean Modal Lengths Progression size (class bin 2 cm).

	13/06/2020	23/09/2020	15/06/2021
Group 1	119.5	47.00	165.61
Group 2	130.84	36.65	173.74
Group 3	140.41	29.05	183.24
Group 4	151.59	22.53	192.53
Group 5	163.67	20.29	204.91
Group 6	174.96	16.72	214.87
Group 7	187.07	13.76	224.42
Group 8	201.75	13.86	236.09
Group 9	212.56	12.29	245.23
Group 10	225.37	9.67	252.51

Table 8. Central Mediterranean Modal Lengths Progression size (class bin 10 cm).

	13/06/2020	23/09/2020	15/06/2021
Group 1	157.46	188.00	194.37
Group 2	207.72	230.12	232.71

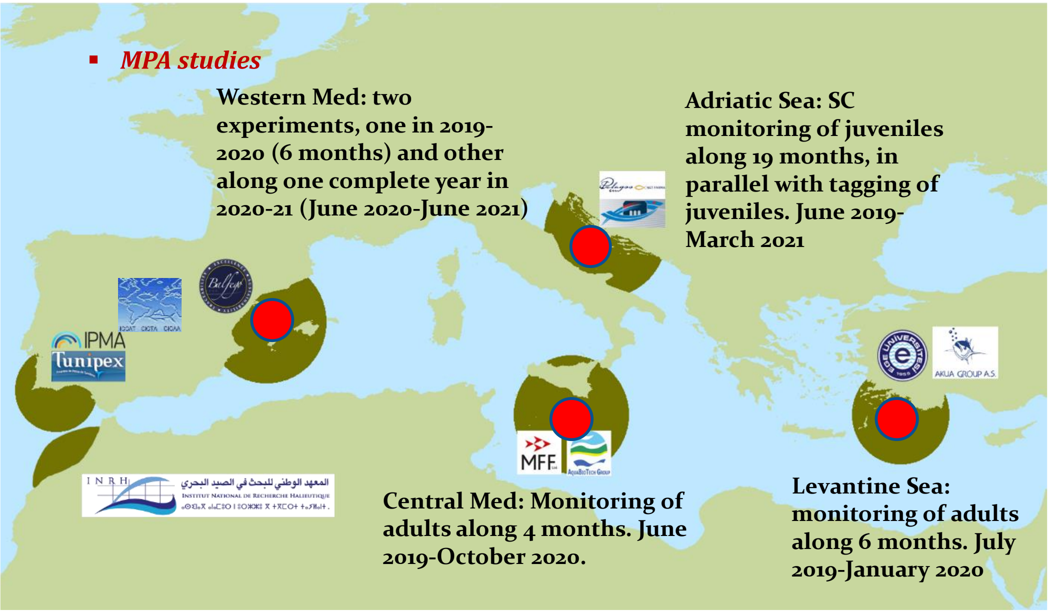

Figure 1. Location of sites where GBYP funded seasonal growth studies by means of MPA analyses have been developed (red dots).

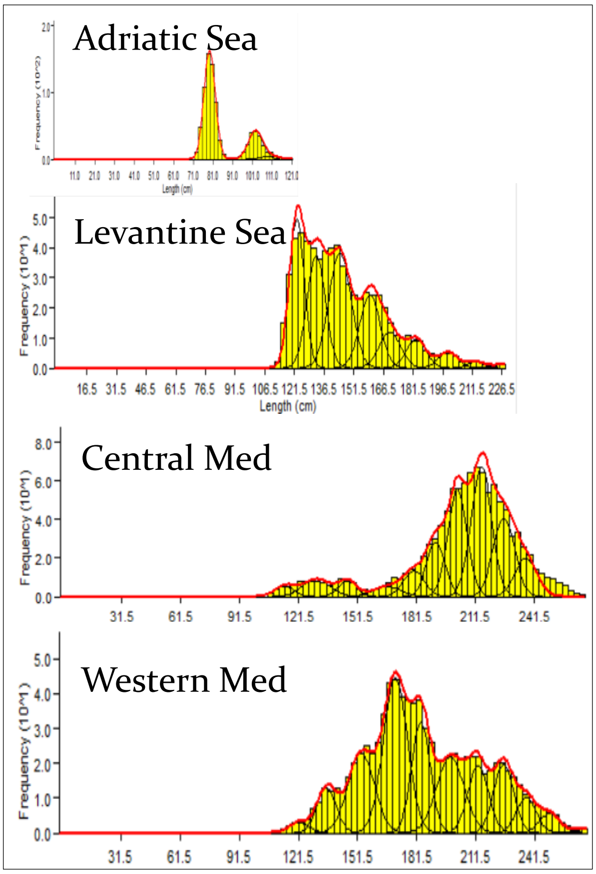

Figure 2. Modal groups detected in initial length distributions from official stereo-cameras measurements in all study areas (Class size bin=2 cm; double running average over 3 applied).

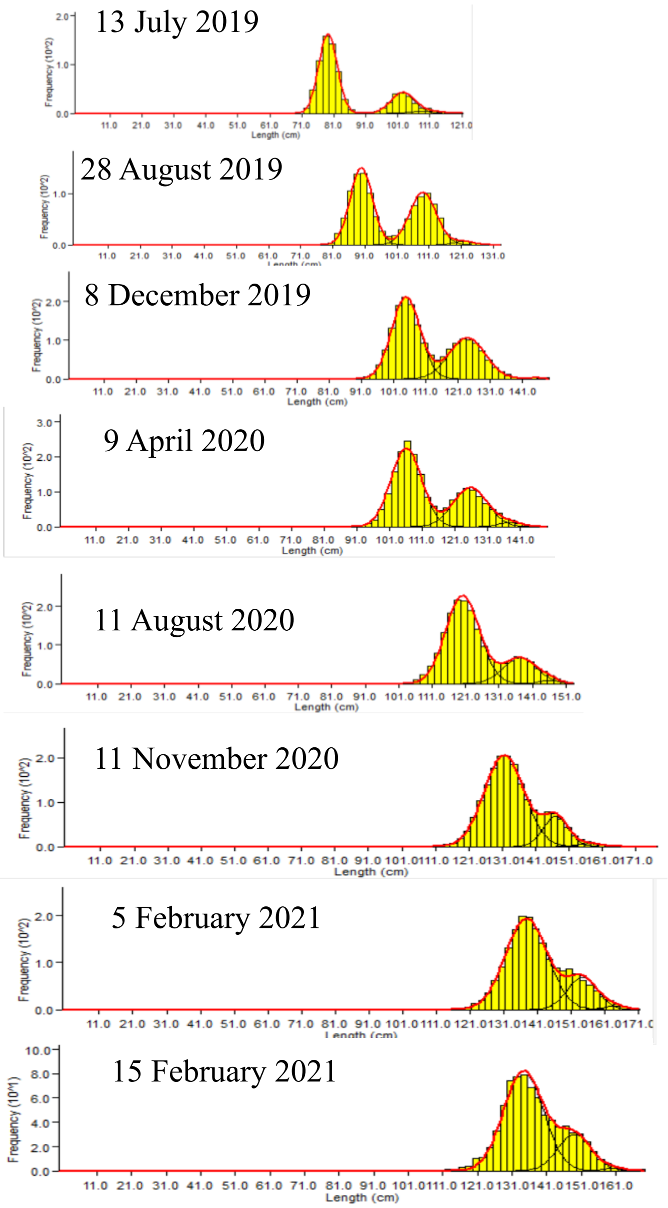

Figure 3. Modal groups (ages 2, 3 and 4 at caging) detected in monitored cages in Adriatic Sea.

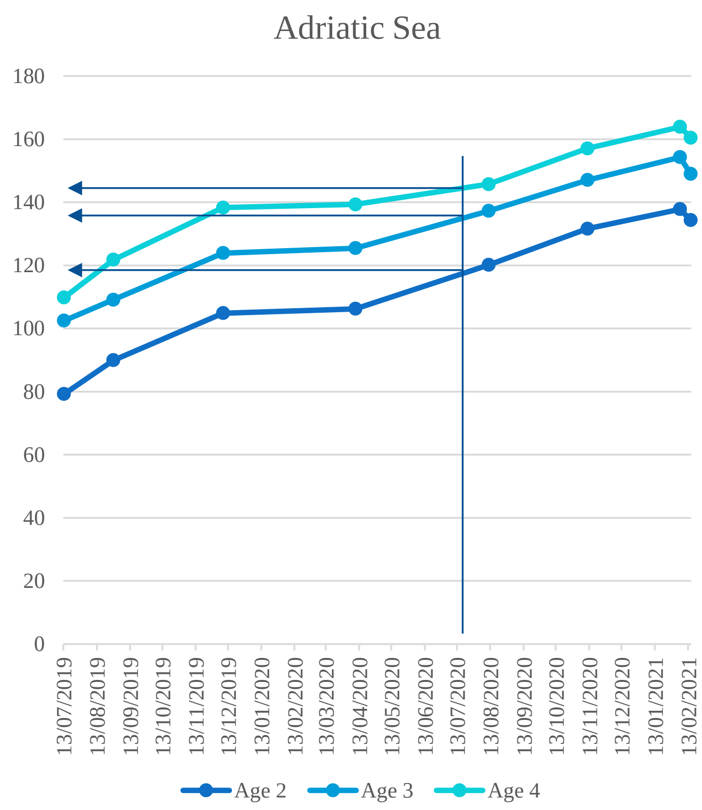

Figure 4. Modal lengths progression of juvenile BFT at Adriatic Sea farm.

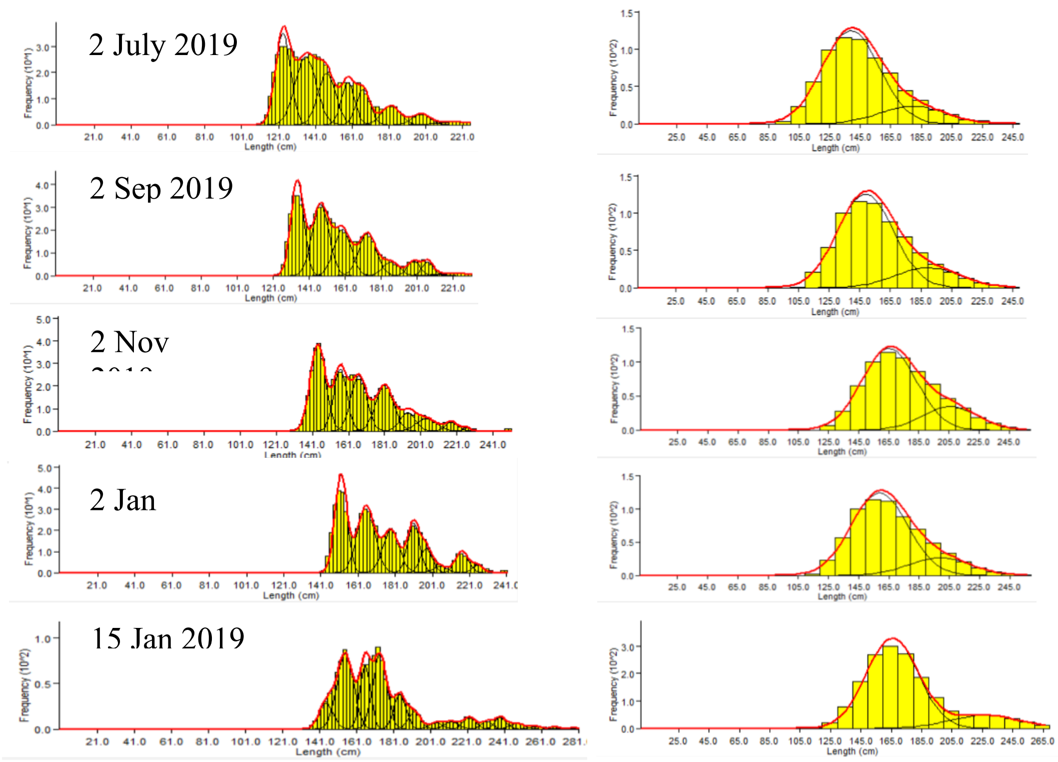

Figure 5. Modal groups detected in monitored cage in the Levantine Sea. Size class bin 2 cm (left) and 10 cm (right).

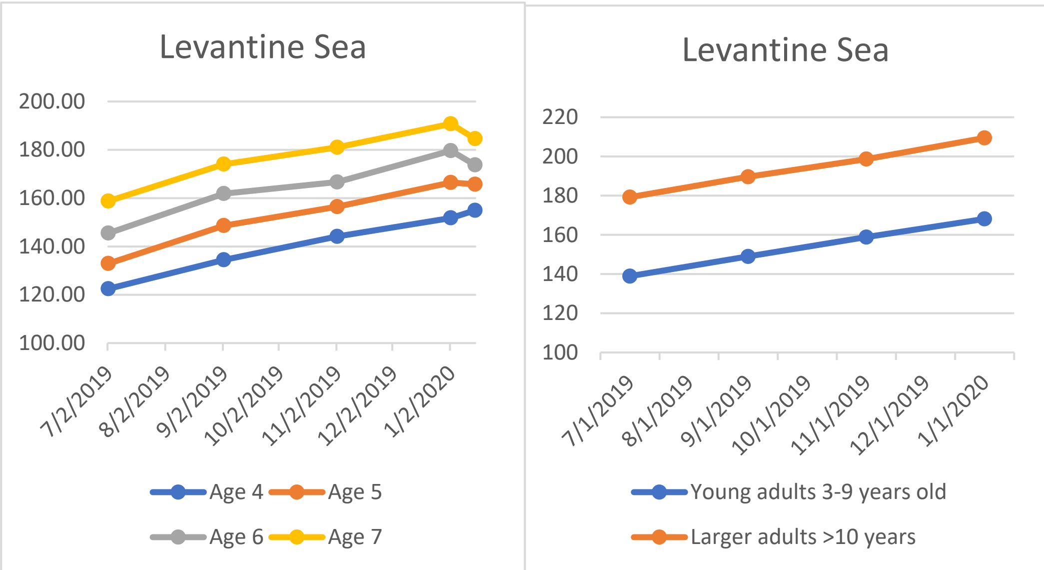

Figure 6. Modal lengths progression of juvenile BFT at the Levantine Sea farm. Size class bin 2 cm (left) and 10 cm (right).

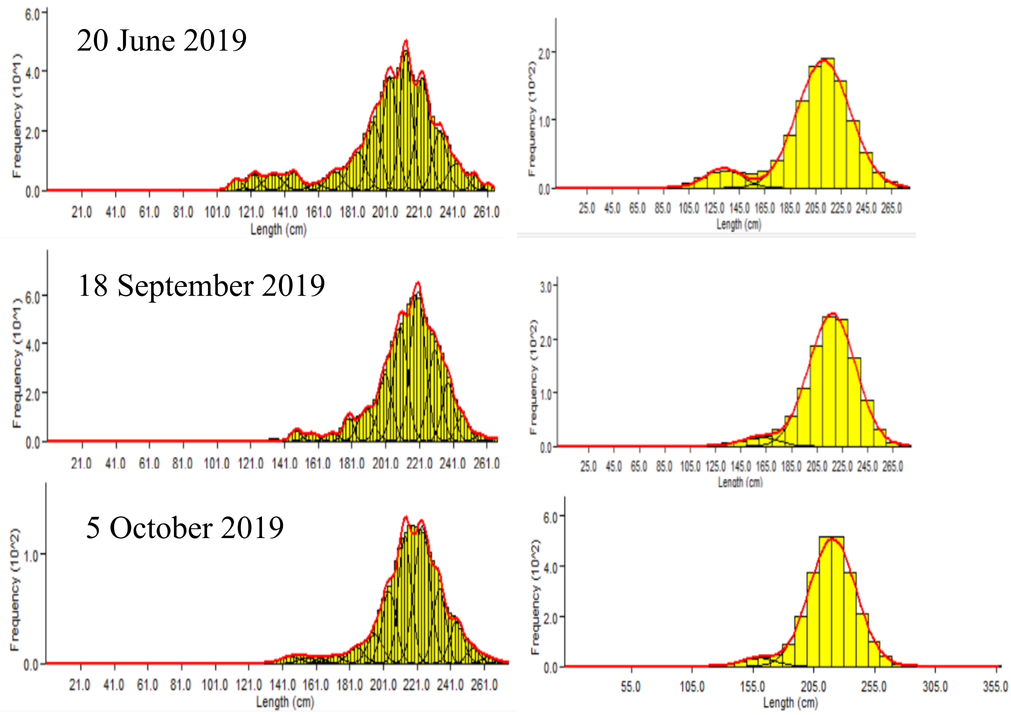

Figure 7. Modal groups detected in monitored cage in the Central Mediterranean. Size class bin 2 cm (left) and 10 cm (right).

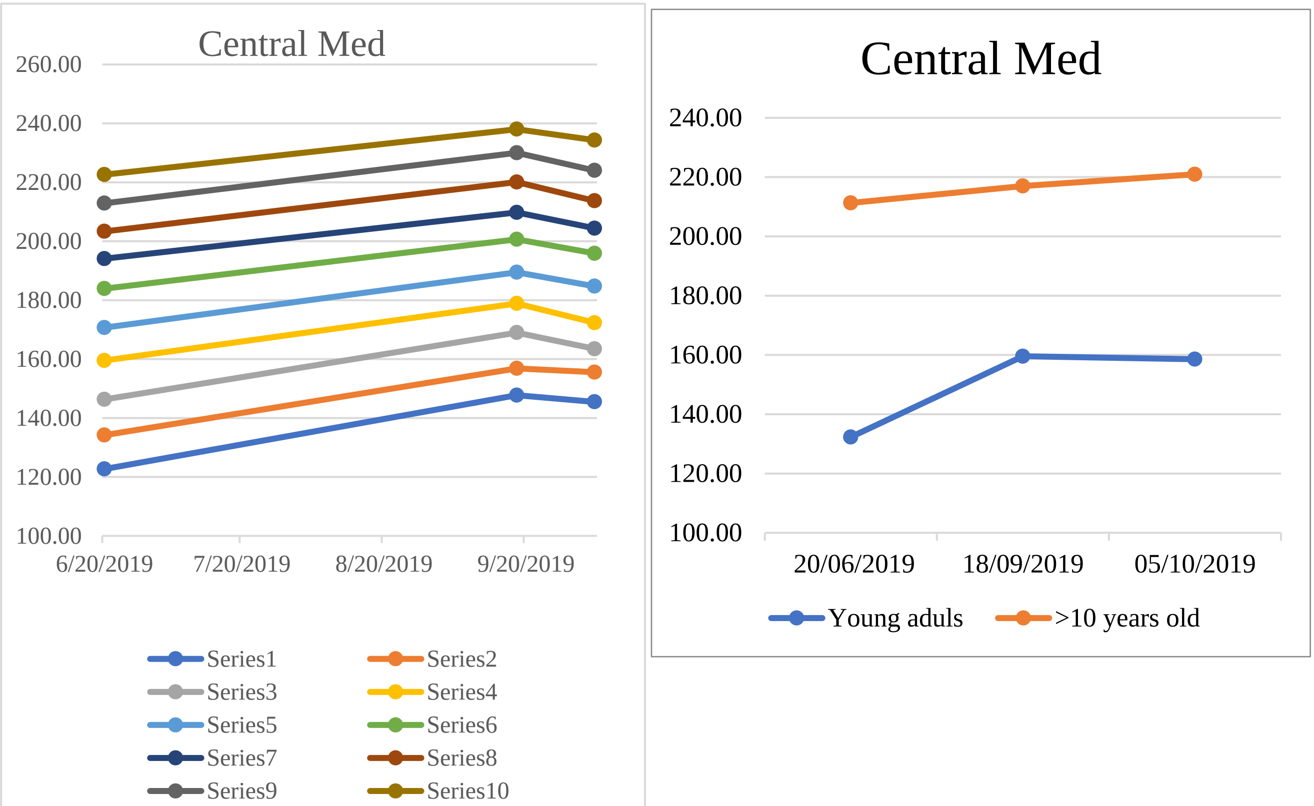

Figure 8. Modal lengths progression of juvenile BFT at Central Mediterranean farm. Size class bin 2 cm (left) and 10 cm (right)

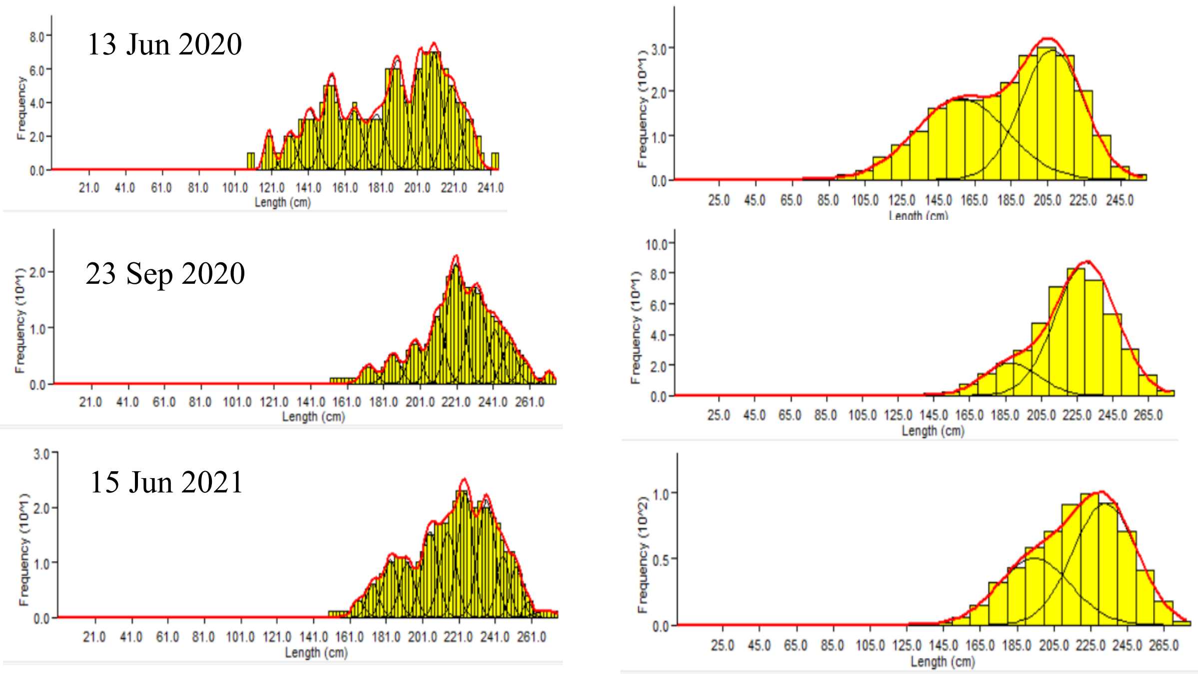

Figure 9. Modal groups detected in monitored cage in the Western Mediterranean. Size class bin 2 cm (left) and 10 cm (right).

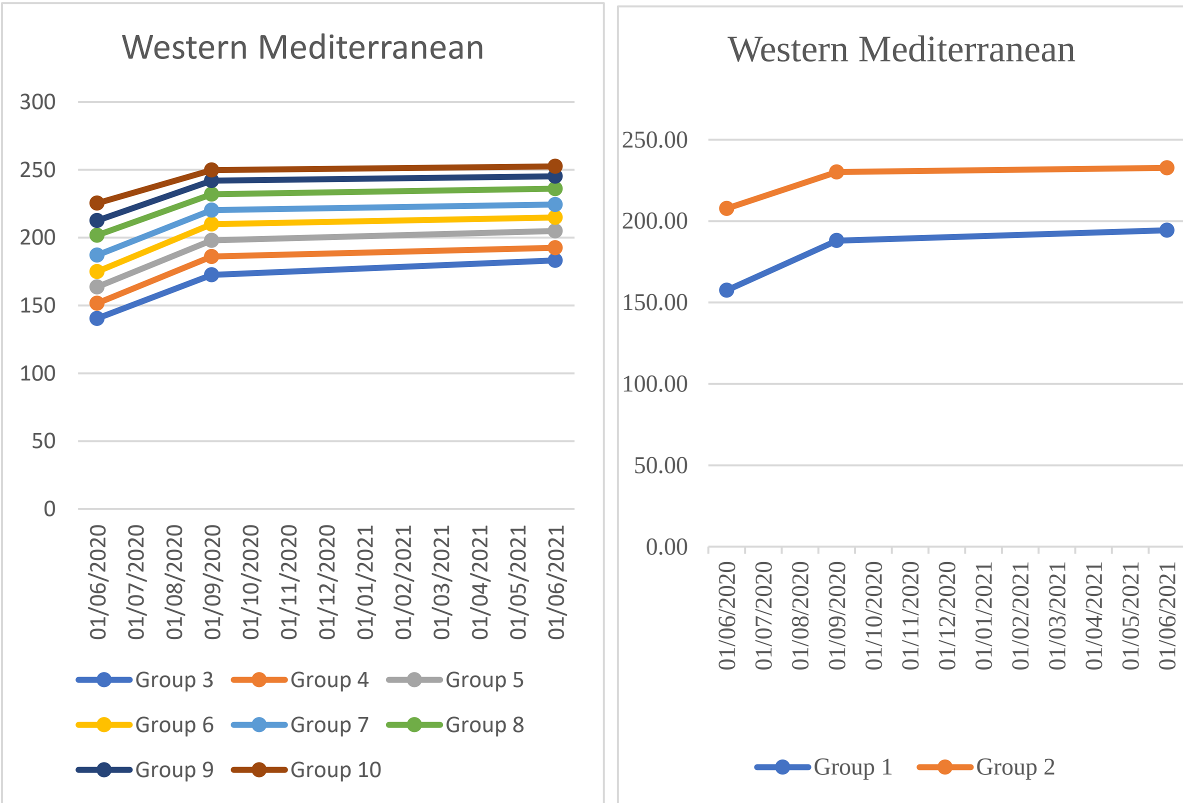

Figure 10. Modal lengths progression of juvenile BFT at Western Mediterranean farm. Size class bin 2 cm (left) and 10 cm (right)